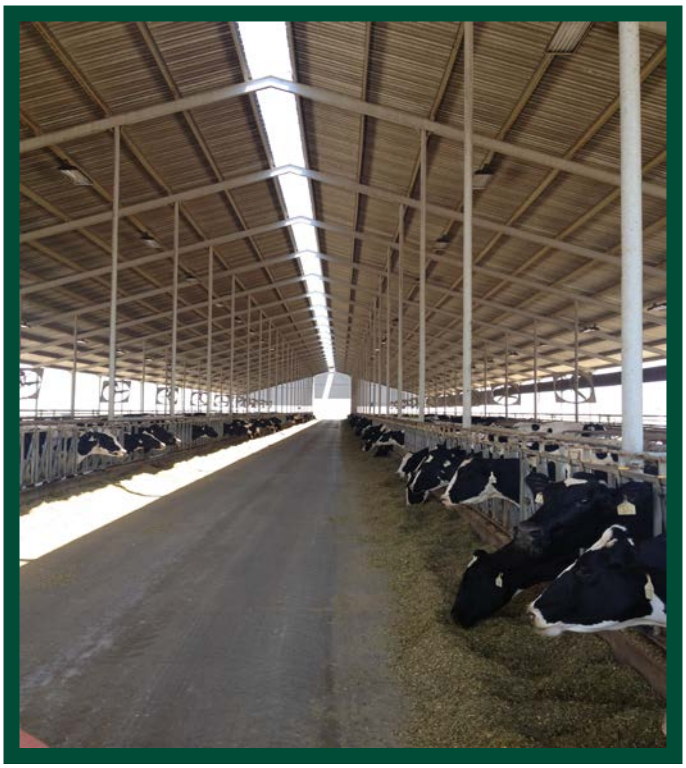
Dairy Farm Technologies

Understanding the Current and Emerging Cooling Methods, Trends in Dairy Farm Operations, and Other Electricity Use Opportunities in Dairy Farms

ET12SCE1070 Report



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November 2013

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Acknowledgements

Southern California Edison's Emerging Products group is responsible for this project. It was developed as part of Southern California Edison's Emerging Technologies Program under internal project number ET12SCE1070. Brian James conducted this technology evaluation with overall guidance and management from Paul Delaney. For more information on this project, contact brian.james@sce.com. The authors would like to thank EPRI for their contribution through the White Paper (EPRI Product ID – 3002002251) titled "A White Paper on Energy Efficiency Improvement Opportunities for Technologies used on a Dairy Farm".

EXECUTIVE SUMMARY

The purpose of this white paper is to provide a more thorough understanding of dairy operations, especially the overall electricity consumption by the dairy farm. The applications that use electricity on a dairy farm are lighting, electric water heating, ventilation, milk cooling, milk harvesting, as well as other applications. This paper identifies various literature surveys from the World Dairy Exposition (October 2012) that detail the share of electricity used by each of the categories; ways to improve the efficiency of operations using energy efficiency technologies also have been identified. Further, a review of water usage on dairy farms is included in this paper.

Generally, milk production is reduced in summer months due to heat stress experienced by the dairy cows. The variation in milk production during summer and winter months is explained in this paper.

Another area for new learning comes from the evaluation of alternative cow cooling methods such as ground source heat pumps (GSHP). Current cooling methods employed on dairy farms as well as some emerging cooling methods are described in detail in this white paper.

Apart from cooling, there are other electrotechnologies that can help in the efficient operation of dairy farms. They are also listed and described in detail in this white paper.

Finally, a market analysis section that discusses the financial state of the dairy farms across the nation is included.

ABBREVIATIONS

Btu	British Thermal Unit
CCT	Correlated Color Temperature
CFM	Cubic Feet Per Minute
CWT	Hundredweight
GPM	Gallons Per Minute
GSHP	Ground Source Heat Pumps
HIF	High intensity fluorescent
HP	Horsepower
HSLV	High Speed Low Volume
HVAC	Heating, Ventilating, and Air Conditioning
kW	Kilowatt
kWh	Kilowatt Hours
MH	Metal Halide
MWH	Megawatt Hour
PSMH	Pulse Start Metal Halide
PV	Photovoltaics
T5HO	High Output Fluorescent
THI	Temperature Humidity Index
V	Volt
VSD	Variable Speed Drive
W	Watt

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INTRODUCTION

BACKGROUND

Dairy farms located in hot, semi-arid, and arid climates around the world are annually hit with the problem of less milk production and deteriorating health conditions, especially the reproductive performance of the cows during the summer season.

A dairy farm study in 1993[1] showed that high-producing dairy cows exposed to long periods of temperature above the comfort zone, especially the temperature humidity index (THI) greater than 72, react in several ways to retain comfort. During excessive heat, cows

- Seek out shade;
- Increase water intake;
- Reduce feed intake;
- Stand instead of lie down (unless wet ground is available);
- Increase respiration rate;
- Increase body temperature; and
- Increase excessive saliva production.

During summer months when the temperature goes over 100^{o}F, milk production drops significantly. Larger dairy farms often use evaporative cooling methods to reduce the internal body temperature of the cows and alleviate summer heat stress. This type of conventional cooling method has several drawbacks. First, during summer months conventional evaporative cooling systems consume large amounts of electricity during peak hours and use large quantities of water for various cow soaking systems. The fans and soaker lines are controlled by a thermostat switch which turns the system on if the temperature goes above a given set point temperature, typically between 72^{o}F and 82^{o}F.

ENERGY USE

On a dairy farm, typical average annual energy costs can be as much as 20% of the annual milk revenue per cow on a farm. The electrical energy used by these dairy farms accounts for 60% of the total of all energy used. The remaining 40% of the energy goes towards fuel that is used to haul manure and milk, fertilizers, and other activities. The electricity usage on dairy farms by end-use is shown in Figure 1. The three largest uses of electricity are milk cooling (refrigeration), lighting and ventilation, according to a NYSERDA report[2].

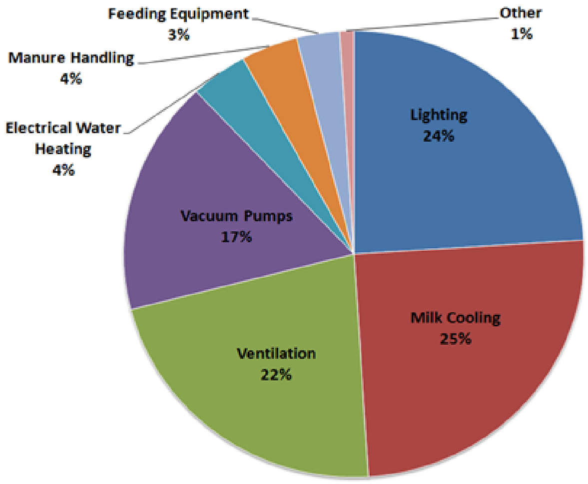


FIGURE 1. ELECTRIC ENERGY USAGE IN A DAIRY FARM[3]

This white paper identifies the following aspects of sustainable dairy farms[4]:

- Effective ventilation for cows
- Efficient lighting
- Efficient milk cooling (refrigeration)

Table 1 shows the energy sinks and possible energy sources on a dairy farm. For a dairy farm to reduce its annual energy consumption and become a net zero energy farm, the energy sinks need to be as energy efficient as possible and the output from the local on-site energy sources need to be increased in order to reduce dependency on existing energy sources[1]

TABLE 1. ENERGY SOURCES AND SINKS IN A DAIRY FARM

ENERGY SOURCES (POTENTIAL ONSITE)	ENERGY SOURCES (EXISTING)	ELECTRICITY SINKS	OTHER FUEL SINKS
Photovoltaics (PV) (Solar)	Electricity	Lighting	Hauling Manure
Manure	Propane Fuel	Refrigeration	Fossil Fuel Water
Hydro Power	Diesel (Farm Grade)	Vacuum Pumping	Heating
Wind	Fuel Oil	Electric Water Heating	Fossil Fuel based
			Feeding Equipment

[1] Note: In this white paper, several current and emerging technologies are mentioned and described with potential energy savings. These energy savings and other benefits are claims made by manufacturers and they have not been verified by EPRI. The paper merely **identifies** various **electric** energy efficient technologies that can be applied on dairy farms.

Daily Electricity Usage on a Dairy Farm

Peak demands for electricity typically occur during milking periods on dairy farms. Most dairy farms will milk twice per day—once in the morning and once at night (Figure 2). However, some dairy farms have three milking periods: morning, midday, and nighttime.

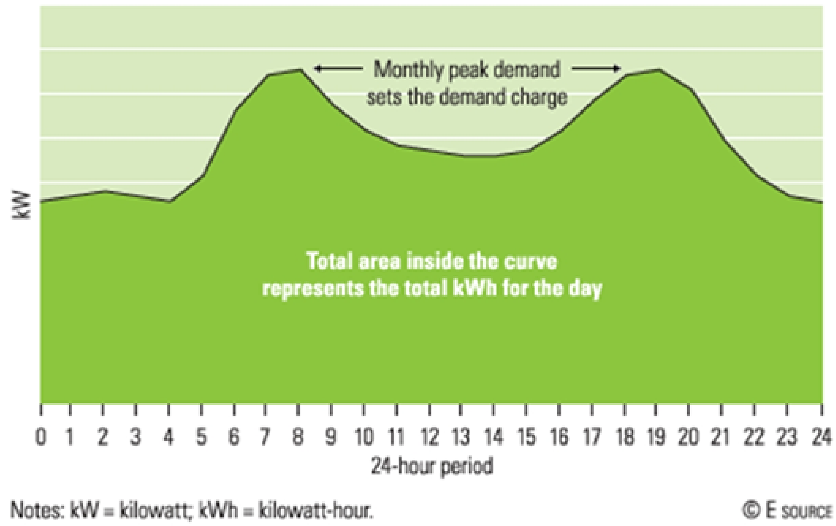


Figure 2. Daily Electricity Use in a Dairy Farm[5]

The consumption component of the electricity bill is based on the amount of electric energy, in kilowatt hours (kWh), that the building consumes during a month. The demand component is the peak power, in kilowatts, drawn by the farm each month or, for some utilities, throughout the previous 12 months. Demand charges can range from a few dollars per kilowatt-month to $20 per kilowatt-month.

