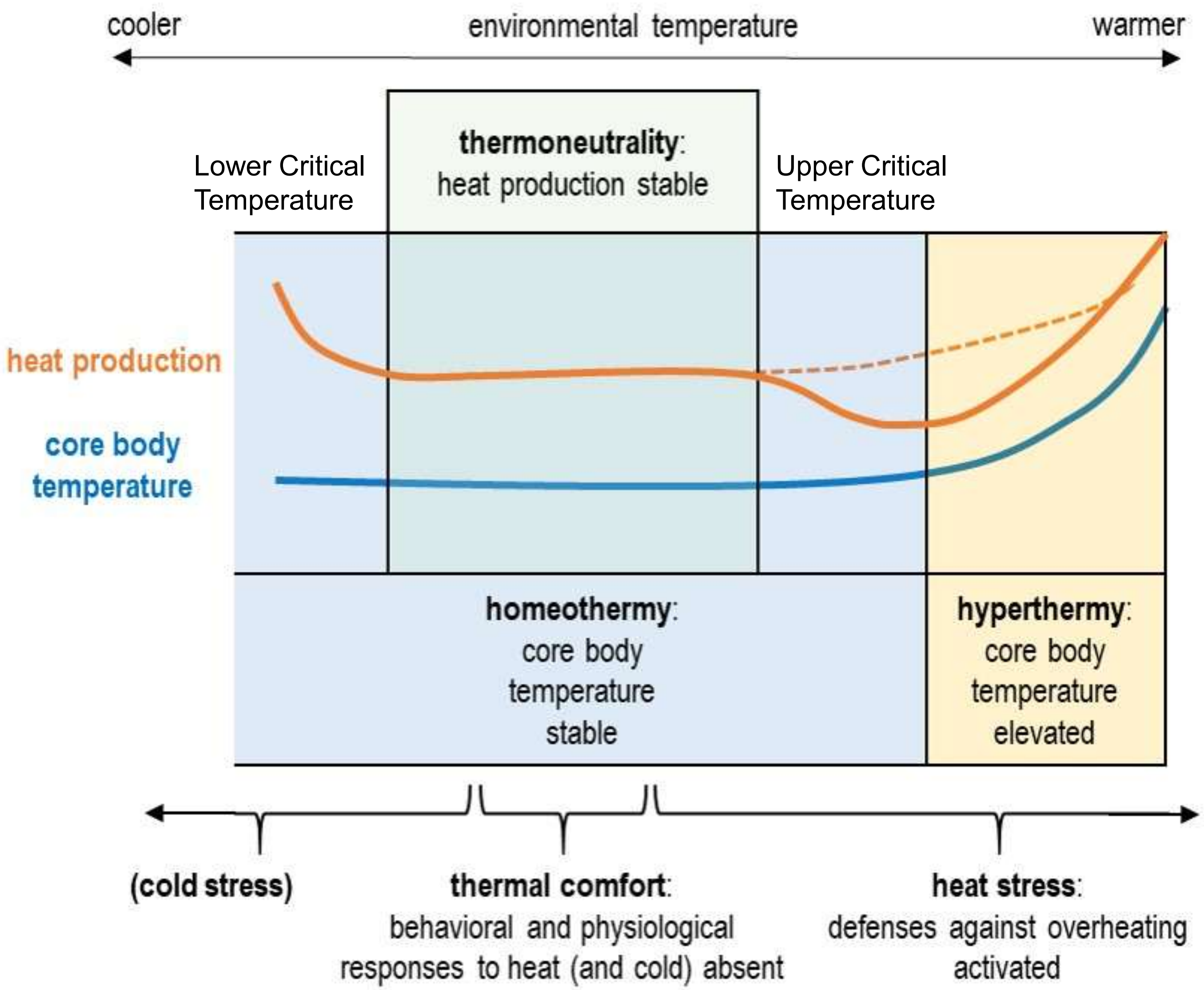
So, you think you have heat stress? How do you know?

Dairyland Initiative
UNIVERSITY OF WISCONSIN–MADISON

When does heat stress begin?



