Emerging Technologies

Conductive Cooling System for Dairy Farms

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Prepared by:

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EXECUTIVE SUMMARY

This project evaluates the effectiveness of conductive cooling technology to reduce energy consumption while alleviating heat stress in lactating dairy cows. The evaluation takes place on a dairy farm located in California's San Joaquin Valley. Heat stress and increased heat load experienced by lactating dairy cattle during the summer months causes decreased milk production, loss of reproductive efficiency, and other physiological and behavioral changes.

Current heat abatement methods commonly used on dairy farms in this region include shade structures, water soaker systems, and fans. This study evaluates a novel approach using conductive cooling technology. The conductive cooling system (CCS) uses cool water circulating through heat exchanger mats installed below the surface of freestall beds and has the potential to cool cows while reducing energy and water usage compared to conventional cooling systems. Conductive cooling occurs by heat transfer from a cow's body while lying on the cooled bedding that is facilitated by the heat exchanger system.

The CCS was installed on one pen in a two-pen freestall barn. The other pen was used to monitor the baseline system's performance side-by-side. Each pen was occupied by an average daily count of 210 dairy cows. A chiller was installed as an additional component to the CCS to mimic well water temperatures between 60°F and 65°F. The well water temperature at the test barn was between 5°F and 10°F warmer than typical well water. This was believed to be caused by the distance of the barn to the well and the depth of the well.

To determine the overall performance of the system the following objectives were made:

- Determine energy usage of the conductive cooling system and a baseline system consisting of shade structures, water soaker systems, and fans during the monitoring period;
- Determine water usage of the feed-lane soaker lines in the test pen and control pen during the monitoring period;
- Evaluate impact of the conductive cooling system on key veterinary parameters.

Table-ES 1 summarizes the annual energy savings, demand impact, and water savings for the CCS. The last row in Table-ES 1 represents savings estimates for a CCS without a chiller.

TABLE-ES 1. SUMMARY OF ENERGY SAVINGS, DEMAND REDUCTION, AND WATER SAVINGS FOR 210 COW PEN

	ANNUAL ENERGY CONSUMPTION (KWH/YR)	ANNUAL ENERGY SAVINGS (KWH/YR)	PEAK DEMAND (KW)	PEAK DEMAND REDUCTION (KW)	ANNUAL WATER CONSUMPTION (GALS)	ANNUAL WATER SAVINGS (GALS)
Baseline	29,718	-	115	-	2,399,022	-
Conductive Cooling System	36,836	-7,118	125.66	-10.66	454,950	1,944,072
Conductive Cooling System – No Chiller	9,816	19,906	115.7	-0.7	454,950	1,944,072

More research is needed to fully understand the impacts CCS has on energy, water, cow health, and milk production. The technology still needs to address concerns about potential milk production impacts and peak demand constraints. Designs are in development to do just this. As the technology develops and matures, capital cost should fall and system efficiency rise. The timeframe for such to happen is still uncertain.

Given the amount of uncertainty that still remains, SCE's Emerging Technologies Program will not actively promote the CCS technology for program incentives for customized offerings. SCE customers can submit for a customized incentive. If this occurs, care is needed to determine the proper baseline and new systems variables. The configuration and design for CCS systems is likely to vary based on dairy owner's wants and needs. All such factors can be accounted for in a customized solution process.

ABBREVIATIONS AND ACRONYMS

BCS	Body Condition Scoring
BGT	Black Globe Temperature
BPM	Breaths per minute
BRD	Bovine Respiratory Disease
CCS	Conductive Cooling System
cwt	hundredweight
DBT	Dry Bulb Temperature
DHIA	Dairy Herd Improvement Association
DMI	Dry Matter Intake
Gpm	Gallons per minute
HLI	Heat Load Index
Hp	horsepower
kW	kilowatt
kWh	kilowatt-hour
mm	Millimeters
PCL	Control Pen
PTX	Test Pen
RH	Relative Humidity
Rms	Root-mean-square

SCC	Somatic cell counts
THI	Temperature Humidity Index
TMR	Total Mixed Ration
TSRB	Temperature-sensing Reticular Boluses
WS	Wind Speed

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INTRODUCTION

Heat stress and increased heat load experienced by lactating dairy cattle during the summer months causes decreased milk production[1], loss of reproductive efficiency[2], and other physiological and behavioral changes[3]. It has also been reported that high production dairy cows have an increased susceptibility to heat stress[4] and have a lowered heat stress threshold when production increases from 80 pounds to 100 pounds of milk per day[5]. Effective and efficient cooling systems are needed to offset the effects of heat stress during the summer months at a reasonable cost that maintains profit margins. Current heat abatement methods commonly found in use on dairy farms in this region include shade structures, water soaker systems and fans. This study evaluates a novel approach using conductive cooling technology. The conductive cooling system (CCS) uses cool water circulating through heat exchanger mats installed below the surface of freestall beds. It has the potential to cool cows while reducing energy and water usage compared to conventional cooling systems. Conductive cooling occurs by heat transfer from a cow's body while lying on the cooled bedding. This is facilitated by the heat exchanger system. The overall purpose of this project was to evaluate the effectiveness of conductive cooling technology for alleviating heat stress in lactating dairy cows on a dairy farm located in California's San Joaquin Valley and its effect on lactating dairy cow performance and energy efficiency.

BACKGROUND

Lactating dairy cattle produce a significant amount of heat during the anaerobic fermentation of feed in the rumen. This, combined with a large body mass, make it challenging for cows to dissipate excess heat[6]. The recommended range for dairy cow comfort and maximum performance is below 72 Temperature Humidity Index (THI). THI measures the combined effects of ambient temperature and humidity to estimate the degree of discomfort experienced by an animal. From 72 THI to 79 THI, a mild amount of heat stress is evident and management interventions are recommended to maintain performance. Starting at 72 THI, signs of heat stress in cows are indicated by reduced milk production due in part to a reduction in dry matter intake, and there can also be some decrease in reproductive performance. Examples of classical management solutions to alleviate heat stress are shade and fans to help cows dissipate heat in this range. Moderate heat stress occurs in cows from 80 THI to 89 THI and is evidenced by increased respiration rate and water consumption, and dry matter intake decreases with a corresponding decrease in milk production. In addition to shade and fans, soaker systems are added to provide cows with additional heat dissipation through evaporative loss of heat from their bodies. Severe heat stress occurs from 90 THI to 98 THI, of which open mouth breathing can be observed as cows struggle to dissipate excess heat. Dry matter intake will be dramatically decreased, reproduction will be impaired and if the heat stress is prolonged and not ameliorated, a cow's health could be jeopardized.

A dairy farm study in 1993 showed that high-producing dairy cows exposed to long periods of temperature above the comfort zone, especially greater than 72 THI, react in several ways to retain comfort[7]. 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.

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 panel fans (Figure 1) 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-minute 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 1. FEED LANE SOAKER AND EVAPORATIVE COOLING SYSTEMS

ENERGY USE ON A DAIRY FARM

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 2. The three largest uses of electricity are milk cooling (refrigeration), lighting, and ventilation, according to a NYSERDA report[8].

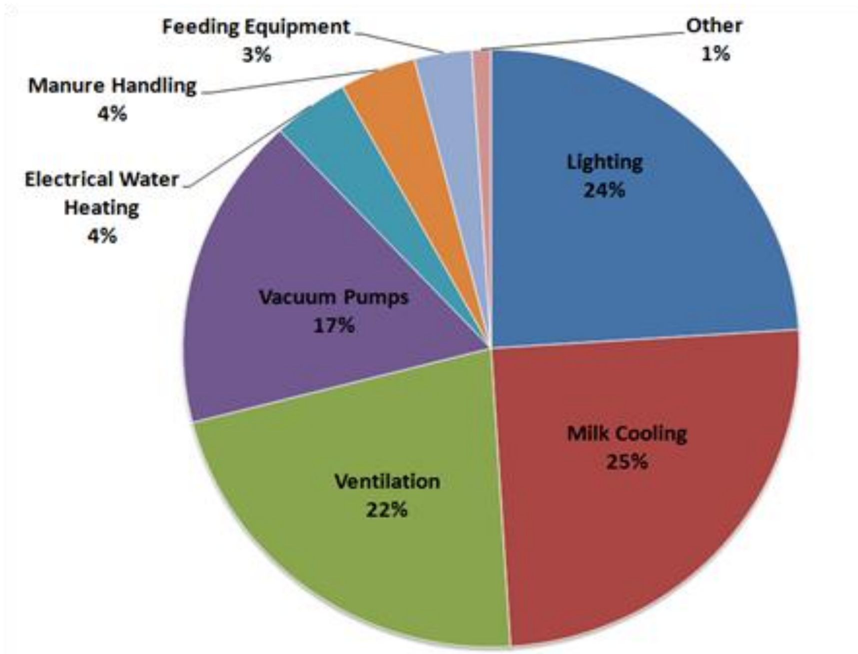

FIGURE 2. ELECTRIC ENERGY USAGE IN A DAIRY FARM[9]

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 3). However, some dairy farms have three milking periods: morning, midday, and nighttime.