Typical Electricity Usage Per Cow

A survey of 93 dairies in the southern San Joaquin Valley was conducted in 1994-95 to provide baseline information on types and sizes of equipment that contribute to the dairy farm electric load[6]. Data was collected during farm visits by University of California, Cooperative Extension personnel who interviewed owners and inventoried equipment, lights, and ventilation fans in the milking center and corral area. Herd sizes ranged from 95 to 3,200 cows and averaged 984 cows per herd. Ninety percent of the dairies milked twice a day and 10% milked three times daily. Average daily milk yield for the 93 dairies was 67.5 lbs/cow. Monthly milk production and electrical energy use data were collected for a 12-month period from 42 of the 93 dairies in the southern San Joaquin Valley. The objectives of studying the data are to examine connected electrical load patterns and to develop energy performance indicators in order to help determine energy management opportunities. Energy use data represented electricity used for harvesting, cooling and storing milk, water pumping and heating, ventilation and lighting.

The report states that electrical energy use averaged 1,603 kWh per dairy per day or about 42 kWh per cow per month (assuming the dairy farm has 1,145 cows). This is also equivalent to electricity usage of 504 kWh per cow annually. The average rate for electricity in the San Joaquin Valley when the study was conducted was $0.09/kWh, so the 42 kWh/cow/month amounted to $3.78 per cow per month for electrical costs. The performance indicator of milk produced per unit of electricity averaged 48 lbs milk/kWh, but there was wide variation ranging from 30 to 67 lbs milk/kWh. As the report further states, kilowatt hours per hundredweight (cwt) of milk averaged 2.15 kWh/cwt of milk with a range from 1.49 to 3.32 kWh/cwt of milk. Applying a rate of $0.09/kWh, electricity costs averaged 19.4 cents per hundred pounds of milk. This represents about 1.6% of total milk production costs for the study time period.

A report published by Wisconsin Department of Agriculture[7] in 2003, estimates that electricity alone accounted for 2% to 5% of a dairy farm's production costs on average; they arrived at this number through audits conducted at several of their dairy farms in Wisconsin. This translates to annual electricity use of 700 to 900 kWh per cow or 3.5 to 4.5 kWh/cwt of milk produced.

MARKET ANALYSIS - MILK PRODUCTION

The annual production of milk for the United States during 2012 was 200 billion pounds, 2.1% more than 2011. Production per cow in the United States averaged 21,697 lbs. for 2012, 361 lbs. more than 2011. The average annual rate of milk production per cow has increased 15.7% from 2003. The average number of milk cows on farms in the United States during 2012 was 9.23 million head, up 0.4% from 2011.

Major trends in U.S. milk production include a:

- Fairly steady slow increase in production as gains in milk production per cow outweigh declines in the number of cows; and
- Consistent decline in the number of dairy operations, matched by a continual rise in the number of cows per operation.

Since 1970, milk production has risen by almost half, even though milk cow numbers have declined by about a fourth (from about 12 million in 1970 to roughly 9 million in 2007. Milk production per cow has nearly doubled, from 9,700 lbs. in 1970 to nearly 19,000 pounds in 2007. Similarly, the number of dairy operations declined from approximately 650,000 in 1970 to approximately 90,000 in the early 2000s, while over the same period, the average herd size increased fivefold from about 20 cows to 100 cows.

The top 10 milk producing States in 2012[8], according to the USDA data is summarized in Table 2. It can be seen that in 2012 California accounted for nearly 21% of U.S. milk production, producing 41,801 million pounds of milk per year. There were 1,782,000 cows each producing an average of 23,457 lbs. of milk per year in California.

TABLE 2. MILK PRODUCTIONS BY STATE, TOP 10 STATES, 2010 - 2012[9]

	STATES	2010 MILLION POUNDS	% TOTAL	2011 MILLION POUNDS	% TOTAL	2012 MILLION POUNDS	% TOTAL
1	California	40,355	21.03	41,462	21.14	41,801	20.87
2	Wisconsin	25,759	13.43	26,058	13.28	27,224	13.59
3	Idaho	12,746	6.64	13,256	6.76	13,558	6.77
4	New York	12,681	6.61	12,838	6.54	13,196	6.59
5	Pennsylvania	10,683	5.57	10,547	5.38	10,493	5.24
6	Texas	8,803	4.59	9,582	4.88	9,596	4.79
7	Minnesota	9,002	4.69	8,890	4.53	9,071	4.53
8	Michigan	8,306	4.33	8,478	4.32	8,889	4.44
9	New Mexico	7,830	4.08	8,177	4.17	8,149	4.07
10	Washington	5,885	3.07	6,169	3.14	6,234	3.11

As the table indicates, the major milk-producing states are in the West and North. The relative importance of the western regions has grown, while other regions have declined or remained steady. Western areas have had lower average costs of milk production for a variety of organizational and climatic reasons.

Most U.S. dairy cows are Holsteins, a breed that tends to produce more milk per cow than other breeds. Holstein milk comprises approximately 87.7% water, 3.7% milk fat, and 8.6% skim solids. In the United States, the decision to produce milk largely rests in the hands of individuals or families. Many of these farmers belong to producer-owned cooperatives. The cooperatives assemble members' milk and move it to processors and manufacturers. Some cooperatives operate their own processing and manufacturing plants. Initially local, many of today's dairy cooperatives are national, with members across the country.

COOLING METHODS USED IN DAIRY FARMS

DAIRY COW HOUSING – TYPES OF BARNS

Dairy cattle, specifically the milking herd and close-up dry cows, are housed in various types of dairy facilities. These facilities can include tie stall barns for individual dairy cows (Figure 3), free stall barns (Figure 3), dry lots with shades (Figure 4), and more recently, compost pack barn commonly called desert-style or Saudi barns (Figure 4). The combination of tunnel ventilation with evaporative cooling systems has recently been installed in some Midwest dairy facilities (Figure 5). Cross-ventilated barns are very similar to tunnel ventilated barns. The difference is in the direction of the air flow. In tunnel ventilated barns the airflow is drawn across the length of the barn while in cross-ventilated barns the airflow is drawn across the width of the building. An evaporative pad is used, that is typically soaked in water, while drawing fresh air into the barn which helps in cooling the cows.

FIGURE 3 .TIE STALL BARN (LEFT) AND FREE STALL BARN (RIGHT)

FIGURE 4. DRY LOTS - WITH SHADE (LEFT) AND DESERT OR SAUDI STYLE BARN

One common thread with all of these dairy cattle housing systems is to ensure that dairy cows are comfortable and managed in an environment to improve their health and prevent diseases. Dairy farmers have always realized and practiced good animal welfare and well-being, and understand that comfortable cows are healthier and give more milk. Heat stress from lack of shade, hunger due to lack of sufficient grazing, exposure to driving rain, snow and freezing cold weather, and control of parasitism are all primary reasons to develop a housing environment where dairy cows can be sheltered.

FIGURE 5 .TUNNEL VENTILATED BARN (LEFT) AND CROSS-VENTILATED BARN (RIGHT)

AREAS THAT NEED COOLING IN A DAIRY FARM

Ventilation is a key energy consuming area for a dairy farm. The dairy farm requires cooling in three main areas as shown in Figure 6. The three main areas are:

- Holding pen: Most cows spend 30 to 60 minutes in a holding pen several times per day. These holding pens are usually hot, humid, crowded, and stressful for cows. The main objective of improving ventilation is to make the conditions in the pen better with the use of air movement.
- Feed line: Feed line cooling is important because the cow's milk production is directly proportional to the feed intake. Making the feed line a comfortable place for the cows to eat will ensure that the cows will stay in the feed line and eat. Providing a shade for the feed bunk and using fans to provide air movement as they eat are vital to creating a comfortable atmosphere for the cows. Cows are more likely to stay and eat in the shaded and ventilated area rather than stand in the hot sun to eat.
- Free stalls: In operations with free stalls, cooling fans can be very effective to cool the cows.

FIGURE 6. AREAS THAT NEEDS COOLING IN A DAIRY FARM[10]

CURRENT METHODS FOR COOLING COWS IN DAIRY FARMS

There are two general approaches to cooling dairy cattle. One must either modify the environment to prevent heat stress or utilize methods that increase heat dissipation from the skin of cattle. Air conditioning is the ultimate method used to modify a warm environment. It reduces air temperature and relative humidity, which greatly lowers the THI of the environment. On a commercial basis, this is not an economical choice for modifying the environment of large barns that house dairy cattle given the large number of air changes per hour. A more economical method used to reduce air temperature is evaporative cooling. When water evaporates it absorbs heat, reducing the temperature, but the relative humidity is also increased due to the increased level of water vapor present.

FANS

At present, in order to reduce heat stress and cool dairy cows, dairy farmers employ various forms of forced convection and evaporative cooling systems such as fans and feed lane soaking systems. Fan diameters typically range from 48 inches to 60 inches with motors typically 1 to 1½ horsepower (hp). Feed lane soaker line nozzles are often at a high flow rate up to 1.5 gallons per minute (GPM) and spaced every 5 feet to 6 feet along the feed lane. With a typical cycle of 1 to 2 minutes ON and 5 to 6 minutes OFF, each nozzle can consume up to 15 gallons of water per hour. Put into perspective a typical California dairy milking 3,600 cows can have up to 1,600 nozzles consuming over 24,000 gallons of water per hour. Well pumps run virtually 24 hours per day, 7 days a week in order to supply the massive water demand required to cool cows during the summer months.

These systems work by enhancing convective heat transfer and reducing the ambient air temperature through the evaporation of water. However, all of these systems require significant amounts of water and electricity and do not work well during humid weather. Energy usage on dairy farms has grown gradually in the past 20 years due to the increase in farm size, use of automated equipment, and around-the-clock operation. Dairy farms in the U.S. typically consume between 800 and 1,200 kWh per cow annually. Approximately 50% of the total energy used on a dairy farm goes toward milk-production equipment, which includes milk cooling, vacuum pumps, and water heating. As reflected in the energy usage audits, ventilation can account for approximately one-quarter of the total energy used.