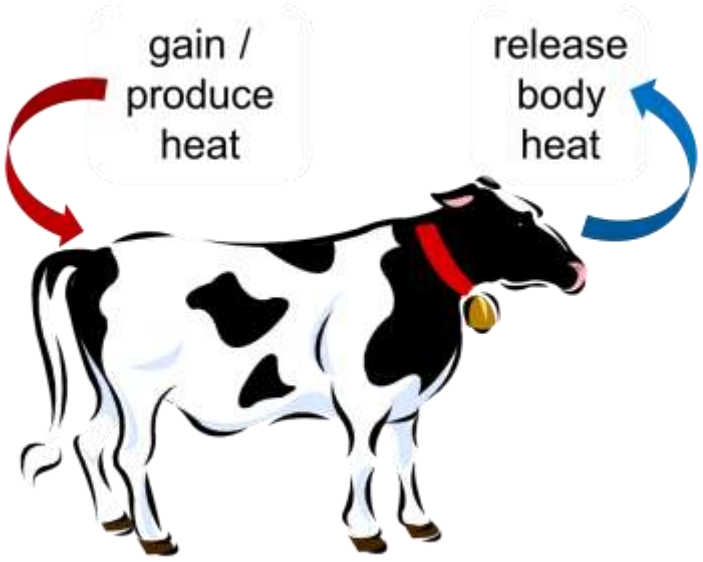
Van Os (2019); Bianca (1968)

Thermal discomfort begins before the Upper Critical Temperature (UCT)

Thermal comfort: physiological & behavioral defense mechanisms <u>not yet</u> activated

Natural early defense mechanisms:

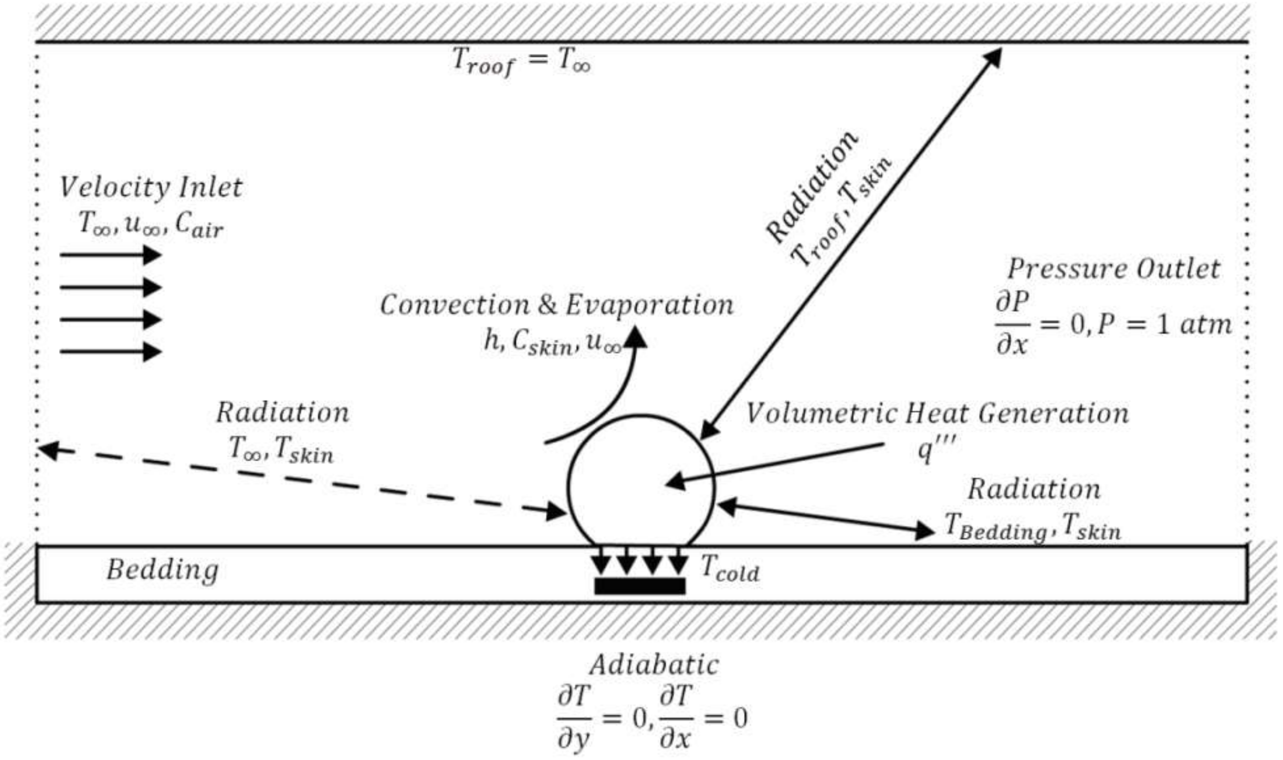
- Vasodilation
- Sweating
- Respiratory rate ⇧, panting
- Behaviors to:
  ⇩ heat production
  ⇩ heat gain from environment
  ⇧ heat dissipation to environment