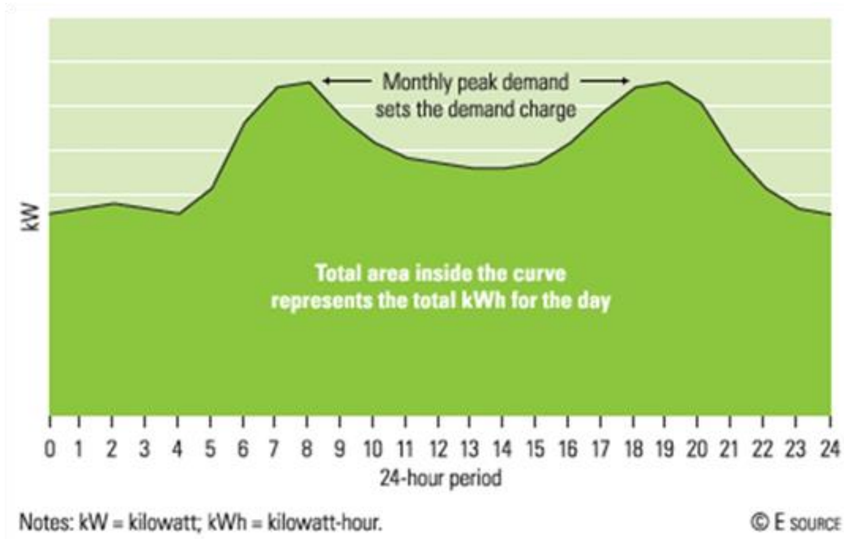

FIGURE 3. DAILY ELECTRICITY USE IN A DAIRY FARM[10]

The consumption component of the electricity bill is composed of three components: a customer charge, energy charge, and facility-related demand charge. A monthly customer charge covers a portion of basic services, such as customer billing. Energy charges are based on the amount of electric energy, in kilowatt hours (kWh), consumed during a billing cycle. Facilities-related demand charges are calculated per kilowatt (kW) according to the highest recorded demand during the billing cycle.

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[11]. Data were 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 ten percent 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[12] 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[13], according to the USDA data is summarized in Table 2. Notice 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[14]

	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 Table 2 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 individual farmers or farm 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.

ASSESSMENT OBJECTIVES

The objective of this project is to evaluate the effectiveness and efficiency of conductive cooling technology for alleviating heat stress of lactating dairy cows in the San Joaquin Valley.

To determine the overall performance of the system the following objectives were made:

- Determine energy usage of the conductive cooling system and baseline system during the monitoring period.
- Determine water usage of the feed-lane soaker lines in the test pen and control pen during the monitoring period.
- Evaluate impact of the conductive cooling system on key veterinary parameters: dry matter intake, milk production and udder health, reproductive efficiency, lameness, body conditions, morbidity/mortality, physiological measures (internal body temperature, respiration rates), behavioral measures (steps, standing, and lying postures).

TECHNOLOGY EVALUATION

This field study compares the performance of a conductive cooling system as an alternative to high-speed low-volume fans and soaker lines as a method of cooling dairy cows in a dairy farm.

SCE partnered with the University of California, Davis' Veterinary Medicine Teaching and Research Center to evaluate the effectiveness of the conductive cooling system in dairy cows as it pertains to heat stress. SCE performed the energy and water usage analysis for this study.

CONDUCTIVE COOLING SYSTEM

The conductive cooling system consists of heat exchanger panels for each bed, a circulating pump, and a chiller. Chilled water is circulated beneath the freestall beds to extract heat from the dairy cows. Temperature setpoints for fans and soaker lines are raised or turned off completely depending on the level of heat stress in cows. For this test, the conductive cooling system was supplemented by the conventional cooling system when ambient temperatures exceeded 92°F. The water in the chilled water loop was chilled to a constant temperature between 60°F and 65°F to mimic well water temperature[1].

The conductive cooling system was previously studied in a laboratory environment at the University of Arizona with favorable results. Promising results also came from a limited field study on 50 dairy cows. The next logical step is to evaluate the performance on a 210 cow freestall barn.

BASELINE FAN AND SOAKER LINE SYSTEM

The baseline system consists of 1-hp fans for every 20 dairy cows and a soaker line system with nozzles every 5 feet to spray cows occupying the feed lane. This configuration is common among freestall barns within SCE's service territory that cool dairy cows. For the dairy's conventional cooling system, in the first stage, 50% of the fans turned on and the soaker times were 1 minute on 7 minutes off when the ambient temperature exceeded 74°F. The second stage occurred at 84°F when all the fans turned on and the soakers were 1 minute on and 5 minutes off.

[1] The chiller is an optional component to the system configuration. The water loop temperature at the test pen was between 5°F and 10°F warmer than typical due to the pen's location relative to the well and the water level of the well. The chiller may also be used to chill water to lower temperatures to increase the temperature gradient between the heat exchangers and dairy cows.

TEST METHODOLOGY

The test methodology for this study is broken up into three parts: energy, water and veterinary.

ENERGY

International Performance Measurement and Verification Protocol (IPMVP) Option A, Retrofit Isolations: Key Parameter Measurement, was followed for this study using IPMVP EVO 1000-1:2010. Sub-metering was conducted on components directly or indirectly affecting the performance of the conductive cooling system and baseline systems only.

The baseline system had the following components:

- 24 fans operating on two separate circuits – high temperature and low temperature setpoints
- One soaker line containing water switching ON/OFF as described previously
- 100 horsepower (hp) well pump supplying water for farm operations to water tank (not solely for control or test pen)
- 20 hp booster pump circulating water to soaker lines throughout dairy farm (not solely to control or test pen)

The measure system had the following additional components:

- 20 ton dual-circuit modular chiller
- 1.5 hp circulating pump for conductive cooling heat exchangers
- 210 embedded heat exchangers

The following instrumentation was installed to capture power data on for the components listed above:

TABLE 3. POWER METER PARAMETERS, METER SPECIFICATIONS AND ACCURACIES

<table>
<tr><th>Parameter</th><th>Location</th><th>Meter Type</th><th>Model</th><th>CT</th><th>Range</th><th>Accuracy</th></tr>
<tr><td>Chiller</td><td>Circuit 1</td><td>Power</td><td>Revolution SN 65120</td><td>TLAR 200/4</td><td rowspan="6">Meter:
Voltage inputs: 0-600 Vrms
Current inputs: 0-5000 Arms, 4166 samples/cycle

*Vrms: root mean square voltage
*Arms: Root mean square current

CT: 1-200 Amps (rms)</td><td rowspan="6">Meter:
1.0% of full scale without probe

CT:
1.5% of reading ±0.5A</td></tr>
<tr><td>Circulating Pump 1.5 hp</td><td>Circuit 2</td><td>Power</td><td>Revolution SN 65125</td><td>TLAR 200/4</td></tr>
<tr><td>Fan bank 1 test pen</td><td>Subpanel circuit 1</td><td>Power</td><td>Revolution SN 61491</td><td>TLAR 200/4</td></tr>
<tr><td>Fan bank 2 test pen</td><td>Subpanel circuit 2</td><td>Power</td><td>Revolution SN 61479</td><td>TLAR 200/4</td></tr>
<tr><td>Fan bank 1 control pen</td><td>Subpanel circuit 3</td><td>Power</td><td>Revolution SN 61514</td><td>TLAR 200/4</td></tr>
<tr><td>Fan bank 2 control pen</td><td>Subpanel circuit 4</td><td>Power</td><td>Revolution SN61518</td><td>TLAR 200/4</td></tr>
</table>

The 100 hp well pump and 20 hp circulation pump were not monitored as part of this project. The pumps are used for end uses throughout the dairy with the soaker lines being just a fraction of that use. Therefore, energy consumption of the pumps was determined by analysis of past electric utility bills for the pump. Since soaker lines turn on only during summer months based on ambient temperature, the increase in pump operation can be directly attributed to the energy increases during this time period.