Conventional fans are typically installed at a ratio of one fan for every twenty cows in a typical 4-row barn. In areas of high humidity, fans are often installed along the feed lane. Fans and soaker systems are controlled by thermostats and typically turn on when temperatures reach 65^{o}F - 75^{o}F.

Figure 7 through Figure 10 show various types of fans used in the dairy farms.

Figure 7. High Volume Low Speed Fans (Photo Taken at World Dairy Exposition 2012)

Figure 8. Deep Guard Circulation Fans (Photo Courtesy: Schaefer Fans)

Figure 9. Panel Fans (Photo Courtesy: GEA Farm Technologies)

FIGURE 10. EXHAUST FANS USED IN CROSS AND TUNNEL VENTILATED BARNS (PHOTO COURTESY: SCHAEFER FANS)

FEED LANE SOAKING AND EVAPORATIVE COOLING SYSTEMS

Evaporative cooling has typically been the conventional method used to cool dairy cows; it combines airflow from large high speed low volume (HSLV) panel fans (Figure 11) and are currently used in many dairy farms. When using the evaporative cooling method,

- Circulation fans and soaking is an extremely cost-effective cow-cooling solution. High capacity, low pressure, large droplet soaker nozzles quickly soak cows to the hide.
- Showering time is typically 0.5 to 3 minutes while the cow is at the feed lane enters the holding pen and returns from milking.
- Circulation fans blow across the cows backs for 5 to 15 minutes intervals, or operate continuously.
- Controllers operate on 110 volt (V) or 220V and control from 1 to 4 zones.
- Sprinklers can be time-activated or motion-activated (e.g., when cows are returning from being milked).

FIGURE 11. FEED LANE SOAKER AND EVAPORATIVE COOLING SYSTEMS

For most dairy producers who already have a covered holding pen, the most economical method of cooling is to combine the use of fans and a sprinkler system where the fans mechanically ventilate the area and a sprinkler system is used to increase the evaporative cooling of the cows.

Table 3 shows an example of a cooling system water requirement for feed lane soaker and evaporative cooling system used in a dairy farm located in Arkansas. It was designed by retired extension engineer, John M. Langston, and has been used on several dairy farms and slightly modified for use on other dairies. In general, the goal of the cooling system is to provide 0.05 inches of water per cycle in ½ to 3 minutes and then blow air on the cows for 10 to 15 minutes in order to increase evaporative cooling. It is recommended that both fans and sprinklers be used. Fans are needed to ensure that the environment from the sprinkler does not become so humid that cows cannot dissipate heat, which may lead to death of the cows if the holding pen is enclosed and/or too humid.

TABLE 3. WATER REQUIREMENT FOR COOLING USING FEED LANE SOAKER AND EVAPORATIVE SYSTEMS[112]

HOLDING PEN CAPACITY (COWS)	TYPICAL PEN SIZE (FEET BY FEET)	TOTAL FAN CAPACITY CUBIC FEET PER MINUTE (CFM)	NUMBER OF 30 TO 36-INCH FANS	NUMBER OF 48-INCH FANS	WATER REQUIRED IN SUMMER (GALLONS/ DAY/COW)	WATER REQUIRED (GALLONS/CYCLE)	MINIMUM FLOW RATE (GPM)	NUMBER OF 360° NOZZLES REQUIRED
40	24 by 32	40,000	4	2	25	20	10	14
60	24 by 42	60,000	6	3	21	25	12	20
80	24 by 50	80,000	8	4	19	30	15	27
100	32 by 48	100,000	10	5	20	40	20	34
120	32 by 56	120,000	12	6	19	45	23	40
160	32 by 75	160,000	16	8	19	60	30	54
200	32 by 96	200,000	20	10	20	80	40	68
300	32 by 144	300,000	30	15	20	120	60	102
400	32 by 192	400,000	40	20	19	150	75	136
500	32 by 240	500,000	50	25	20	200	100	170

[2] To calculate the water requirement for a 2,000 cow farm with 50 pens (24 ft. x32 ft.), each holding 40 cows in summer from May through September, multiply 50 pens*40 cows*153 days(summer)*25 gallons/day/cow=7,650,000 gallons of water. This number is based on the assumptions listed.

The following assumptions can be made:

- Flow rate is on a 2-minute ON cycle with 10 minutes OFF and 5 cycles per hour.
- Nozzles have an 8-foot spray diameter and 0.5 gpm capacities.
- There are 0.025 gallons of water per cycle per square foot of pen area.
- Summer hours start in May and continue through September where the ambient temperatures are above 75^{o}F for at least 10 hours per day, resulting in 1,530 summer hot hours for 153 days.

HIGH SPEED LOW VOLUME WITH HIGH PRESSURE MISTING

The cooling power of HSLV fans with high pressure misting is based on the process of atomizing water droplets to a size that can quickly evaporate[12]. Water is forced through a specially designed high pressure nozzle to create an ultra-fine mist that rapidly absorbs heat and cools surrounding air as it evaporates (Figure 12). High pressure water mist systems are efficient because of the high rate at which water is evaporated.

During this rapid evaporation process, the minute water droplets quickly absorb the heat energy in the environment and evaporate, turning into water vapor, thus cooling the area.

Some of the features of this system are (per manufacturer's data sheet):

- Water has high cooling potential (approx. 8,000 British thermal units (Btu)/gallon).
- The larger the surface area, the faster water evaporates.
- Even in humid climates, this technology can easily lower temperatures up to 30 degrees or more when needed most.
- This system uses 1½ hp to 2 hp HSLV fans with high pressure misting.

FIGURE 12. HIGH PRESSURE MISTING SYSTEMS

EMERGING COOLING METHODS FOR THE DAIRY FARMS

Some of the emerging cooling methods used or advertised for dairy farm applications include conductive cooling, evaporative cooling, turbulence ventilation, and roof ventilation.

CONDUCTIVE COOLING

An innovative method has been developed to provide cooling for dairy cows that significantly reduces the high energy and water usage requirements of current, conventional cooling systems (evaporative and/or forced air flow). The patented process utilizes heat exchangers in order to remove excess heat from cows through conduction. The heat exchangers are placed under the bedding material on which the animal lies, and chilled water or low-temperature groundwater circulates through the exchangers, thereby conducting heat out of the cow, through the bedding (Figure 13). This approach greatly increases the cows' conductive heat loss over a wide range of temperatures without the typical restriction from high ambient humidity conditions.

The conduction cooling system utilizes minimal power to circulate water through the system, specifically when compared to conventional fans. In some installations, the system requires no additional power to operate beyond the power already used by the well pump(s) to supply water at the dairy operation. The removal of excess cow heat by conduction allows for better cow comfort in areas subject to high humidity and/or water restrictions.

FIGURE 13. SCHEMATICS OF HEAT EXCHANGER BED IN CONDUCTION COOLING (PHOTO COURTESY: CONCO TECHNOLOGY INC.)

LIMITED FIELD TESTING RESULTS OF CONDUCTION COOLING

Prior testing in the environmental chamber at the University of Arizona (U of A), Tucson, Arizona, validated the concept of conduction cooling (June 2010). This testing was followed by a singular live cow test in Tucson, Arizona (July 2010) that confirmed the significant heat reduction via conduction was possible. The results of two field test projects (California, September 2010 and Ohio, June through August 2011) supported the results that conduction cooling will allow for large savings in the electrical energy required to meet the seasonal cooling needs at dairies that happen to mirror the peak electrical demand loads for electrical producers. Savings projections were determined to be in the range of 50%-75% of a typical cooling fan's electrical load requirements. These savings also applied to the reduction of water usage associated with soaker lines in the California test (no soakers were used in the Ohio test). The system resulted in essentially duplicate milk production when compared to control the test groups of cows without the use of fans or mister/soakers for the encountered summer conditions.

It was deemed necessary to perform a larger scale, live animal test to further refine the system in a commercial dairy operation, while gathering energy usage data, confirm animal wellness between test and control cows, and, compare milk production from the test and control group cows. The University of California, Veterinary Medicine Teaching and Research Center (VMTRC) and the University of Arizona's Animal Science Department were approached as academic partners to advise and monitor the testing.

A representative dairy in Tulare, California was selected as the site for a suitable test. The dairy owner agreed to provide 52 cows for testing, with 150 cows as the control group. Turlock Irrigation District (TID) provided financial and field support for the proposed testing in July 2010 in order to evaluate the energy savings potential for dairies that incorporate conductive cooling. The test ran for the month of September 2010. The VMTRC monitored milk production; the University of Arizona monitored the physiological conditions of both the test cows and the control cows.

The conduction cooling system was installed and operated with a range of monitored parameters using flow meters, thermocouples, and electronic temperature data loggers. Additionally, digital meters were installed to monitor humidity and temperature in the test and control areas.

The test results supported the energy savings with performance equivalent to fans to at least 90^{o}F. This represents an electrical savings of 75% under typical central California summer weather conditions. The conclusion of the field test is that conduction cooling has the potential to significantly reduce the amount of energy and water required to protect lactating dairy cows from heat stress. It is also surmised that conduction cooling will provide an important advantage over the existing cow cooling methods in that it should work effectively under all weather conditions whereas conventional cooling methods become drastically ineffective during humid conditions.

EVAPORATIVE COOLING

It is well known that evaporative cooling is an effective way to provide cooling to the cows in the dairy farm. The following are new methods or variations in evaporative cooling systems.

EVAPORATIVE FAN MOTION COOLING SYSTEM FOR TRAFFIC LANES

This cooling technology uses controllers and nozzles optimized by a microprocessor to provide cooling to the cows. Air movement from fans helps evaporate the water, which then pulls heat from the animal. The fully-automated cooling system for any cow traffic lane is temperature and motion activated in order to provide a cool shower to cows in transit. The system is triggered only when the dual motion sensors detect an animal is present and the air temperature is above the specified set point.

Similarly, controllers are available to provide infinite-stage cooling by increasing shower frequency automatically as temperatures rise. This technology adjusts the length of time between shower cycles in correspondence to fluctuations in temperature. The tuning capabilities help conserve water when temperatures fall[13].