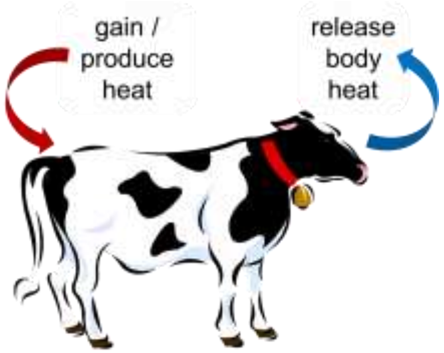
Van Os (2019); Bianca (1968)

Crash course on heat transfer!

- Conduction
- Convection
  - $q'' = hA(T_{air} - T_{cow})$
- Evaporation
- Radiation



Heat dissipation

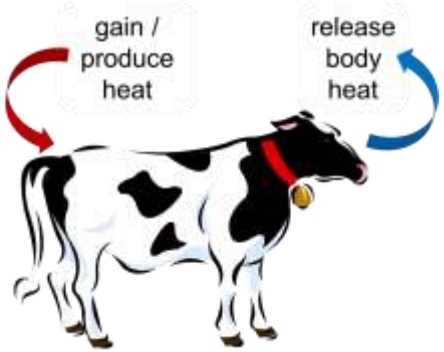


Sensible (non-evaporative)

- Conduct heat from body core to surface through tissues
- Convection through blood movement and vasodilation
- Lose heat to environment through convection (air movement) or conduction to cooler surface
- In proportion to temperature gradient
  → rate of heat loss ⇩ in hot conditions

Bianca, 1968

Heat dissipation



Latent (evaporative)

- Water converted from liquid to vapor using energy (from animal & surroundings)
- Does not depend on a temperature gradient
- High skin temperature
  → stimulates peripheral thermal receptors
  → triggers natural evaporative cooling responses
  (**elevated respiration rates, panting, sweating**)

Bianca, 1968

Impact of Heat Stress at ~ THI 68

THI = (dry bulb) Outdoor Temp ^{o}F - (0.55- (0.55 x (Relative Humidity %/100)) x (Outdoor Temp ^{o}F – 58)

THI takes into account the impact of relative humidity (RH)

THI 68:

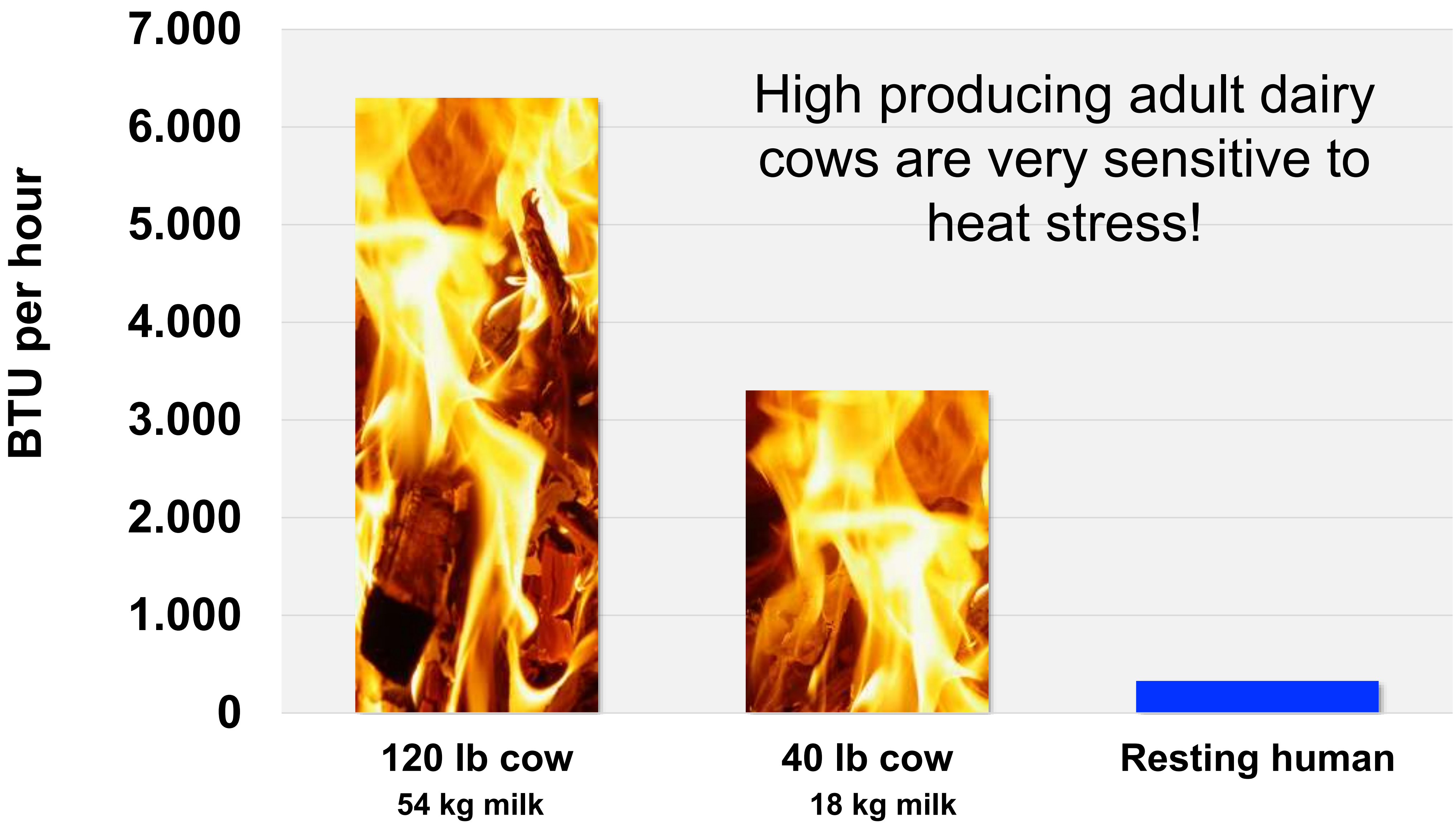
At 20% RH, temperature would be 75^{o}F (24^{o}C),

At 90% RH, temperature would be 69^{o}F (21^{o}C).