CLIMATIC CONSIDERATIONS

Weather station equipment was obtained and installed at the dairy 200 feet west of the study pens. Climatic information was collected at 10-minute intervals for air temperature (T, °C), relative humidity (RH, %), wind speed (WS, m/s) and direction, and black globe temperature (BGT, °C).

Temperature/relative humidity data loggers were installed with solar shields inside the freestall areas to continuously monitor ambient temperature and relative humidity conditions at 10-minute intervals. Sensor locations in pens were feed alley, back alley of the freestalls and the freestall bedding area.

Heat load index (HLI) and temperature-humidity index (THI) were calculated from these data and were used as the measure for thermal exposure for dairy cows. These calculations were performed according to the following equations:

EQUATION 1. TEMPERATURE-HUMIDITY INDEX[15]

$$THI = (1.8T + 32) - [(0.55 - 0.0055RH) \times (1.8T - 26)]$$

EQUATION 2. HEAT LOAD INDEX[16]

$$HLI = IF[BGT > 25, \quad 8.62 + (0.35RH) + (1.55BGT) + e^{-WS+2.4} - 0.5WS,$$
$$10.66 + (0.28RH) + (1.3BGT) - WS]$$

T = dry bulb temperature, °C

RH = Relative Humidity, %

BGT = Black Globe Temperature, °C

WS = Wind Speed, m/s (meters/second)

WATER

Flow meters were installed to monitor water usage for the control and test pens. Each pen had a dedicated soaker line that was fed from the well water. Soaker nozzles were placed five feet apart. Each nozzle had a flow rate of 1.5 gallons per minute (gpm). The flow meters were installed on the vertical 3-inch galvanized steel water pipe that supplies the water just before the actuator valve. The meters were installed per manufacturer instructions allowing for sufficient pipe length before and after the meter to ensure the flow was fully developed. Figure 4 shows a picture of an installed flow meter.

FIGURE 4. A FLOW METER INSTALLED ON THE SOAKER LINE WATER SUPPLY LINE

Flow meter parameters, meter specifications and meter accuracies are displayed in Table 4.

TABLE 4. FLOW METER PARAMETERS, METER SPECIFICATIONS AND ACCURACIES

NAME	LOCATION	METER TYPE	MODEL	RANGE	ACCURACY
Flow meter	Pen 9 Soaker line test pen, Pen 10 Soaker line control pen	Single Turbine Insertion Flow Meter	Onicon F-1110	4 – 460 GPM	±2%
Flow meter display module	Each flow meter	GPM and total gallons display	Onicon D-1200	4-460 GPM	±2%
Data logger with 4-20mA input adapter sensor	Each flow meter	Multi-channel data logging system	Onset HOBO H22-001 with S-CIA-CM14	Sensor: 4-20mA	Sensor: ±0.04mA ±0.3%

Annual Savings Calculator

The Annual Savings Calculator allowed for the extrapolation of energy savings to an annual basis since field monitoring was not performed over a 12-month period. The calculator also enables the user to input various configurations of the conductive cooling system to estimate energy consumption and savings (i.e., setpoint temperatures, chiller/no chiller, number of fans, weather data, etc.).

Figure 5 shows the inputs chosen for the calculator

	Baseline	New System
Fan Low Temp Setpoint (°F)	**74**	**92**
Fan High Temp Setpoint (°F)	**84**	**92**
Soaker Line Low Temp Setpoint (°F)	**74**	**92**
Soaker Line High Temp Setpoint (°F)	**84**	**92**
Soaker Line GPM Low Temp Setpoint (gal)	**16.7**	**22.5**
Soaker Line GPM High Temp Setpoint (gal)	**22.5**	**22.5**
No. Fans Low Temp	**6**	
No. Fans High Temp	**6**	
kW per Fan	**1**	
Circulation Pump Measure Average kW	**0.70**	
Chiller Measure Average Daily kWh	**126.91**	
Test Period (Days)	**365**	
Well Pump Main kW	**86**	
Well Pump Circulation kW	**17**	

Figure 5. Annual Savings Calculator Inputs

See Appendix A. Annual Savings Calculator for details on the Annual Savings Calculator assumptions and inputs.

Veterinary

While SCE's objective is to monitor energy and water savings potential of the new cooling system, milk production, health and well-being of the cows is essential in determining the true performance, viability, and effectiveness of the cooling system. The following parameters are measured, monitored, or observed during the study to determine cow production and performance:

- Feeding and feed intake;
- Milk production and udder health;

- Reproductive efficiency;
- Cow lameness, body conditions and morbidity/mortality;
- Physiological measures (internal body temperature, respiration rates, etc.);
- Behavioral measures (steps, standing, lying postures);

See Appendix B. Veterinary Study Parameters and Results for details on the veterinary portion of the project.

RESULTS

ENERGY

FIELD TEST ENERGY CONSUMPTION COMPARISON

Table 5 shows the energy savings measured in the field from mid-July 2013 until the beginning of November 2013. As shown, the data results indicate there is negative savings with the configuration tested in the field over the trial period. As expected, fan and well pump energy consumption was greatly reduced, 45% and 73% respectively. However, the addition of the circulation pump and chiller outweighed the energy benefits over the test period resulting in a 34% energy increase overall. Figure 6 graphically displays the energy consumption comparison.

TABLE 5. ENERGY CONSUMPTION COMPARISON OF BASELINE VS. MEASURE SYSTEM OVER TEST PERIOD

	PARAMETER	CONSUMPTION (KWH)	SAVINGS (%)
Baseline	Fan Energy	11,202	-34%
	Well Pump Energy*	5,587	
	TOTAL	**16,789**	
Measure	Fan Energy	6,149	
	Well Pump Energy*	1,508	
	Circulation Pump Energy	1,730	
	Chiller Energy	13,071	
	TOTAL	**22,459**	

*Calculated based on meter billing data.

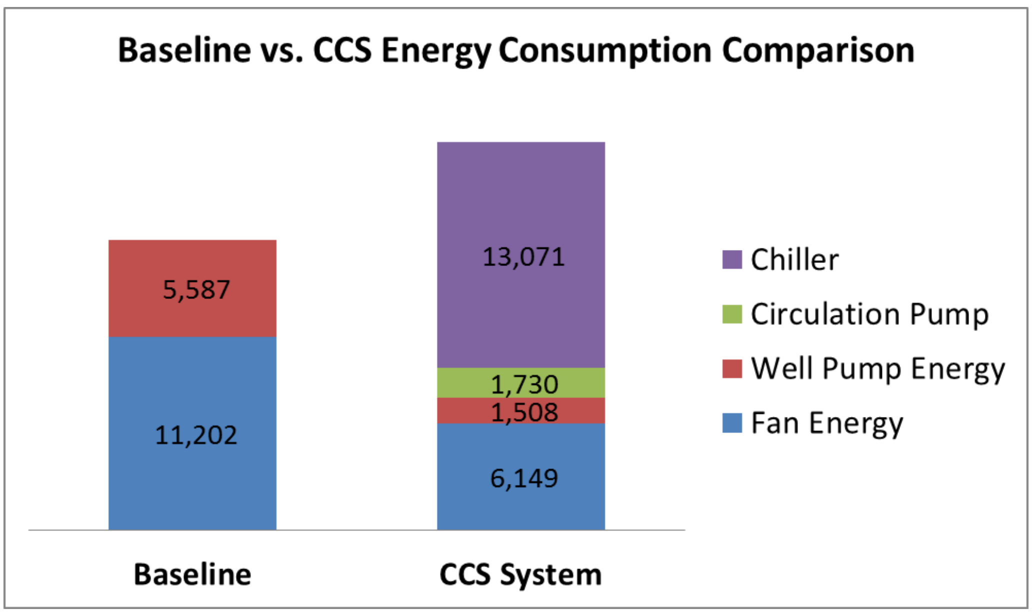

FIGURE 6. BASELINE VS MEASURE ENERGY CONSUMPTION COMPARISON OVER TEST PERIOD

ANNUAL SAVINGS CALCULATOR RESULTS

Table 6 shows the annual energy savings calculated using the Annual Savings Calculator. As shown, the calculator estimates 24% annual energy increase for the configuration tested. Fan energy savings is projected to be 78% annually, and well pump energy savings increased to 81%. Note, fan energy and well pump for the measure actually decreased in comparison to the field test data and annual energy calculation. This may seem counter-intuitive, however, the calculator uses a different weather data set based on a typical meteorological year. Since typical meteorological year temperatures were cooler than temperatures recorded in the test, the calculator assumptions resulted in fewer operating hours overall. Figure 7Figure 6 graphically displays the energy consumption comparison.