EVAPORATIVE COOLING SYSTEMS FOR CROSS- OR TUNNEL-VENTILATED BARNS

Several companies use the concept of evaporative cooling system by constructing a cooling pad on one side of the wall and drawing the air through it, which causes cooling effect to the cows inside the barn (Figure 14). Typically cross-ventilated barns are selected for this cooling method. Evaporative systems are available in various sizes and typically include a cooling pad, end panels, sump pump, and plumbing[14,15,16].

FIGURE 14. PICTURES SHOWING INSTALLATION OF AQUACOOL® EVAPORATIVE COOLING SYSTEMS

PORTABLE EVAPORATIVE COOLING

Portable evaporative cooling systems are available to provide cool air to the cows especially in the holding pens and exit lanes. The cooling is achieved through the process of evaporation. Units use forced air over water-soaked evaporative cooling pads to reduce temperatures up to 30°F. A small motor, typically ½ hp, powers a fan to create air circulation. It also has flexible capabilities for ducting. Both unit and water supply are portable and housed in molded plastic poly-ethylene. Units are available with an energy-efficient motor and pump[17]. Tank capacities are typically approximately 30 liters (~8 gallons).

ROTATING-TRACKING FANS WITH MISTERS

Manufacturers have demonstrated innovation in adding features to fans in order to provide more cooling efficiency. An example of such a system combines fans and misting with a horizontal rotational mounting structure that allows the fans to flip to point outside the shade for night-time cooling. The new technology couples fans and misters with shade throughout the entire day by rotating along a horizontal axis to compensate for the angle of sun and wind speed (Figure 15). A previous version of this technology employed shade tracking fans and misters oscillating around a vertical. This system was limited by the fact that cows were in the arc of the cooling rotation for only a portion of the time. The updated version of this system enables cows to remain in the cooling zone as they follow shade movement to benefit from fans and misters throughout the day, further minimizing heat stress and reduction in milk production.

FIGURE 15. ROTATING TRACKING FANS WITH MISTERS [18]

TURBULENCE VENTILATION

Turbulence ventilation uses positive pressure to create air flow turbulence inside the enclosed dairy barns. Air is blown into the barn from all areas uniformly. Heat transfer from a cow is influenced by speed and direction of air. Turbulence ventilation uses turbulence to increase the heat release from the cow during hot weather. Manufacturer claims the convective heat transfer increases 50% in hot air[19]. The concept offers three-dimensional airflow. Air blowing into the building from all sides creates big whirls of air which, in turn, create little whirls that feed on their velocity. Positive pressure supply systems are simpler because they use entry and egress openings for discharge points. These are primarily used in enclosed dairy farms (Figure 16).

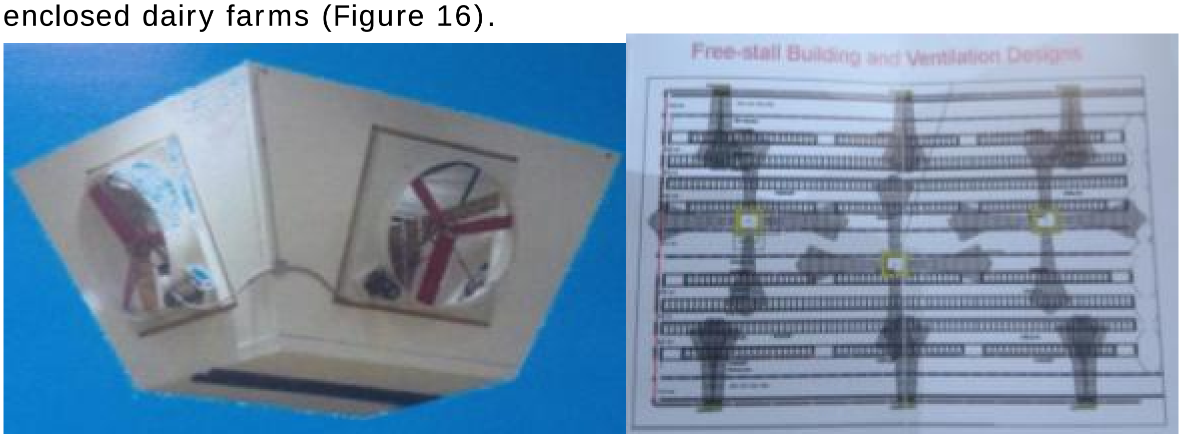


FIGURE 16. PICTURE OF FANS USED FOR TURBULENCE VENTILATION

ROOF VENTILATION

Another solution available involves roof ventilation[20]. The roof/ridge intake and exhaust vents are for dairy, hog, poultry, equine and many other buildings that benefit from allowing air in and out of the roof. Warm air rises to the top and escapes through the ventilation roof in the summer months. In cooler weather, fans reverse the air flow and allow fresh air into the building through the roof. This technology features rugged polyethylene material with ultraviolet inhibitors (Figure 17). One-piece construction prevents leaking and the design blocks rain and snow. It also includes a bird screen. The intake is 24"H x 36"W x 48"L and designed for 3,000 cfm.

FIGURE 17. PICTURE SHOWING VENTILATION ROOFS

MILK PRODUCTION VARIATIONS IN DAIRY FARMS

VARIATION IN MILK PRODUCTION WITH COWS INTERNAL BODY TEMPERATURE

Heat stress is a major cause of diminished milk production and increased disease among lactating dairy cows, and because of it the dairy industry suffers significant financial losses every year. Annual losses to the American dairy industry are estimated between $897 million to $1.5 billion. The heat stress has the following impacts on the dairy cows:

- Decrease in milk production,
- Acute health problems,
- Significant drop in pregnancy rate,
- High incidence of miscarriages, and
- Higher death loss.

In June, 2006 a severe heat wave cost the California dairy industry over $1 billion in losses. Of importance to the livestock industry are the complex physiological and adaptive responses of heat stress and how they affect the ability of domestic animals to reproduce and produce milk on an economic basis[21] .

Projections estimate the global average temperature will rise by an additional 2.0°F to 9.7°F throughout the 21st century[22]. These changes will have large and measurable impacts on dairy cattle worldwide[23] through a variety of routes including changes in food availability and quality, changes in pest and pathogen populations, alteration in immunity, and both direct and indirect impacts on animal performance such as growth, reproduction, and lactation.

Improving productivity in dairy animals exposed to adverse environmental conditions during the last quarter-century has focused on improving the environment around the animals and their nutritional management. This approach has dramatically increased productivity of dairy animals. However, as energy costs have increased, the return on investment for modifying environments around animals has declined. Therefore, there is renewed interest in lowering the energy costs of cow cooling.

The physical factors that are important to productivity of livestock include air temperature, humidity, solar radiation, and wind speed. Therefore, the microclimate around an animal is thought of as a four-dimensional space (e.g., hot, humid, sunny, windy or hot, dry, sunny and calm) in which the four independent environmental variables are acting simultaneously.

Mammals may survive, thrive, or die in an unfavorable thermal environment depending on their limit of tolerance and ability to utilize efficient physiological and behavioral mechanisms to maintain a heat balance between their bodies and the environment.

The effect of ambient heat on dairy cattle milk production is well known and heavily influenced by relative humidity. A majority of the world’s human and domestic animal populations lie in regions where seasonal stressors adversely influence productivity. Research to date has shown that cows start to experience heat stress when ambient temperatures reach 80°F with 0% humidity. However, as milk production continues to increase, the THI at which cows become “stressed” continues to decrease.

DAIRY CATTLE PHYSIOLOGICAL RESPONSE TO HEAT STRESS

Dairy cattle produce large amounts of heat from both ruminal fermentation and metabolic processes. Genetic selection for milk production has also increased metabolic heat output per cow. As production increases, the total amount of heat produced increases. A high-producing, lactating cow will produce approximately 4,500 Btu/hr. In order to maintain normal body temperature, heat-stress free range cows must exchange this heat with the environment. Figure 18 displays the process of how cattle exchange heat through the mechanisms of convection, conduction, evaporation, and radiation.

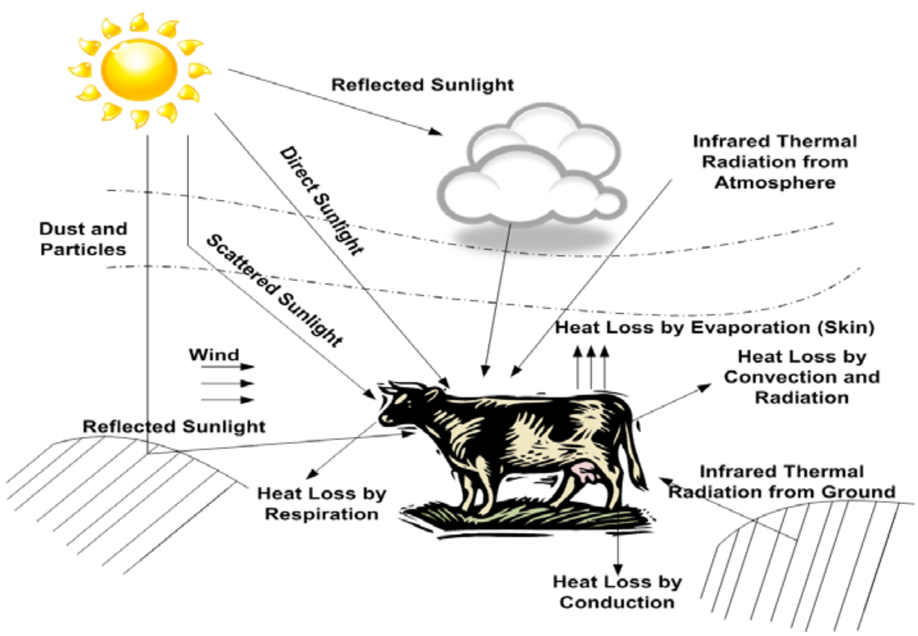


FIGURE 18. ILLUSTRATION OF THE ROUTES OF HEAT EXCHANGE BETWEEN A COW (OUTDOORS) AND ITS THERMAL ENVIRONMENT INCLUDE RADIATION, CONDUCTION, CONVECTION, AND EVAPORATION (FROM THE SKIN AND RESPIRATION) AS THE FOUR BASIC MODES OF NATURAL HEAT TRANSFER.[24]

SPECIFIC RESEARCH DATA REGARDING HEAT STRESS

Figure 19, shows the details for the THI index for various temperature/humidity conditions surrounding dairy cows. As shown in the figure, higher temperatures (shown vertically on the left) cause lower stress when combined with lower humidity (shown horizontally at the top). Higher humidity requires lower ambient temperatures to stay within the stress threshold, which occurs at a THI of 68.