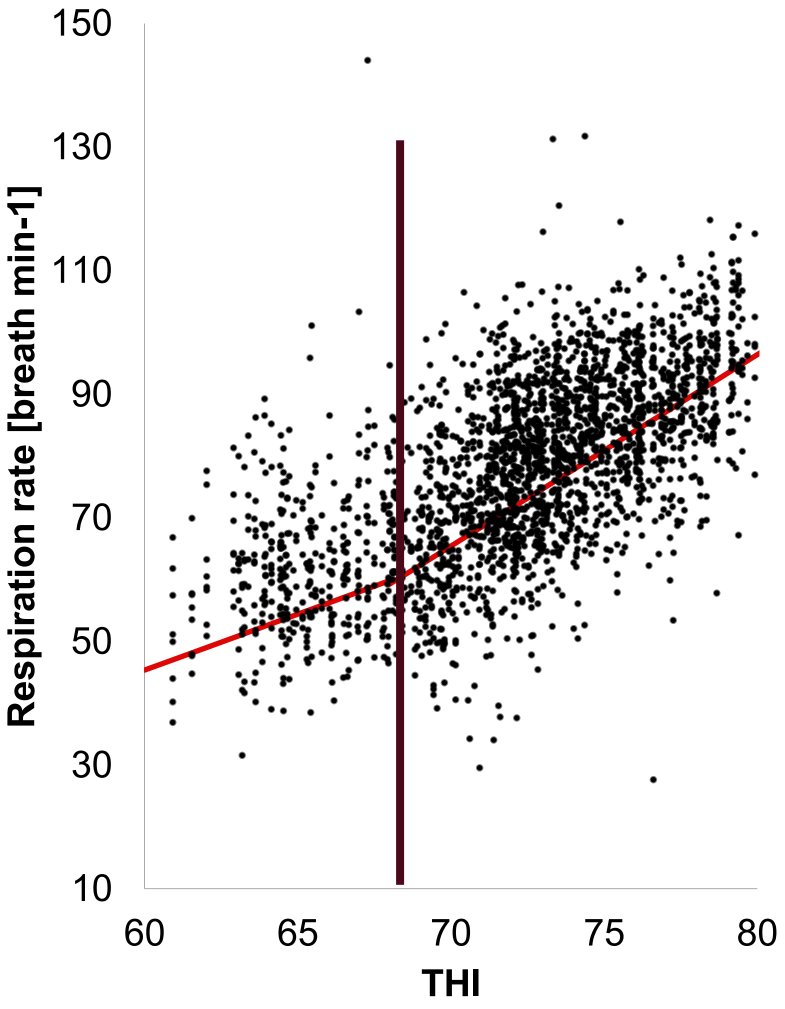
Air Temperature	Relative Humidity (%)																				
(°F)	0	5	10	15	20	25	30	35	40	45	50	55	60	65	70	75	80	85	90	95	100
65	61	61	62	62	62	62	62	62	63	63	63	63	63	64	64	64	64	64	65	65	65
70	63	64	64	64	65	65	65	66	66	66	67	67	67	68	68	68	69	69	69	70	70
75	66	66	67	67	68	68	68	69	69	70	70	71	71	72	72	73	73	74	74	75	75
80	68	69	69	70	70	71	72	72	73	73	74	74	75	76	76	77	78	78	79	79	80
85	70	71	72	72	73	74	75	75	76	77	78	78	79	80	81	81	82	83	84	84	85
90	72	73	74	75	76	77	78	79	79	80	81	82	83	84	85	86	86	87	88	89	90
95	75	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90	91	92	93	94	95
100	77	78	79	80	82	83	84	85	86	87	88	90	91	92	93	94	95	97	98	99	100
105	79	80	82	83	84	86	87	88	89	91	92	93	95	96	97	99	100	101	102	104	105
110	81	83	84	86	87	89	90	91	93	94	96	97	99	100	101	103	104	106	107	109	110

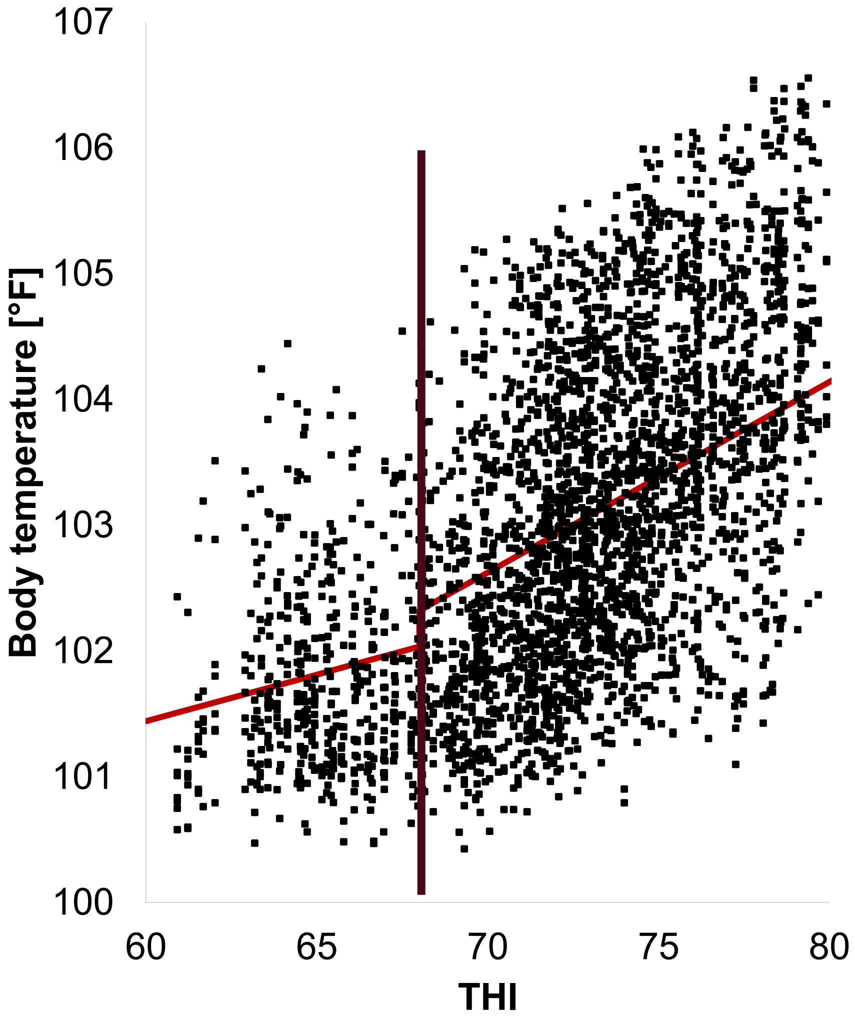
https://dairy.extension.wisc.edu/articles/animal-handling-during-heat-stress/