TABLE 6. ANNUAL ENERGY CONSUMPTION COMPARISON OF BASELINE VS. MEASURE SYSTEM

	PARAMETER	CONSUMPTION (KWH)	SAVINGS (%)
Baseline	Fan Energy	18,168	-
	Well Pump Energy*	11,550	
	TOTAL	**29,718**	
CCS	Fan Energy	4,044	
	Well Pump Energy*	2,195	-24%
	Circulation Pump Energy	3,577	
	Chiller Energy	27,020	
	TOTAL	**36,836**	
CCS – No Chiller	**TOTAL**	**9,816**	70%

*Calculated based on meter billing data.

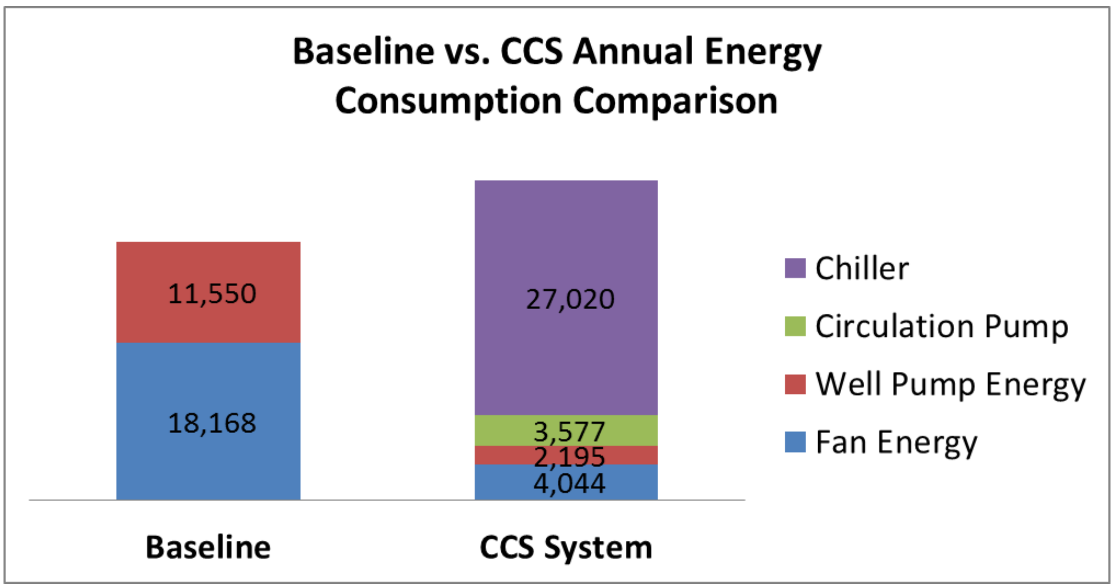

FIGURE 7. ANNUAL ENERGY CALCULATOR RESULTS FOR BASELINE VS. MEASURE ENERGY CONSUMPTION

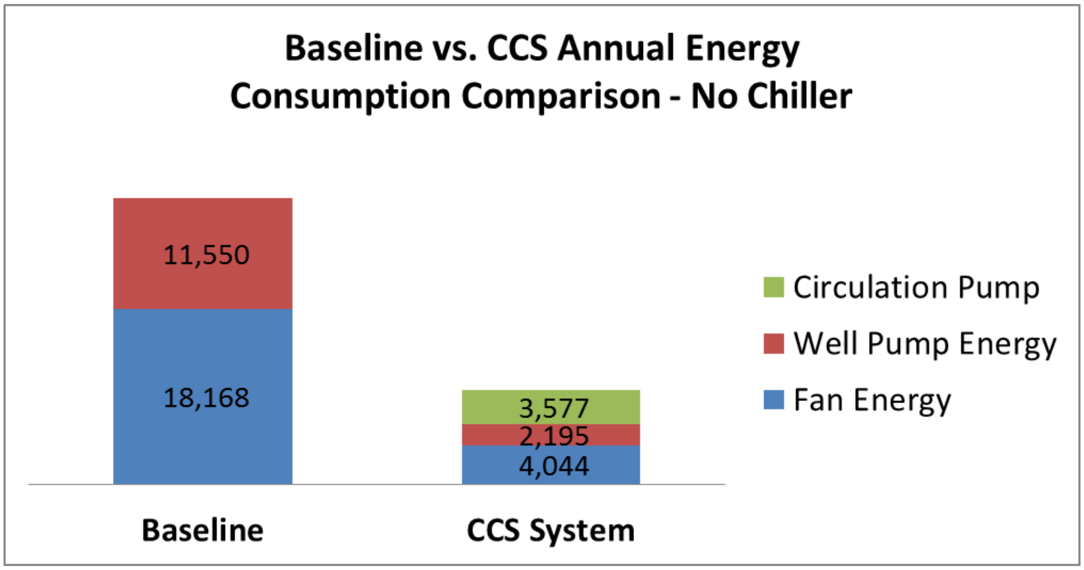

FIGURE 8. ANNUAL ENERGY CALCULATOR RESULTS FOR BASELINE VS. MEASURE ENERGY CONSUMPTION WITHOUT CHILLER

POWER DEMAND COMPARISON

Table 7 shows the peak power demand comparison for the baseline and measure systems. These numbers assume all systems are operating. Note, only a fraction of the well pump serves the soaker lines in pens 9 and 10. On peak, the CCS consumes over 10kW more. This is due to the baseline system operating in addition to the chiller and circulation pump. Taking the chiller out of the equation, the peak load is 0.7 kW more due to the CCS circulation pump.

TABLE 7. POWER DEMAND COMPARISON FOR BASELINE AND CCS SYSTEM

	PARAMETER	POWER DEMAND (KW)	DIFFERENCE (KW)
Baseline	Fan	12	-
	Well Pump*	103	
	TOTAL	**115**	
CCS	Fan	12	
	Well Pump*	103	-10.66
	Circulation Pump	0.7	
	Chiller	9.96	
	TOTAL	**125.66**	
CCS – No Chiller	**TOTAL**	**115.70**	**-0.7**

*Calculated based on meter billing data.

WATER SAVINGS

Table 8 shows the water savings measured in the field from mid-July 2013 until the beginning of November 2013.

TABLE 8. WATER SAVINGS AND WELL PUMP ENERGY SAVINGS DURING TEST PERIOD

PARAMETER	WATER CONSUMPTION DURING TEST PERIOD (GALLONS)	WATER SAVINGS DURING TEST PERIOD (GALLONS)	SAVINGS (%)
Soaker Line Baseline	1,050,204	768,279	73%
Soaker Line Measure	281,925		

Table 9 shows the water savings calculated on an annual basis using the Annual Energy Calculator, field test results and well pump meter billing data.

TABLE 9. CALCULATED ANNUAL WATER SAVINGS

PARAMETER	WATER CONSUMPTION DURING TEST PERIOD (GALLONS)	WATER SAVINGS DURING TEST PERIOD (GALLONS)	SAVINGS (%)
Soaker Line Baseline	2,399,022	1,944,072	81%
Soaker Line Measure	454,950		

VETERINARY RESULTS

SUMMARY OF TESTED COW PARAMETERS

There were a total of 95 days of observation between August 2, 2013 when the conductive cooling system was fully operational in PTX and November 4, 2013 when fall seasonal temperatures became too low for the THI to be greater than 72 and observations where stopped. Based on a THI index of greater than 72, cows experienced heat stress for 71 days in the control pen (PCL) and 77 days in the test pen (PTX) using the maximum THI observed. The range of parameters tested, indicated that PTX experienced a mild heat stress response that was greater for PTX compared to PCL as indicated by the significant differences in parameter estimates for milk production (decreased), respiration rate (increased), core body temperature (increased), feed consumption (decreased dry matter intake (DMI)) and a decrease in lying behavior for PTX during the afternoons as determined by manual observations of the number of cows lying. There was no significant difference in lameness scores, body condition scores and 4 out of the 5 parameters measured with the activity motion sensors.