Themperature		% Relative Humidity																				
°F	°C	0	5	10	15	20	25	30	35	40	45	50	55	60	65	70	75	80	85	90	95	100
72	22.0	64	65	65	65	66	66	67	67	67	68	68	69	69	69	70	70	70	71	71	72	72
73	23.0	65	65	66	66	66	67	67	68	68	68	69	69	70	70	71	71	71	72	72	73	73
74	23.5	65	66	66	67	67	67	68	68	69	69	70	70	70	71	71	72	72	73	73	74	74
75	24.0	66	66	67	67	68	68	68	69	69	70	70	71	71	72	72	73	73	74	74	75	75
76	24.5	66	67	67	68	68	69	69	70	70	71	71	72	72	73	73	74	74	75	75	76	76
77	25.0	67	67	68	68	69	69	70	70	71	71	72	72	73	73	74	74	75	75	76	76	77
78	25.5	67	68	68	69	69	70	70	71	71	72	73	73	74	74	75	75	76	76	77	77	78
79	26.0	67	68	69	69	70	70	71	71	72	73	73	74	74	75	76	76	77	77	78	78	79
80	26.5	68	69	69	70	70	71	72	72	73	73	74	75	75	76	76	77	78	78	79	79	80
81	27.0	68	69	70	70	71	72	72	73	73	74	75	75	76	77	77	78	78	79	80	80	81
82	28.0	69	69	70	71	71	72	73	73	74	75	75	76	77	77	78	79	79	80	81	81	82
83	28.5	69	70	71	71	72	73	73	74	75	75	76	77	78	78	79	80	80	81	82	82	83
84	29.0	70	70	71	72	73	73	74	75	75	76	77	78	78	79	80	80	81	82	83	83	84
85	29.5	70	71	72	72	73	74	75	75	76	77	78	78	79	80	81	81	82	83	84	84	85
86	30.0	71	71	72	73	74	74	75	76	77	78	78	79	80	81	81	82	83	84	84	85	86
87	30.5	71	72	73	73	74	75	76	77	77	78	79	80	81	81	82	83	84	85	85	86	87
88	31.0	72	72	73	74	75	76	76	77	78	79	80	81	81	82	83	84	85	86	86	87	88
89	31.5	72	73	74	75	75	76	77	78	79	80	80	81	82	83	84	85	86	86	87	88	89
90	32.0	72	73	74	75	76	77	78	79	79	80	81	82	83	84	85	86	86	87	88	89	90
91	33.0	73	74	75	76	76	77	78	79	80	81	82	83	84	85	86	86	87	88	89	90	91
92	33.5	73	74	75	76	77	78	79	80	81	82	83	84	85	85	86	87	88	89	90	91	92
93	34.0	74	75	76	77	78	79	80	80	81	82	83	85	85	86	87	88	89	90	91	92	93
94	34.5	74	75	76	77	78	79	80	81	82	83	84	86	86	87	88	89	90	91	92	93	94
95	35.0	75	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90	91	92	93	94	95
96	35.5	75	76	77	78	79	80	81	82	83	85	86	87	88	89	90	91	92	93	94	95	96
97	36.0	76	77	78	79	80	81	82	83	84	85	86	87	88	89	91	92	93	94	95	96	97
98	36.5	76	77	78	80	80	82	83	83	85	86	87	88	89	90	91	92	93	94	95	96	98
99	37.0	76	78	79	80	81	82	83	84	85	87	88	89	90	91	92	93	94	95	96	98	99
100	38.0	77	78	79	81	82	83	84	85	86	87	88	90	91	92	93	94	95	96	98	99	100
101	38.5	77	79	80	81	82	83	84	86	87	88	89	90	92	93	94	95	96	98	99	100	101
102	39.0	78	79	80	82	83	84	85	86	87	89	90	91	92	94	95	96	97	98	100	101	102
103	39.5	78	79	81	82	83	84	86	87	88	89	91	92	93	94	96	97	98	99	101	102	103
104	40.0	79	80	81	83	84	85	86	88	89	90	91	93	94	95	96	98	99	100	101	103	104
105	40.5	79	80	82	83	84	86	87	88	89	91	92	93	95	96	97	99	100	101	102	103	105
106	41.0	80	81	82	84	85	87	88	89	90	91	93	94	95	97	98	99	101	102	103	104	106
107	41.5	80	81	83	84	85	87	88	89	91	92	94	95	96	98	99	100	102	103	104	106	107
108	42.0	81	82	83	85	86	88	89	90	92	93	94	96	97	98	100	101	103	104	105	107	108
109	43.0	81	82	84	85	87	89	89	91	92	94	95	96	98	99	101	102	103	105	106	108	109
110	43.5	81	83	84	86	87	89	90	91	93	94	96	97	99	100	101	103	104	106	107	109	110
111	44.0	82	83	85	86	88	90	91	92	94	95	96	98	99	101	102	104	105	107	108	110	111
112	44.5	82	84	85	87	88	90	91	93	94	96	97	99	100	102	103	105	106	108	109	111	112
113	45.0	83	84	86	87	89	91	92	93	95	96	98	99	101	102	104	105	107	108	110	111	113
114	45.5	83	85	86	88	89	92	92	94	96	97	99	100	102	103	105	106	108	109	111	112	114

Stress Threshold Respiration rate exceeds 60 BPM. Milk yield losses begin. Repro losses detectable. Rectal Temperature exceeds 38.5°C (101.3°F)

Mild-Moderate Stress Respiration Rate Exceeds 75 BPM. Rectal Temperature exceeds 39°C (102.2°F)

Moderate-Severe Stress Respiration Rate Exceeds 85 BPM Rectal Temperature exceeds 40 °C (104°F)

Severe Stress. Respiration Rate 120-140 BPM. Rectal Temperature exceeds 41 °C (106°F)

FIGURE 19. REVISED THI FOR LACTATING COWS [25]

SEASONAL VARIATION IN MILK PRODUCTION AND COWS' INTERNAL BODY TEMPERATURE

There are various observable and measurable effects of elevated core body temperature in lactating and dry (non-milk producing) cows. The effects of heat on dairy cows include:

- Elevated body temperature: Body temperatures greater than 102.5°F (normal is 101.5°F).
- Increased respiration rates: Rates greater than 70-80 breaths/minute.
- Increased maintenance energy requirement: Dairy cows will activate mechanisms in an attempt to dissipate the excess heat and maintain body temperature. The increased respiration rate is one example. The maintenance energy requirement may increase by 20-30% in cows under heat stress. This decreases the intake energy available for productive functions such as milk production. Blood flow to the skin will increase in an attempt to dissipate heat. At the same time, blood flow to the core of the body will decrease.
- Feed nutrient utilization: An increased loss of sodium and potassium is usually associated with heat stress. This is due to losses associated with the increased respiration rate. This can shift the acid-base balance and result in a metabolic alkalosis; there can also be a decrease in the efficiency of nutrient utilization.
- Dry matter intake: Dry matter intake decreases in dairy cows subjected to heat stress. This depression in dry matter intake can be either short term or long term depending on the length and duration of heat stress. Decreases of up to 35% are common in commercial dairy herds. Even on well-managed and well-cooled dairies, heat stress can decrease feed intake by 15%[26,27].
- Milk production: Another easily recognized heat stress factor is reduced milk yield. This decrease can be either transitory or longer term depending on the length and severity of heat stress. Even on well-cooled dairies, heat stress typically decreases milk yield by 10%-15% and on non-cooled management systems milk yield can decrease by 40%-50% during severe conditions[28].

- Reproduction: Ultimately, the physiological effects of heat stress decrease the reproductive performance of dairy cattle. Heat stress impairs follicle selection and increases the length of follicular waves; thus reducing the quality of oocytes, modulating follicular steroidogenesis, and reducing fertility[29,30]. During summer, heat stress reduces pregnancy and conception rates, which can carry over into the fall months[31]. This occurs because the follicle destined to ovulate emerges 40-50 days prior to ovulation. Thus, oocytes contained in follicles that emerge near the end of the summer are damaged by heat stress months before they ovulate. Numerous in vitro and in vivo experiments have clearly demonstrated the devastating effects of heat stress on the developmental competence of oocytes[32,33,34,35]. Not only can heat stress affect the oocyte and early embryo, it can also reduce embryo growth up to day 17, which is the period critical for maternal recognition of pregnancy. Embryonic loss following maternal recognition of pregnancy is also elevated during periods of heat stress. Dairy cows conceiving are up to five times more likely to lose their embryo, respectively, during the hot versus cool season[36]. In addition, the likelihood of pregnancy loss has been shown to increase by a factor of 1.05 for each unit increase in mean maximum THI from day 21 to day 30 of gestation.

AREAS TO IMPROVE ENERGY EFFICIENCY IN A DAIRY FARM

The previous sections covered cooling or ventilation in the dairy farm which accounts for nearly 25% of electricity usage. In this section, the focus is directed to other areas where new and emerging technologies are entering the market place. Some of those areas include:

- Compressors,
- Lighting,
- Pumps,
- Milk pre-cooling equipment, and
- Water heating.

According to an article published by Efficiency Vermont[37], the following are the top areas other than ventilation that could help improve energy efficiency in a dairy farm:

- Milk Pre-Cooling: Using groundwater to pre-cool the milk cuts compressor use. This in itself can reduce milk cooling costs by up to 50%.
- Variable Frequency Drive: Installing variable speed vacuum pump controls can save up to 65% of vacuum pump energy costs.
- Lighting: Replacing older incandescent lighting with energy-efficient light fixtures can reduce lighting costs by up to 65%.
- Heat Recovery: Adding a heat recovery system, which uses waste heat from the compressor to preheat water, can save about half of the energy used for water heating.
- Variable Speed Milk Transfer Systems: Regulating the flow of milk through a plate cooler can significantly enhance the effectiveness of equipment.
- Efficient Pumps: Pumping systems consume almost one-fifth of all the energy on dairy farms.