Adult cows generate a lot of heat!



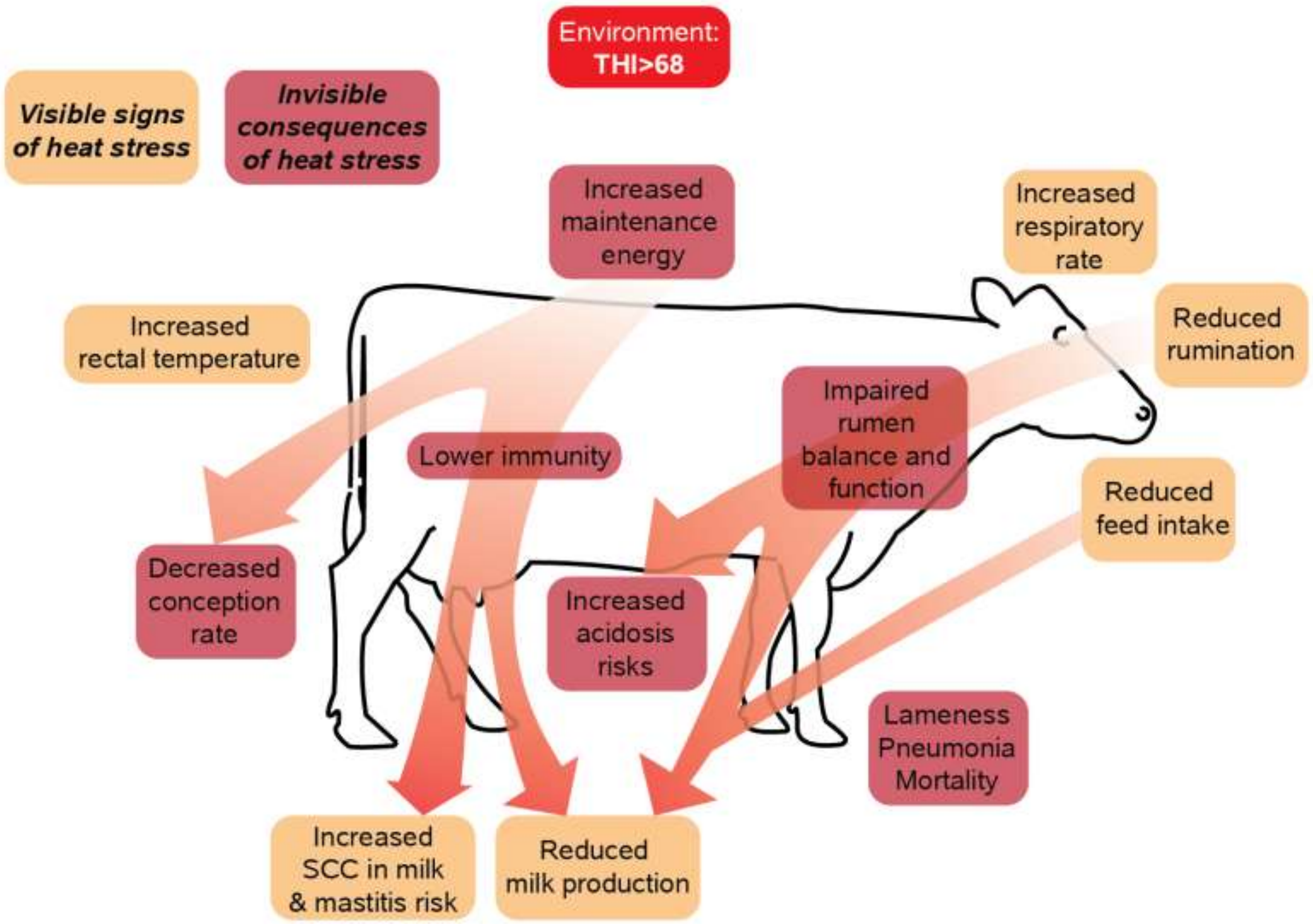
Relationship Between THI and Respiration Rate and Body Temperature