Three major behaviors that will impact milk production in dairy cows are eating, resting, and rumination. These behaviors must be met for optimal cow performance and milk output. Analysis indicates that the resting time was similar, DMI/eating was 1.0/lb/cow/day less in PTX and was a contributing factor for the difference of 5.97 lbs less milk production in PTX.

One consideration is that PTX had a different solar exposure than PCL although both pens were located under the same barn roof structure. PTX had direct southern sun exposure and PTX shielded PCL from the same solar exposure.

TABLE 10. SUMMARY TABLE OF TESTED COW PARAMETERS ANALYZED BY THE MIXED MODEL PROCEDURE

	MODEL PREDICTIONS FOR THE DIFFERENCE PTX VS. PCL	UNITS	SIGNIFICANCE (P-VALUE) MIXED MODEL
Milk Production	-5.97	lb/cow/day	<0.001
Respiration Rate	5.1	breaths/min	0.038
Lying Rate (manual observation)			
Overall PTX vs. PCL	-2.9	%	0.030
PM vs. AM for both PTX and PCL	- 9.5	% / PM	<0.001
PM - PTX vs. PCL	- 10.1	% / PM	<0.001
Lameness: Lame & Severely Lame	0.6%	Percent	0.238
Body Condition Scoring	-0.15	BCS	0.249
Activity Sensor			
Motion Index	-202.8	index	0.764
Standing Time	0.060	h/cow/day	0.022
Lying Time	0.054	h/cow/day	0.084
Steps	51.9	count/cow/day	0.707
Lying Bouts	1.2	count/cow/day	0.194
Core Body Reticular Temperature	0.62	°F	0.001
Dry Matter Intake	-1.0	lb/cow/day	0.001

See Appendix B. Veterinary Study Parameters and Results for further details.

DISCUSSION

Results from the field trial and data analysis show promise for the CCS in the future, particularly in its water saving potential. However, more work is needed to optimize the system to ensure consistent and sustainable energy savings. Fan and well pump energy are greatly reduced, but adding a chiller eliminates energy savings opportunity and likely increases overall system energy consumption in most applications.

On-peak power demand for the CCS in the tested configuration is a concern. When ambient temperatures reach over 92°F, all systems turn on. This increases peak demand by over 10 kW during peak hours of the day when demand across the grid may already be strained. Alternative approaches to mitigate increased demand for CCS have been considered and continue to be evaluated. These strategies aim at on-site generation, shifting demand, or exploring solutions that can eliminate the use of the baseline system altogether.

Potential solutions include:

- Solar panels to offset chiller demand;
- Thermal energy storage or battery storage to shift demand;
- Evaporative cooling solutions coupled with CCS[2];
- Identify customer sites where no chiller is required.

The water saved during this study is a key component to the environmental, cost, and energy component of this technology. The 73 to 81% water savings that results in nearly 2 million gallons of water saved annually per pen helps contribute both in water conservation efforts and in embedded energy.

From a cow's health perspective, three major behaviors impact milk production in dairy cows: eating, resting, rumination. The results of the study indicate DMI/eating was 1.0/lb/cow/day less in PTX than PCL. This resulted in 5.97 lbs./cow less of milk product in the test pen.

It should be noted that there was significant cow movement in/out of pens and in between pens during the study. While a general mixed effects regression model was used by researchers to account for this, industry experts have questioned the validity of the results. The concerns include:

- Lactation curves were used on single cows when they are only applicable when evaluating a group;
- Cows that moved from one pen to another should all be excluded from the analysis;
- Cows in the study seem to have only moved in one direction from PCL to PTX;
- The study employed two sets of milking equipment for DHIA;
- Data should be included only when heat stress conditions are present.

SCE acknowledges the concerns of the industry experts who peer reviewed the study and suggests more understanding of the impacts on milk production and cow health is needed. The veterinary results at this point are inconclusive.

[2] Proprietary configurations and designs being developed by manufacturer.

CONCLUSIONS

Overall, the CCS is a technology that has the capability to provide energy and water savings to dairy farm owners if applied correctly. The study also shows it is possible CCS increases demand and energy consumption due to the equipment configuration and weather conditions. As the largest field study of the CCS to date, researchers expected to discover areas for improvement and optimization. Energy and water savings can be increased by optimizing setpoint temperatures used to initiate conventional cooling to supplement conductive cooling. This will result in increased economic benefits of the technology. A complete analysis of the economics of the dairy milk receipts, energy savings, and installation costs of the conductive cooling system would be important in assessing when to best use the advantages that this technology may offer.

More research is needed to fully understand the impacts CCS has on energy, water, and cow health and milk production. The technology still needs to address concerns about potential milk production impacts and peak demand constraints. Designs are in development to do just this. As the technology develops and matures, capital cost should fall and system efficiency rise. The timeframe for such to happen is still uncertain.

RECOMMENDATIONS

Given the amount of uncertainty that still remains, SCE's Emerging Technologies Program will not actively promote the CCS technology for program incentives for customized offerings. SCE customers can submit for a customized incentive. If this occurs, care is needed to determine the proper baseline and new system's variables. The configuration and design for CCS systems is likely to vary based on dairy owner's wants and needs. All such factors can be accounted for in a customized solution process.

APPENDIX A. ANNUAL SAVINGS CALCULATOR

The Annual Savings Calculator allows for the extrapolation of energy savings to an annual basis since field monitoring was not performed over a 12-month period. The calculator also enables the user to input various configurations of the conductive cooling system to estimate energy consumption and savings (i.e., setpoint temperatures, chiller/no chiller, number of fans, weather data, etc.).

Figure 5 shows the data input chosen for the calculator for this report.

	Baseline	New System
Fan Low Temp Setpoint (°F)	**74**	**92**
Fan High Temp Setpoint (°F)	**84**	**92**
Soaker Line Low Temp Setpoint (°F)	**74**	**92**
Soaker Line High Temp Setpoint (°F)	**84**	**92**
Soaker Line GPM Low Temp Setpoint (gal)	**16.7**	**22.5**
Soaker Line GPM High Temp Setpoint (gal)	**22.5**	**22.5**
No. Fans Low Temp	**6**	
No. Fans High Temp	**6**	
kW per Fan	**1**	
Circulation Pump Measure Average kW	**0.70**	
Chiller Measure Average Daily kWh	**126.91**	
Test Period (Days)	**365**	
Well Pump Main kW	**86**	
Well Pump Circulation kW	**17**	

FIGURE 9. ANNUAL SAVINGS CALCULATOR INPUTS

The following were sources for the input data:

- Temperature setpoints (fan and soaker line) – test site setpoints
- Soaker Line GPM inputs – test site flow meter data
- No. Fans – test site
- kW per Fan – test site
- Circulation Pump Measure Average kW – test site
- Chiller Measure Average Daily kWh – test site power meter data
- Well Pump Main kW – test site
- Well Pump Circulation kW – test site

APPENDIX B. VETERINARY STUDY PARAMETERS AND RESULTS

ANIMALS, HOUSING, MANAGEMENT, AND TREATMENT

This study and all conditions and procedures conducted during the study were with an approved Animal Use Protocol approved by the Institutional Animal Care and Use Committee from the University of California at Davis. The study was conducted at a dairy in Tulare, CA. The study dairy housed 2,600 milking cows and was the fourth highest producing dairy in Tulare County in 2011. Lactating cows were milked two times daily in two double 36 herring bone parlors (total of 72 milking units). The dairy has a mixture of older dry lots and new freestall pens. The bedding in the freestalls used recycled sand and stalls were rebedded at a minimum of twice per week. High-production lactating dairy cattle in pens 9 and 10 within one of the newer freestall barns were monitored and evaluated for this study. Average daily count in these pens was approximately 210 cows per pen. These pens were freestall pens with 100% shade cover and were flushed four times per day for solids removal. Pen 10 was converted to the conductive cooling, treatment pen (PTX) and continued to be supplemented by the conventional cooling system during severe heat periods when ambient temperatures exceeded (92°F). The control pen, Pen 9 (PCL), retained the dairy industry standard cooling system of soakers and fans. For the dairy's conventional cooling system, in the first stage, 50% of the fans turned on and the soaker times were 1 minute on 8 minutes off when the ambient temperature exceeded 74°F. The second stage occurred at 84°F when all the fans turned on and the soakers were 1 minute on and 6 minutes off. PTX and PCL had 94 nozzles spaced every five feet in each pen with a flow rate of 1.5 gallons per minute (gpm). The soakers were located above the cows at the lockup stanchions along the feed mangers.