MILK COOLING SYSTEMS

SCROLL COMPRESSORS

On a dairy farm, the milk cooling system keeps milk at the proper temperature. While this equipment is critical, it also can be expensive to operate. In a milk cooling system, the function of a compressor is to reduce, pump, and cycle the refrigerant through the cooling system. The scroll compressor features a pair of scrolls, in which only one moves and the other is fixed. This orbiting motion compresses and moves refrigerant more efficiently and reliably than traditional compressors. Scroll compressors have performed very well in various industries for many years.

One way to maintain or improve quality and cut costs is to switch from standard compressors to scroll compressors. According to a document[38] published by Wisconsin Public Service, scroll compressors provide the following benefits:

- Reduction of costs: Scroll compressors can reduce costs by streamlining operations.
- Use less energy: Scroll compressors use about 30% less electricity than conventional models, and can run on single-phase electricity.
- Run Quieter: Scroll compressors have only one moving part so they run at lower decibel levels and vibrate less than a standard compressor.
- More Durable and Reliable: Scroll compressors last longer than conventional compressors because they have no seals to tear and need no lubrication. They also operate well in cool weather and do not require crankcase heaters. Additionally, scroll compressors can start under any system load, so you do not need a start kit.
- Better Control Over Milk Quality: Scroll compressors have few mechanical parts. Their simple design makes them very reliable in keeping milk cooled at a consistent temperature and controlling bacteria.

Although scroll compressors have fewer breakdowns than conventional compressors, it is still important to have this equipment inspected regularly by a qualified professional. Dust and other debris can build up on refrigeration equipment and impede energy efficiency. Clean units use up to 5% less energy than those that are dirty, according to a study by the University of Wisconsin. Figure 20 displays a cross-section of a scroll compressor.

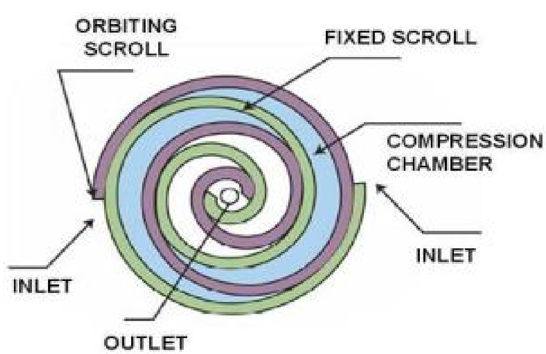


FIGURE 20. CROSS-SECTION OF SCROLL COMPRESSOR39

Magnetic Bearing Compressor

Higher efficiencies can be obtained using magnetic bearings in concert with variable-speed centrifugal compression, permanent-magnet motor, and digital electronic technologies that are designed for the heating, ventilating, and air conditioning (HVAC) and process cooling. Figure 21 displays a schematic of a magnetic bearing compressor.

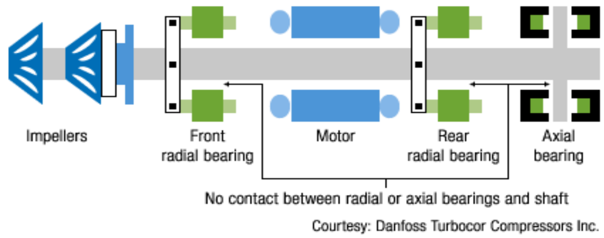


Figure 21. Schematic of Magnetic Bearing Compressor[40]

Advantages and features of this compressor include:

- Range of capacities from 60 tons to 200 tons;
- Oil-free operation resulting in no oil-management hardware, controls or downtime costs, and improved heat transfer efficiency;
- Extended equipment life;
- Minimal scheduled maintenance due to solid-state electronics, no lubrication and no metal-to-metal contact of rotating components; and
- Quiet operation at approximately 70 decibels (conversation level) sound with reduced vibration.

In a U.S. Department of Energy report, the tests showed higher efficiency for a magnetic bearing compressor over a commonly available reciprocating compressor. Figure 22 shows that magnetic bearing compressors draw less electrical power (kilowatt (kW) per Ton) for a wide range of chiller demand (in Tons)[41].

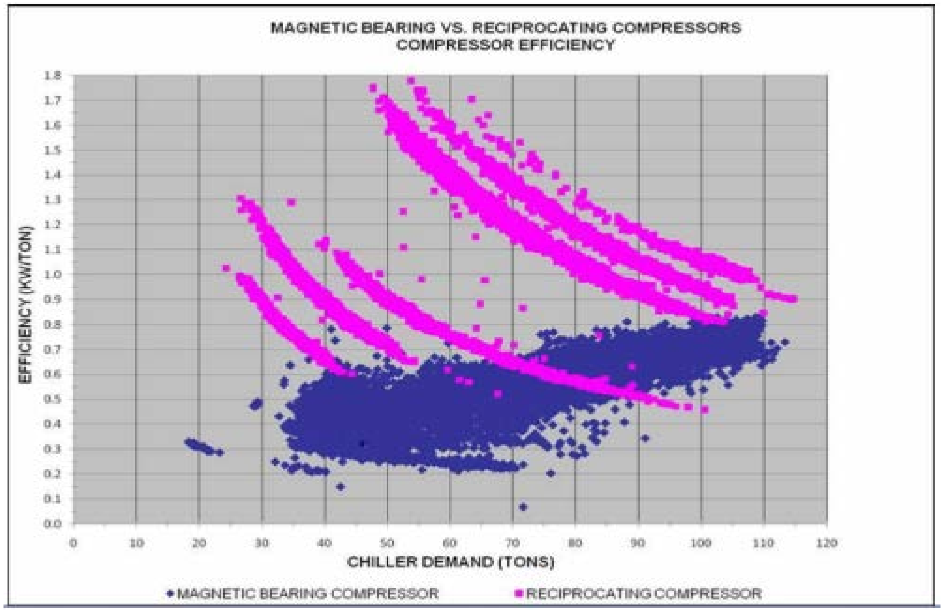


FIGURE 22. TEST RESULTS ON A MAGNETIC BEARING VS. RECIPROCATING COMPRESSOR

LIGHTING IN A DAIRY FARM

Lighting, another major electricity using device, accounts for nearly one-fourth of the total dairy electricity use. This section describes some advancement made in lighting technologies. Table 4 shows various lamp types used in a dairy farm.

TABLE 4. VARIOUS LAMP TYPES USED IN A DAIRY FARM[42]

LAMP TYPE	EFFICIENCY (LUMENS/ WATTS)	COLOR	CORRELATED COLOR TEMPERATURE (CCT) (K)	LIGHTING TASKS
Incandescent	5-20	White	2800	General
Fluorescent (T-8 and T-12)	60-110	Bluish to White	2700-6500	Milking parlor, milk room, holding area, office, equipment washing, veterinary area
Compact Fluorescent	45-72	White	2700-6500	General
Mercury Vapor	25-60	Bluish	3200-7000	Outdoor
Metal Halide	41-110	Bluish	3700	Milking parlor, holding area, milk room, equipment washing, outdoor and veterinary area
High Pressure Sodium	50-140	Yellow - Orange	2100	Milking parlor, holding area, feeding area, outdoor
Low Pressure Sodium	60-150	Yellow		Outdoor

LED LIGHTS

National Rural Electric Cooperative Association's (NRECA)[43] Cooperative Research Network, along with Oklahoma State University, commissioned several agricultural LED field assessments in 2010. Some key findings from this study are:

- Early field data at the dairy shows a 6% increase in milk yield on the LED lit side of the barn.
- Energy savings of 50% have been validated for LED conversions in dairy facilities.
- For the experiment:
  - A 500-cow free stall barn on a large commercial dairy was split in half.
  - One side outfitted with LED lamps and the control side with traditional metal halide lamps.
  - It was conducted in late September, so the researchers expected a normal increase in milk production because of the drop in fall temperatures.
  - The control group went from 60.1 to 64.2 pounds of milk, while the LED group jumped from 62 to 70 pounds of milk.

A wide range of agriculture-ready technologies and LED lights are available. LED light fixtures for dairy farms may possess the following features and benefits[44]:

- Designed and engineered optics for precise light control; no light pollution.
- Automated control that can include schedule on/off, daylight harvesting, or nightlight switching; helps eliminate human error and enhance energy efficiency.
- Adaptable for high or low bay applications.
- Weatherized for harsh conditions (waterproof and corrosion resistant).
- Temperature ratings from -40°F to +113°F.
- Consumes approximately 65%-75% less energy (actual savings may vary depending on the application.) Clear, crisp white light enables workers in the barn to see colors properly, more easily spot injuries or other animal welfare issues and clearly identify the animals.
- Emits no ultraviolet light and doesn't attract flies, which helps control population, annoyance, and reduces spread of disease.
- Instant ON capability and dimmable (during day times).

HIGH INTENSITY FLUORESCENT VAPOR TIGHT FIXTURES

High intensity fluorescent (HIF) lamps, displayed in Figure 23, possess the follow features[45]:

- T5 High Output Fluorescent (T5HO) lamps provide better light quality and lumen maintenance compared to metal halide.
- Have up to 50% longer lamp life than metal halide.
- Higher lumen per lamp equals fewer lamps and fixtures required when compared to T8 high lumen fixtures.
- Program rapid start ballast (similar to a soft start) extends lamp life up to 36,000 hours and still starts at temperatures as low as –20°F.
- HIF consumes approximately 40-60% less energy and requires 50% less maintenance than HID.