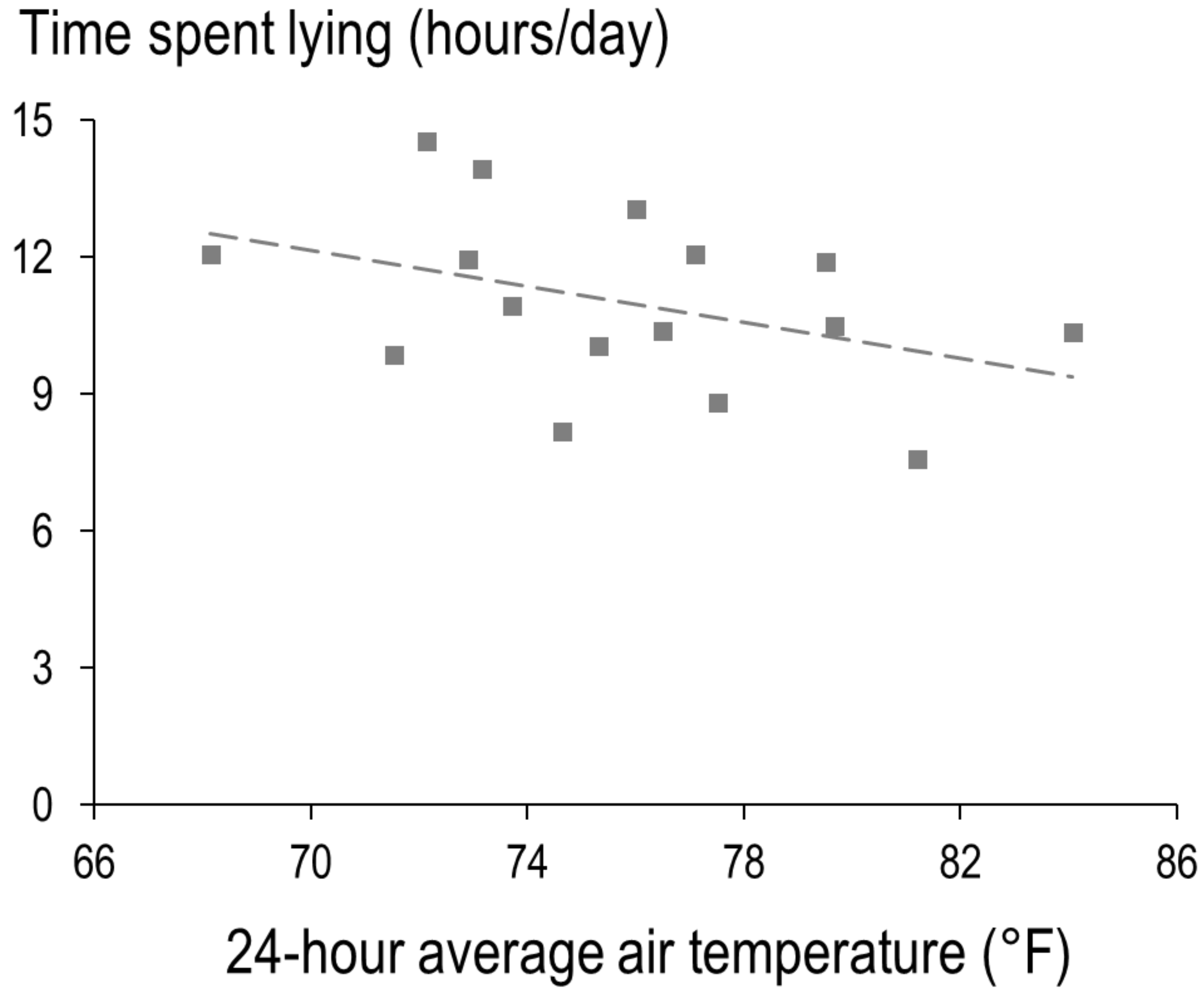


Atkins et al. (2018). Transactions of the American Society of Agricultural and Biological Engineers (ASABE).61(5):1475-1485, 2018.