Animal husbandry was conducted by dairy personnel per their standard management procedures. All routine animal husbandry practices (including but not limited to: feeding, milking, daily health observations and treatments, feed bunk cleaning, artificial breeding, animal movement between pens for management needs, and water trough cleaning) were conducted by dairy farm personnel as part of their normal daily work routine in caring for the farm animals. Cow breeding and herd health evaluations and treatment by the herdsman occurred daily during feeding stanchion lockup times between 5 AM and 7 AM. Since Pens 9 and 10 were the high-production pens for the dairy, cows that completed a transition period following calving and were increasing in milk production were moved into these pens by dairy personnel according to their normal management procedures. As cows progressed in their lactation with decreasing milk production, they were moved out of the pens by dairy personnel according to normal management procedures to accommodate higher-producing dairy cows that had more recently calved. Cow movement to and from the pens took place on Wednesdays to maintain proper stocking density. Lame cows were also moved on Wednesday afternoons to a holding pen for hoof work on Thursdays at 5 AM and returned to their original pen later that same morning. These lame cows had a total time out of their respective pen that was typically less than 12 hours. Cows diagnosed with mastitis by either a milker or the herdsman were moved to Pen 1, the hospital pen, until their mastitis responded to treatment and then returned to their original pen. The only exception to cow movement for management purposes was a group of 30 cows referred to as "bolus cows". Bolus cows were selected to be less than 110 days in milk so that dry-off before calving did not occur during the study period. Cows in pens 9 and 10 that were > 75lbs of milk per day, Relative Value > 80, with gestation < 3 months were randomly selected and assigned to either pen 9 or 10 for the duration of the study. There were a total of 15 bolus cows per pen.

Cows located in PTX or PCL throughout the study were confirmed using backups from the dairy management software and the dairy's manually maintained "Cow Move List", which was used before entering data into the dairy management software. Cows located within either pen for the entire study (8/2 – 11/4) were there for a total of 94 days. Pen movement, as far as which cows were moved and the pen transfers, varied depending on the week and the normal management needs for the dairy with the exception of the bolus cows. Health events were recorded daily.

Trial Period and Observation Schedule

The temperature sensing switches were set to delay the normal start temperatures to 92°F for the fans and soakers in PTX in mid-July. The conductive cooling system Pen 10 was operational by the end of July 2013 after making some initial adjustments to the soaker controller to operate in sync with the fan controller because it was in a different location. For data analysis, August 2, 2013 was chosen as the start date to assess the effectiveness of the conductive cooling system and dairy cow performance. Ambient October temperatures in the Central Valley of California were above 72°F (some days greater than 80°F), which was the threshold temperature for the onset of heat stress in dairy cows, so the trial was continued until November 4, 2013. Daily observations of respiration rates and cow lying occurred on Mondays, Wednesdays, and Fridays at 7 AM and 3 PM. Pens were observed on all other days but respiration rates were not recorded.

Inclusion Exclusion Criteria

All dairy management practices were allowed to continue as normal for the dairy, including routine decisions regarding cow movement. The exception to this was the 30 bolus cows that never left their assigned pens unless a significant health event required moving for treatment intervention. After treatment, a bolus cow would return to her assigned pen.

A total of 709 cows entered pens 9 and 10 during the study between August 2, 2013 and November 4, 2013. Of these, 77 animals were censored from the data analysis based on rules described below. This reduced the total numbers of animals available for analysis to 632, specifically 298 in Pen 9 (PCL), and 334 in Pen 10 (PTX). For cows to be included in the study analysis in either PTX or PCL, a cow had to have a residence time in a study pen of at least 7 days.

Cows entering into PTX could have come from any other pens on the dairy, including the control pen PCL. Movement from PCL into PTX was considered neutral since all of the dairy's freestalls operated on the same cooling system except for the conductive cooling pen PTX. Upon evaluation of the individual animals and "Cow Move Lists", it was noted that there were "double cows". A double cow was one that was moved between PCL and PTX during the study period. A set of rules was established to exclude and/or determine their suitability to remain in the data set for analysis.

The rules for inclusion or exclusion of "double cows" that moved into PCL and PTX are as follows:

1. If a cow was in PTX first for greater than 7 days, exclude all following data from PCL.
2. If a cow moved from PTX to PCL for less than 2 days, assume this scenario is similar to being moved into the hospital pen and exclude PCL data
3. If a cow was in PTX before PCL for 1 day only, prior to being in PCL for 7 or more days, then include PCL data and exclude PTX data
4. If a cow was initially in PCL for 7 days or greater first, and then was more than 7 days in PTX, include PCL data and exclude PTX data.
5. If a cow was in PCL for 7 days or less and then in PTX for 7 days or more, then include PTX and exclude PCL.

CLIMATIC CONDITIONS DURING THE TRIAL

The weather station and temperature/humidity data loggers (continuous monitoring sensors by Onset HOBO®) in PTX and PCL between the dates of August 2, 2013 and November 4, 2013 were used to calculate the THI. The humidity in the Tulare region is typical for the central valley of California where early morning humidity levels can be high but as the day warms, moisture in the air redistributes. Afternoons in this region have a relatively low humidity level in the range of 15% to 25%. From the initiation of the data analysis period of August 2, 2013 through September 14, 2013, PCL and PTX, experienced daily heat stress based on an observed THI Max > 72. After that date, there were a total of 20 days for PCL and 18 days for PTX where there was no heat stress based on THI Max >72 out of the remaining 51 observation days in the study period. When looking at only the daily average THI for each 24-hour time period, the daily average exceeded 72 THI on 27 days out of the 95 during the study period for both PTX and PCL. No daily average THI was so extreme that it moved into the moderate range of 80 to 89 THI. When looking at the daily maximum THI, there were 35 days that were in the moderate heat stress zone for PCL and 37 days for PTX. The rates for heat stress were based on the average of the 5 sensors in each cow pen.

The rear and south side of PTX (Pen 10) was at the perimeter of the cow housing area, was subject to late afternoon sun, and had no adjoining structure to provide extended shade on the south side to deal with the southward migration of the sun after the June solstice. PTX was in the same barn as PCL, but the roof covering over PTX that was located under the south half of the freestall roof structure provided shade in the late afternoon for PCL, which was located under the north half of the freestall roof structure. During mid to late afternoon sun exposure, the sensor on the south side of PTX recorded temperatures that were no more than 1 to 2 degrees Fahrenheit greater compared to the sensors on more northern portions of the interior of the pen. This is notable in that the cows in PTX did behave differently than cows in PCL. On the sun exposed side of PTX, fewer cows were lying in the area receiving sun on the hottest days, and there were fewer cows at the feed bunk during these days. It is possible that the sensor, which was 10 feet off the ground, was not low enough to detect the thermal warming on the southern exposure that the cows were experiencing. The reason for the 10-foot high placement of the sensors was to keep it out of reach of the cows. The natural behavior of cows is to be curious, and they will lick and rub anything within reach that is located in their environment. To prevent sensor damage, the sensor was placed out of the reach, which included enough distance to clear the stretching of their neck with a full extension of the tongue. Table 11 displays the number of heat stress events that occurred during the trial period.

TABLE 11. FREQUENCY IN DAYS FOR TEMPERATURE HUMIDITY INDEX - HEAT STRESS EVENTS

	THI RANGE[1]	HEAT STRESS	BASED ON DAILY AVERAGE		BASED ON DAILY MAXIMUM	
			FREQUENCY[2]	DAY LAST OBSERVED	FREQUENCY	DAY LAST OBSERVED
Pen 9 PCL	72-79	Mild	27 (28%)	Sept 14	36 (38%)	Oct 27
	80-89	Moderate[3]	0	N/A	35 (37%)	Sept 14
	90-98	Severe[3]	0	N/A	0	N/A
Pen 10 PTX	72-79	Mild	27 (28%)	Sept 15	40 (42%)	Nov 3
	80-89	Moderate	0	N/A	37 (39%)	Sept 16
	90-98	Severe	0	N/A	0	N/A

[1] 72-79 THI – mild heat stress, 80-89 THI – moderate heat stress, 90-98 – severe heat stress

[2] Difference of 0.5 THI or less were not considered significant between pens.