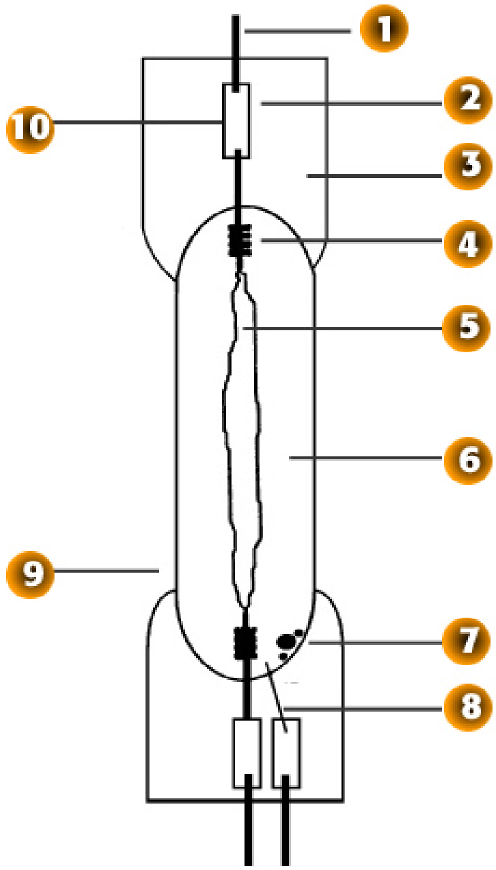
FIGURE 23. HIGH INTENSITY FLUORESCENT LIGHTS

PULSE START METAL HALIDE LAMPS

A probe-start quartz metal halide lamp requires high starting voltage from the ballast to initiate an arc. Typically a starter electrode (item #8 in Figure 24) is installed next to the main electrode to help in gas ionization during the first few seconds after which it is turned off by means of a bi-metallic switch[46,47].

Contrary to the Probe start metal halide (MH) lamp, the pulse start metal halide (PSMH) lamps have a slightly different construction that helps them to produce and maintain higher lumens. The following features are true of the PSMH lamps:

- Do not have the starting probe electrode;
- Have a high-voltage igniter that works with the ballast to start the lamp using a series of high-voltage pulses (typically 3 to 5 kilovolts); and
- Less electrode material is removed from the electrodes of a pulse-start lamp versus a probe start lamp.



1. Wire lead electrical connection
2. Molybdenum ribbon
3. Quartz pinch seal
4. Tungsten (main) electrode – impact lamp life
5. Electric Arc
6. Small amount of Argon gas
7. Mercury and pure metal salts
8. ***Starter electrode (probe start lamps only)***
9. The arc tube body is made from quartz because it has a very high melting temperature and is not affected by the extreme heat produced by the electric arc.
10. In the case of non-pulse start metal halide and mercury vapor lamps, Heated Quartz is pinched tight around an extremely thin molybdenum ribbon that carries current to the electrodes. The pinch makes an air-tight seal that prevents the small amount of gas and chemicals from leaking out of the arc tube which would cause the lamp to fail.

FIGURE 24. DIFFERENCE BETWEEN PULSE START AND PROBE START METAL HALIDE LAMPS[48]

Advantages of PSMH include:

- Longer lamp life of up to 50%;
- Increased lumen maintenance by up to 33%;
- Better cold starting capability; these lamp-ballast systems will start at temperatures as low as -40°C (-40°F);
- Allows faster starting when cold, shorter warm-up times and a faster re-strike (re-start); and
- Pulse Start lamp systems can yield fewer fixtures for a given system because of the increased lumen output which can reduce the capital cost for the system. Also, lumen maintenance of pulse start lamps is better than the probe start lamps as shown in Figure 25; this may result in fewer lamp replacements over the life of the system.

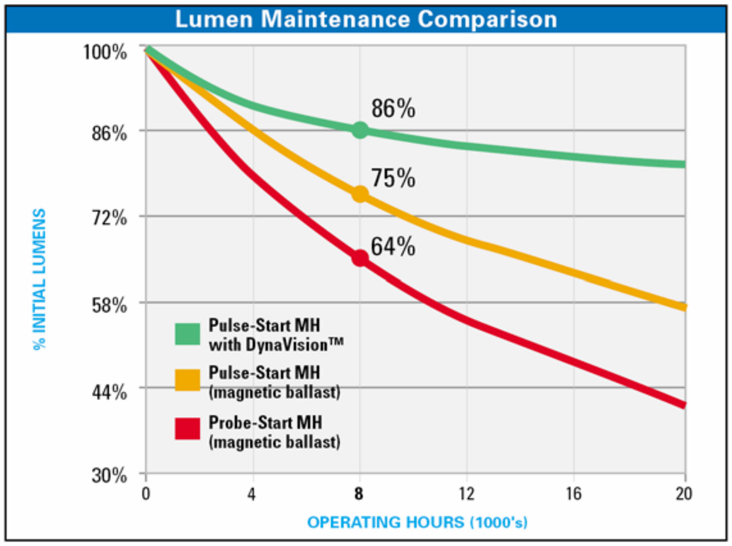


FIGURE 25. EXAMPLE OF LUMEN DEPRECIATION IMPROVEMENTS FROM USE OF PULSE-START METAL HALIDE LAMPS AND ELECTRONIC HID BALLASTS[49]

CASE STUDY

Figure 26 shows a comparison of various energy-efficient lamp retrofits at a New York dairy farm[50]. Lighting is a major load, accounting for nearly 24% of electricity use in a dairy farm; switching to energy-efficient lighting can help farm owners save energy and money in the long run.

How Real $avings Light Up an Average NY Dairy Farm (110 Cow Herd)

Area	Current Lighting Fixture	Recommended Replacement Fixture	No.# Light Units	Estimated Annual Electricity Savings (kWh)	Estimated Annual Energy Savings	Estimated Cost to Farm	Daily Run Hrs.	Estimated Payback (in Years)
Calf Barn	100W Incandescent 100W Total Input Watts	23W CFL, 23W Total Input Watts	5	422	$59	$45	8	0.6
Yard Lights	250W Mercury Vapor 290W Total Input Watts	150W PSMH, 163W Total Input Watts	2	1,112	$156	$370	8	2.3
Free Stall	400W Standard Metal Halide 456W Total Input Watts	6-Lamp, 4ft.T8, 32W Bulbs, 220.8W Total Fixture Wattage	12	8,241	$1,154	$3,480	12	3.0
Parlor	4-Lamp, 4ft. T12 40W Bulbs, 152W Total Input Watts	Appropriate T8 or T5 Fluorescent Fixture*	14	1,864	$261	$2,394	8	9.1
Holding Area	2-Lamp, 4ft. T12 (40W Bulbs, 76W Total Input Watts	Appropriate T8 or T5 Fluorescent Fixture*	6	399	$56	$513	3	9.1
			Totals	12,038	$1,685	$6,802		4.0

FIGURE 26. CASE STUDY OF ENERGY SAVING ACHIEVED DUE TO ENERGY EFFICIENT LIGHT TECHNOLOGIES IN A DAIRY FARM

INTEGRATED PUMP SYSTEMS

From simple water pumping systems to oil refineries, hot water circulation systems to pool pumps, pumps find application in many different capacities within commercial, residential, industrial, and agricultural sectors. Though there are many applications, pumps can be classified into two basic types based on the way they transmit energy to the fluid they carry. The first type of pump is known as a positive displacement pump while the second is referred to as a kinetic pump. Centrifugal pumps are the most common type of kinetic pumps. Centrifugal pumps transmit energy to fluid as it flows through the pump. Liquid first flows into the inlet or suction side of the centrifugal pump. This liquid is then captured by the impeller and thrown to the outside of the pump casing, or volute. The volute converts the velocity imparted to the fluid by the impeller into pressure, causing the fluid to flow through the system.

A newer class of centrifugal pumps has now entered the market (Figure 27). These pumps have a variable speed drive (VSD) integrated with the electric motor that has helped to do the following:

- Make it simple for the owner to purchase the correct VSD for the pump application.
- Avoid over-sizing pump hp for the VSD.
- Optimize control schemes already programmed by the manufacturer for the motor to operate at its best efficiency point on the pump curve.
- Size the pump for optimum hydraulic efficiency at part-load.
- Size motor for optimum mechanical efficiency at part-load.
- Size VSD for optimum electrical efficiency at part-load.

The integration of perfectly matched pump, motor, and variable speed controls allows for lower first cost (at least 20% according to the manufacturer) and lower operating cost. Manufacturer claims also indicate the pump can offer up to 70% energy savings for variable load applications with proper selection.[51] They also come with built in DC line reactors to reduce harmonics. These integrated pump systems can also optionally be equipped with demand response (DR) capabilities. Pumps controlled by a microprocessor can be made to receive utility signals and slow the pump or turn off the pump using the DR signal. Even though this current version of the pump does not have this feature, the manufacturer has mentioned that they are working on this for the next generation of the pumps. The pumps are available from 7.5 hp to 450 hp range.

FIGURE 27. INTEGRATED PUMP SYSTEMS (COURTESY: ARMSTRONG, WILO, GRUNDFOS & MOOG)

ALTERNATE WATER HEATING OPPORTUNITIES IN DAIRY FARMS

Heating water is often cited as the most energy-intensive function on the dairy farm. Nearly 4% of electricity energy is used in the dairy farm for water heating. Today there are many types of water heating systems available that can use a variety of energy sources. The more common types of water heating systems[52] include:

- Storage tank water heaters,
- Tankless “on-demand” water heaters,
- Heat pump water heaters,
- Hybrid heat pump water heaters,
- Hot-water supply boilers, and
- Combinations of the above.

Sources of energy for heating water include electricity, natural gas, liquefied petroleum gas, propane, fuel oil, and solid fuels such as coal and biomass (chunk wood, wood chips, biomass pellets, and crop residues) and solar energy.

Some energy efficiency measures[53] that can be used for water heating are:

- Selecting a new water heater (e.g., heat pump);
- Reducing hot water use, if possible;
- Lowering water heating temperature;
- Insulating water heater tank;
- Insulating hot water pipes;
- Installing heat traps on a water heater tank;
- Installing a timer and use off-peak power for an electric water heater; and
- Installing a drain-water heat recovery system.

However, hot water is needed for several purposes in the dairy farm including the most important one, sanitation. The following two sub-sections look at some alternate energy efficient water heating methods.

SOLAR WATER HEATING – EVACUATED-TUBE

Dairy farms use a tremendous amount of energy to heat the water used for the cleaning and sanitizing necessary for milking operations. Solar thermal is capable of capturing two to three times the energy than PV. Evacuated-tube technology[54] provides higher water temperatures than traditional flat-plate collector technology; however the concept for heating water using both collectors is the same, as shown in Figure 28.