[3] References:

a. Armstrong D.V. 1993. Environmental modifications to reduced heat stress. In: Western Large Herd Dairy Management Conference Proceedings, Las Vegas NV 1993
b. Beede, D. K. and Shearer, J.K. 1991. Heat Stress, Part 4. Nutritional Management of Dairy Cattle During hot Weather. Agri-Practice, Vol 12, No.5 Sep/Oct 1991.
c. Bray, D.R. and Bucklin R. 1996. Recommendations for Cooling Systems for Dairy Cattle. University of Florida, Cooperative Extension Service. Fact Sheet DS-29.
d. Patton, RA 1994. The Dairy Cow in Hot Environment: Production and Physiological changes and their effect on Management. Proceedings of the Stress in Domestic Animals Conference. UNAM, Mexico.

MILK PRODUCTION

Milk production data was derived from meters placed on individual milking units in the milking parlor. The milk meters were managed by DHIA, which calibrates and ensures the accuracy of their equipment in their Quality Certification Program. DHIA testing of dairies for individual cow performance is a nationally recognized program and is the basis for multiple certifications including all breed associations whose genetics rely on DHIA test results for cow performance related to milk production. The Council on Dairy Cattle Breeding works closely with DHIA associations to ensure the accuracy and reliability of these results. The entire scientific literature database for over 30 years in dairy research and clinical trials with dairy cows is based on DHIA milk production data. The only exception would be those who have used a far more expensive option and installed permanent milk meters to obtain daily milk weights.

CRUDE COMPARISON

For the current trial, a total of 5,156 individual milk DHIA records for PCL and PTX from 13 test dates between August and November were used. The average 3.5% FCM milk produced per cow for PCL in the months of Aug, Sept, Oct, and Nov was 98.0, 101.6, 102.7, and 106.5 lbs, respectively, and for PTX was 92.4, 92.7, 98.9, and 102.3 lbs, respectively. This represents a difference in PTX production of -5.6, -

8.9, -3.8 and -4.3 lbs of 3.5% FCM per cow compared to cows in PCL for each of these months.

MILK PRODUCTION MODELING

The data set used in all models censored cows (removed from the data set used for analysis) that resided in both PCL and PTX as a common consequence of normal pen movement of cows in commercial dairy herds. Animals that resided in a pen for less than 7 days were also censored as being deemed not having enough exposure for comparison. The detailed rules that were established for creating the final data set for analysis are fully described in the Materials and Methods section. It is important to note that these exclusion/inclusion rules to manage cow movement were identified a priority – prior to running models thus removing the potential for bias during rule development. The model was also offered a variable for length of stay outside the pen and number of entries into the pen (in case of being moved from the study pen to the hospital pen).

A linear mixed effect regression model with a two-piece spline was used to model the shape of the lactation curve for each cow in the data set. Model results showed a significant decrease in daily milk of - 5.97 lb of 3.5% FCM in PTX compared to PCL after adjusting for parity and stage of lactation ($P < 0.001$) with a 95% confidence interval that ranged between -8.38 to -3.56 lb. For cows in lactation 1 vs. lactation 2 there was no significant difference in milk production. However, there was a significant difference over both pens between lactations 2 and 3 or greater of 4.97 lb ($P = 0.041$) with lactation 3 cows producing more milk.

The above mixed model analysis adjusted for growth hormone use, parity of the cows and days in milk production or days since the cow calved. Adjusting for time spent outside the study pen and number of entries into the pen showed that these two variables were not significant predictors of milk production and hence were dropped from the final model.

Although variable coding for movement of cows during the study period into and out of the study pens were shown to have no significant effect on milk production, we further analyzed the dataset generated for:

1. Cows enrolled on 8/2/2014 and exited the trial on 11/4/14 AND with 0 days spent outside the pen between enrollment and exit (fixed study time for each cow). A total of 78 cows in each group with a total of 2,012 test day records met this alternate set of criteria. The final model that fit this dataset adjusted for growth hormone use, parity and days in milk estimated that cows in PTX produced 19.4 lb less than the control group ($P <0.001$).
2. Cows enrolled on or after 8/2/2014 and exited the trial on or before 11/4/14 AND with 0 days spent outside the pen between enrollment and exit (variable lengths of study time). This dataset yielded 244 cows in PCL and 263 in PTX with a total of 4,426 test day records. The final model adjusted for growth hormone use, parity and days in milk and estimated that cows in PTX produced 15.0 lb less than the control group ($P<0.001$)

The above milk models document a linear trend of reduced milk production in cows in PTX compared to PCL. Furthermore, the 3 models used 3 subsets of the entire dataset that only varied by restricting cow movement and can be interpreted that the difference between treatment and control pen cows' production increased in magnitude as cows stayed longer in the study.

RESPIRATION RATE

Respiration is a protective mechanism used by cows during periods of heat stress to help maintain body temperature. As heat stress increases, respiration rate will increase. Respiration is measured in breaths per minute (BPM). Using the THI index for dairy cows during mild heat stress (72-79 THI) events, respiration can be from 60 to 75 BPM and during moderate heat stress (80-89 THI) respiration can range from 75 to 85 BPM. Respiration of 85 to 120 BPM can be an indication that a cow is experiencing severe heat stress. During the trial, respiration rates in PCL and PTX were lower in the morning when THI levels were under 72 and increased in the afternoons when THI levels ventured into the mild and moderate heat stress zones. For early morning respiration rates around 7 AM, the average BPM for PCL was 52 and PTX was 54. In the mid-afternoon from 3 to 4 PM over the 95 day trial period, the average respiration rate in PCL was 58 BPM (range 24 to 106) and PTX was 64 BPM (range 28 to 116). Analysis using a mixed model procedure showed a significant difference ($P = 0.038$) with the model predicting that PTX had 5.1 more BPM overall.

LYING BEHAVIOR FROM MANUAL OBSERVATIONS

Lying behavior was analyzed on the percent of animals in each pen that were observed on the daily observations by trial personnel. Observations were conducted on 41 separate days in the morning and evening on the same dates and times that respiration rates were observed. All cows in PCL and PTX that were lying in the individual stalls of the study pens were counted. Percent lying was based on the total pen count for the day the observation was made. The average morning percent for PCL and PTX was 62.2% and 64.4% respectively. The average mid-afternoon percentages were 52.6% and 44.7% for PCL and PTX, respectively. Analysis with the mixed model procedure was significant when looking at overall lying rates for PTX and PCL in the afternoon with the model predicting 9.5% fewer animals lying ($p=<0.001$) compared to the morning for both pens. When comparing PTX vs. PCL, the mixed model predicted an additional 10.1% fewer animals lying in PTX ($P=<0.001$) in the afternoon in addition to the combined difference. These analytical results were very consistent with the descriptive statistics for this parameter.

LAMENESS / LOCOMOTION SCORING

For locomotion, the scoring system used a scale of 1 to 5 with 1=normal, 2=mildly lame, 3=moderately lame, 4=lame, and 5=severely lame. Conditions causing lameness range from metabolic disorders, infections, and physical trauma associated with rocks and extended time periods of standing on concrete. Once cows become lame to severely lame, the pain that a cow experiences in standing and walking will force it to lie down and avoid standing. This will cause a drop in dry matter intake and an associated drop in milk production. Conductive cooling was conjectured to possibly improve lameness scores because it was thought that these cows might possibly spend more time lying in the freestall beds compared to standing on concrete. During the 95-day trial period, PCL and PTX were scored weekly using the locomotion scoring system. On a weekly basis an average of 89% of PCL was scored as a normal or mildly lame and 88% for PTX. For the higher locomotion scores indicating moderately to severely lame cows: counts of cows with a locomotion score of 4 or 5 ranged from 14 to 30 cows per week in PCL and 7 to 40 cows per week in PTX.

Statistical analysis using a mixed model indicated that there was not a significant difference between PCL and PTX for lameness based on locomotion scoring (P = 0.238).

Body Condition Scoring

Body condition scoring (BCS), which relates to the amount of subcutaneous fat on a bovine animal, is used as an indicator of overall health and an important assessment tool for helping to maximize milk production and reproduction. This scoring system was based on values of 1 to 5 with 1 representing extremely thin cows and 5 representing extremely over-conditioned cows. Over-conditioned animals at the time of calving (BCS > 4.0) can be associated with reduced feed intake and increased post-parturition problems. Under-conditioning at calving (BCS < 3.0) is related to lower peak milk production and decreased total lactation period yields. Herd management aims to have most cows in the range of 2.75 to 3.25. Quarter-point differences are not considered to be significant.

Bolus cows in PCL and PTX were scored every two weeks. The average BCS during the trial for the bolus PCL cows was 2.89 and PTX was 2.75. Mixed model analysis of BCS indicated that there was no significant difference between PCL and PTX (P = 0.249)

Motion and Position Sensor

Sufficient daily lying time is important in the overall welfare of dairy cattle and impacts lameness and milk production. Before the introduction of automated sensing equipment, assessment of lying was achieved by manual observation or review of video recording. Both approaches have limits on sampling time since researchers cannot spend unlimited time to observe, and bias can be introduced due to the objectivity of the observer. Additionally, when manually observing cows, there is the risk of changing the behavior of the cows through the presence of the observer. Automated technology can increase the observation time, is objective, and has been validated with manual observations[17,18,19]. Several companies now provide products to use in monitoring this aspect of dairy cow behavior: Ice Robotics, Gemini Data Loggers, Afikim, and Onset Computers. Dr. Cassandra Tucker, a project collaborator has also validated automated position/motion recording sensors in dairy cattle as an effective method to assess dairy cattle behavior[20,21]. In this trial we used the product from Ice Robotics, IceQubes.

The IceQube sensor is attached to the cow’s leg and is a continuously recording electronic device that translates 3-axis accelerometer data into steps, standing time, lying time, and lying bouts. There is a linear correlation of 100% for lying time and standing time, and 98% for Motion Index. The IceQube motion detector uses a 4 Hz sample rate. The data is summarized into 15 minute blocks.

In our study, the IceQube sensors were placed on the 30 bolus cows, 15 in PCL and 15 in PTX. Analysis of the activity monitor was based on summation of total activity measurements in 24-hour time blocks for each day. Mixed model analysis of the individual bolus cow’s data showed that there was only a significant difference in one activity parameter, standing time (P = 0.022), out of the five parameters the IceQube sensor measured for steps, standing time, lying time, motion index, and lying bouts. The difference in standing time predicted by the model was only 0.06 hours per day more for PTX compared to PCL. Lying time was the smallest difference between PCL and PTX and was not significantly different. Table 12 summarizes and describes the statistics captured by the Ice Robotics motion sensor device.

TABLE 12. SUMMARY AND DESCRIPTIVE STATISTICS OF ICE ROBOTICS MOTION ACTIVITY SENSOR DATA

		Motion Index[1] (per day)	Standing[a] Time[2] (hours / day)	Lying Time[2] (hours / day)	Steps[3] (per day)	Lying Bouts[4] (per day)
PCL	Mean	10,101	11:29	11:43	2,371	11.7
	Median	10,126	11:54	11:54	2,369	12.0
	Standard Dev.	2,682	2:51	2:53	608	3.6
PTX	Mean	10,300	12:05	11:47	2,524	13.9
	Median	10,187	12:01	11:54	2,507	14.0
	Standard Dev.	2,717	2:20	2:20	558	3.9

a. Duration of lying and standing do not add to 24 hours since they are based on averages and not individual animal values.

1. Motion Index indicates the overall activity of the cow calculated using the acceleration on each of the 3 axes. This is a proprietary measure of the Ice Robotics system and the manufacturer recommends this over the Step Count as a measure of activity.
2. Standing/Lying is determined by the sensor passing a specific threshold between horizontal/vertical.
3. Step Count is the number of times the cow lifts her tagged leg, based on the amount of force the animal uses.
4. Lying Bouts is based on the exact start and end time of each lying bout.

CORE BODY TEMPERATURE

The impacts of environmental conditions are manifested in the body temperature of a cow. Normal cow core body temperatures range from 101.5°F to 102.5°F. The lowest core temperatures are found in the early morning hours when the ambient temperatures are lowest, and the core temperatures are highest in the afternoon or early evening. Core body temperatures are affected by internal and external factors such as an animal's physiological status, feed intake, feed composition, water intake, parity, season, and overall health[22,23].

Monitoring a cow's core body temperature can be done with temperature-sensing reticular boluses (TSRB). Another measure of body temperature would be sensors placed in the vagina of a cow, but this requires weekly removal since the placement of the temperature sensing device in this body cavity acts as an irritant and can induce infections. Temperatures of the three collection methods (rectal, reticular, and vaginal) differ and should not be compared directly to one another though each is used to assess an animal's temperature status. Bewley, Einstein *et al*. demonstrated that in 2,042 paired readings, rectal temperature, 101.9°F ± 0.64, were significantly correlated with reticular temperatures, 102.7°F ± 0.72, r=0.645, $p<0.0001$[24].

Use of TSRB have been investigated in a study of important dairy cow diseases and a significant association was found for mastitis and pneumonia with a 1.1°F to 1.8°F change[25]. TSRB were used in a study by Timsit, Assie *et al.* for Bovine Respiratory Disease (BRD) in young bulls going into a feedlot[26]. In the study, water episodes were removed before analyzing the data and 52 hyperthermic events were detected in 22 animals where BRD was diagnosed by physical examinations in 21 of these animals. This study had a reticular/ rectal temperature correlation of r=0.91, R2=0.82 where reticular temperatures were 1.03°F ± 0.49 higher than rectal temperatures. Reticular temperatures are impacted by water drinking events that temporarily lower the observed temperature and do not reflect the core temperature of the animal. Reticular temperatures will decrease after ingestion of water but will return to their baseline temperature in 0.5 to 3.5 hours[27,28].

Table 13 displays the descriptive statistics for reticular temperature sensing boluses from the test site.

TABLE 13. DESCRIPTIVE STATISTICS FOR RETICULAR TEMPERATURE SENSING BOLUSES

	PCL (°F)	PTX (°F)
Mean	103.53	103.75
Median	103.70	103.70
Standard Dev.	1.09	1.34
Maximum	108.20	108.20
Minimum	90.20	89.30

A TSRB is administered to cows orally with a bolus gun. The TSRB resides in the cow's reticulum and provides continuous temperature monitoring. In this study, the TSRB used for reticular temperature monitoring was from DVM Systems. The TSRB can store up to 12 readings and will log 24 readings in a one day period. Each TSRB has a unique identifier, and the stored TSRB temperature readings are transmitted to a receiver. The data collected from the TSRB is then transmitted to a base station. At the base station, each unique TSRB is associated with the animal's ID and maintained on a computer. Water drinking events were monitored and flagged by the software previously described in the methods section. For analysis of the reticular temperature data, all water drinking events were removed. This left greater than 30,000 recorded temperature readings for analysis for each group of 15 bolus cows in PCL and PTX. The average reticular temperature for PCL was 103.5 and 103.7 for PCL. Using the mixed model procedure, there was a significant difference between groups (P=0.001) and the modeling predicted a 0.62°F higher temperature for PTX as compared to PCL.

DRY MATTER INTAKE

DMI used the dairy's FeedWatch program, which receives weight data from the feed wagon that has load cells and continuously tracks the truck's load weight. As the feed wagon distributes feed, the driver designates pen changes. The start and end weights are sent directly to a receiver that downloads data into the dairy's FeedWatch program. Dry matter is calculated by the program from the distributed feed in each pen less the refusals that are picked up and weighed before new feed is added every day. Dry matter intake is reported out in pounds per cow per day. Dry matter intake has a direct impact on milk production and could help in understanding any differences observed in milk production. Reduced dry matter intake is also a sign that the cows might be experiencing heat stress when the THI goes above 72.

When looking at dry matter intake, one can assess the impact on milk production by looking at dairy efficiency/feed efficiency, defined as the pounds of milk produced per pound of dry matter intake. A feed efficiency value of approximately 1.4 to 1.8 is considered to be optimal[29]. In this study, feed efficiency was 1.54 for PTX and 1.61 for PCL. Though PTX was lower than PCL in DMI, the differences were small and other factors than just DMI must be taken into consideration to assess what is impacting the differences in milk production between PTX and PCL.

Mixed model analysis of dry matter intake indicated that there was a significant difference (P=0.001) between groups and the model prediction of PTX having 1.0 lbs/cow/day less intake than PCL was in close agreement with the average difference in descriptive statistics. Table 14 describes the statistics for daily DMI in pounds/day/cow.

TABLE 14. DESCRIPTIVE STATISTICS FOR DAILY DRY MATTER INTAKE IN POUNDS PER DAY PER COW

	PCL (LB/DAY/COW)	PTX (LB/DAY/COW)
Mean	63.28	62.26
Median	63.48	62.17
Standard Dev.	2.23	2.24
Maximum	67.42	71.18
Minimum	57.97	56.69
Feed Efficiency[1]	1.61	1.54

1. Feed Efficiency is defined as the pound of milk produced per pound of dry matter intake per cow per day.

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