FIGURE 28. EVACUATED TUBE SOLAR WATER HEATERS [55]

In a case study, a dairy farm with 600 cows was chosen for a demonstration. Prior to the installation of a 10-collector solar thermal system, the farm relied on electricity and propane as the energy sources for hot water heating. A 1,205 gallon storage tank is located on the barn floor underneath the roof-mounted collector array. The closed loop system uses a nontoxic propylene glycol solution as the heat transfer liquid that circulates through the collectors and a heat exchanger inside the solar storage tank. On average, the solar hot water system produces 520,000 Btu/day, resulting in an annual energy savings equivalent to 55.6 megawatt hour (MWh)/year. This translates into an annual savings of $5,560 (at an average of 10 cents/kWh.

HEAT PUMP WATER HEATERS

Heat pump water heaters use electricity to move heat from one place to another instead of generating heat directly (Figure 29). Therefore, they can be two to three times more energy-efficient than conventional electric resistance or gas water heaters. To move the heat, heat pumps work like a refrigerator in reverse. A stand-alone air-source heat pump water heater pulls heat from the surrounding air and dumps it (at a higher temperature) into a tank to heat water. Heat pump water heaters, however, will not operate efficiently in a cold space.

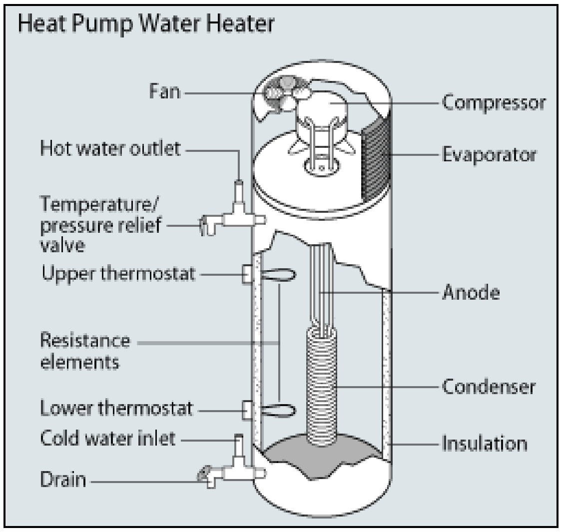


FIGURE 29. SCHEMATIC OF A HEAT PUMP WATER HEATER

HEAT RECOVERY SYSTEMS FOR HEATING WATER

Heat recovery systems capture lost heat from the milk cooling system to heat the water (for free). The heated water is then stored in the system until it is needed[56].

In a milk cooling system without a heat recovery system, the refrigerant removes the heat from the milk being cooled and the valuable heat escapes into the air. For such systems a heat recovery system can easily be retrofitted.

MILK PRE-COOLING

Milk pre-coolers use cold well water to remove heat out of the milk before it enters the refrigeration system. This reduces the amount of heat the refrigeration system must remove as it cools the milk to its safe storage temperature. As a result, the amount of electricity needed to cool the milk is also reduced. If a nearby well is available, a pre-cooler can be a very effective way to cut energy costs.

VARIABLE SPEED MILK TRANSFER CONTROL SYSTEM

Advanced variable speed milk transfer control systems can automatically and smoothly adjust pumping requirements to any flow rate and head pressure as needed by the cooling system. The milk pump matches the flow rate of incoming milk for a more efficient cooling system and lower energy consumption. Since flow rates are managed more efficiently, overall cooling system size requirements can be reduced.

PLATE HEAT EXCHANGERS

Plate heat exchangers cool milk with well or chilled water before it reaches the tank in order to provide quick cooling and ensure the quality of the milk produced. Warm milk passes through alternate stainless steel plates in one direction, while water passes in the opposite direction. Heat exchangers vary by manufacturer, but one example is a herringbone configuration, which causes the milk and water to roll through the plates. This rolling action maximizes contact between the liquids and the plate walls for highly efficient heat transfer. Plate heat exchangers can be used to pre-cool milk or to completely cool milk before it reaches the bulk milk tank. Figure 30 shows an example of a plate heat exchanger.

FIGURE 30. PLATE HEAT EXCHANGERS [57]

MARKET ANALYSIS OF DAIRY FARMS

TRENDS IN DAIRY FARMS ACROSS THE UNITED STATES

The farm value of milk production is second only to beef among livestock industries and is equal to corn. There are approximately 51,500 dairy operations milking 9.2 million dairy cows in the United States. Milk is produced in all 50 states, with the major producing states as of 2011 being California, Wisconsin, Idaho, New York, Pennsylvania, Texas, Minnesota, Michigan, New Mexico, and Washington (Figure 31). Most U.S. dairy cows are Holsteins, a breed that tends to produce more milk per cow than other breed. Holstein milk comprises approximately 87.7% water, 3.7% milk fat, and 8.6% skim solids. Dairy products range from cheese, fluid milks, yogurt, butter, and ice cream to dry or condensed milk and whey products.

The U.S. dairy industry is the sixth largest in the world in terms of milk production and represented more than one-tenth of the total world milk production in 2010. The dairy industry in the U.S. has undergone significant structural changes over the past eight years, with the number of large operations increasing while the total number of milk cow operations declined significantly. During the past century the U.S. dairy industry has experienced various changes that range from a sharp reduction in total cow numbers to a near six-fold increase in average production per cow, declining per capita consumption of whole milk equivalent and fluid milk, and the marked increase in the consumption of cheese. Current trends show that U.S. milk production is shifting to the Western half of the U.S., primarily from the South-Eastern and North-Eastern States. In terms of trade, approximately 13% of U.S. milk production was sold overseas in 2010. Mexico, Southeast Asia, and Canada remained the largest destinations for U.S. dairy products. The U.S. dairy industry is under greater pressure to compete more aggressively, both domestically and globally, in order to secure a share of the consumer's food budget and for resources to keep the industry moving forward.

Milk Cows and Production – States and United States: Revised April - June

[Excludes milk sucked by calves]

State	April - June milk cows[1]		April - June milk production[2]		
	2012	2013 [3]	2012	2013	Change from 2012
	(1,000 head)	(1,000 head)	(million pounds)	(million pounds)	(percent)
Alabama	10.0		37.0	34.0	-8.1
Alaska	0.4		1.4	0.8	-42.9
Arizona	192.0		1,214.0	1,200.0	-1.2
Arkansas	11.0		38.0	30.0	-21.1
California	1,784.0		10,899.0	10,825.0	-0.7
Colorado	132.0		814.0	834.0	2.5
Connecticut	18.5		93.0	98.0	5.4
Delaware	5.0		24.8	24.6	-0.8
Florida	123.0		638.0	647.0	1.4
Georgia	80.0		409.0	419.0	2.4
Hawaii	2.0		7.6	7.9	3.9
Idaho	580.0		3,434.0	3,450.0	0.5
Illinois	100.0		503.0	507.0	0.8
Indiana	176.0		967.0	1,012.0	4.7
Iowa	206.0		1,125.0	1,172.0	4.2
Kansas	125.0		693.0	749.0	8.1
Kentucky	74.0		294.0	284.0	-3.4
Louisiana	18.0		61.0	58.0	-4.9
Maine	33.0		158.0	157.0	-0.6
Maryland	51.0		252.0	249.0	-1.2
Massachusetts	12.0		56.0	61.0	8.9
Michigan	375.0		2,252.0	2,308.0	2.5
Minnesota	465.0		2,291.0	2,322.0	1.4
Mississippi	14.0		54.0	51.0	-5.6
Missouri	94.0		386.0	369.0	-4.4
Montana	14.0		76.0	76.0	-
Nebraska	56.0		300.0	299.0	-0.3
Nevada	29.0		173.0	174.0	0.6
New Hampshire	14.0		72.0	68.0	-5.6
New Jersey	7.5		35.0	33.0	-5.7
New Mexico	335.0		2,111.0	2,093.0	-0.9
New York	610.0		3,370.0	3,472.0	3.0
North Carolina	46.0		246.0	246.0	-
North Dakota	18.0		88.0	89.0	1.1
Ohio	271.0		1,379.0	1,403.0	1.7
Oklahoma	49.0		219.0	216.0	-1.4
Oregon	123.0		649.0	650.0	0.2
Pennsylvania	536.0		2,677.0	2,719.0	1.6
Rhode Island	1.0		5.0	4.7	-6.0
South Carolina	15.5		74.0	72.0	-2.7
South Dakota	93.0		494.0	501.0	1.4
Tennessee	50.0		210.0	203.0	-3.3
Texas	440.0		2,475.0	2,456.0	-0.8
Utah	91.0		498.0	489.0	-1.8
Vermont	133.0		653.0	672.0	2.9
Virginia	96.0		444.0	451.0	1.6
Washington	263.0		1,600.0	1,636.0	2.3
West Virginia	10.0		41.0	41.0	-
Wisconsin	1,271.0		6,887.0	6,996.0	1.6
Wyoming	6.0		31.3	32.7	4.5
United States	9,259.0		51,509.0	51,962.0	0.9

\- Represents zero.
[1] Includes dry cows, excludes heifers not yet fresh.
[2] Excludes milk sucked by calves.
[3] Survey was not conducted in April and July.

FIGURE 31. EXCERPT FROM USDA REPORT ON INDIVIDUAL RANKING OF COWS AND MILK PRODUCTION, BY STATE[58]

Dairy farms, overwhelmingly family-owned and managed, are generally members of producer cooperatives. As previously stated, the industry has seen a consistent decline in the number of operations, matched by a rise in the number of cows per operation. The number of operations with 500 or more head of milk cows has increased. From 2001 to 2009, the number of operations with 500 or more head increased by 20%, from 2,795 to 3,350. The largest size group, places with 2,000 or more head, showed the greatest percentage of change from 2001 to 2009, and increasing from 325 dairies to 740, a gain of 128%. While larger operations grew in number, smaller operations declined in number. Dairies with less than 500 head went from 94,665 in 2001 to 61,650 in 2009, a decline of over 33,000 operations, or 35%.

SUMMARY

This white paper provides a better understanding of dairy operations especially the overall electricity consumption in the dairy farm. The applications that use electricity on a dairy farm are lighting, electric water heating, ventilation, milk cooling, milk harvesting and other applications.

It is generally found that milk production is reduced in summer months due to heat stress experienced by the dairy cows.

Another area for new learning comes from the evaluation of alternative cow cooling methods such as ground source heat pumps (GSHP).

Apart from cooling, there are other electrotechnologies that can help in the efficient operation of dairy farms.

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