Heat Stress Consequences: Physiological



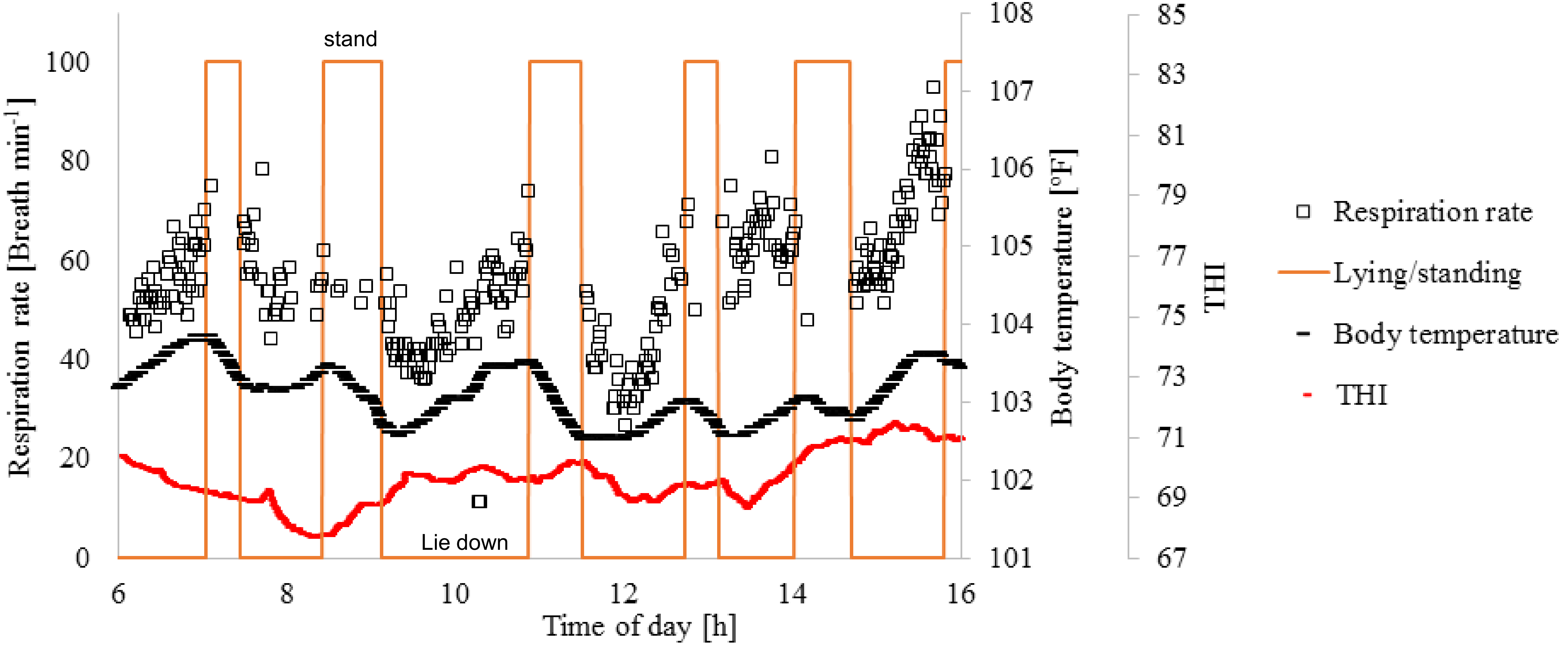
Heat Stress Consequences: Behavioral



Lying time impact:
~3 h/d loss due to heat stress

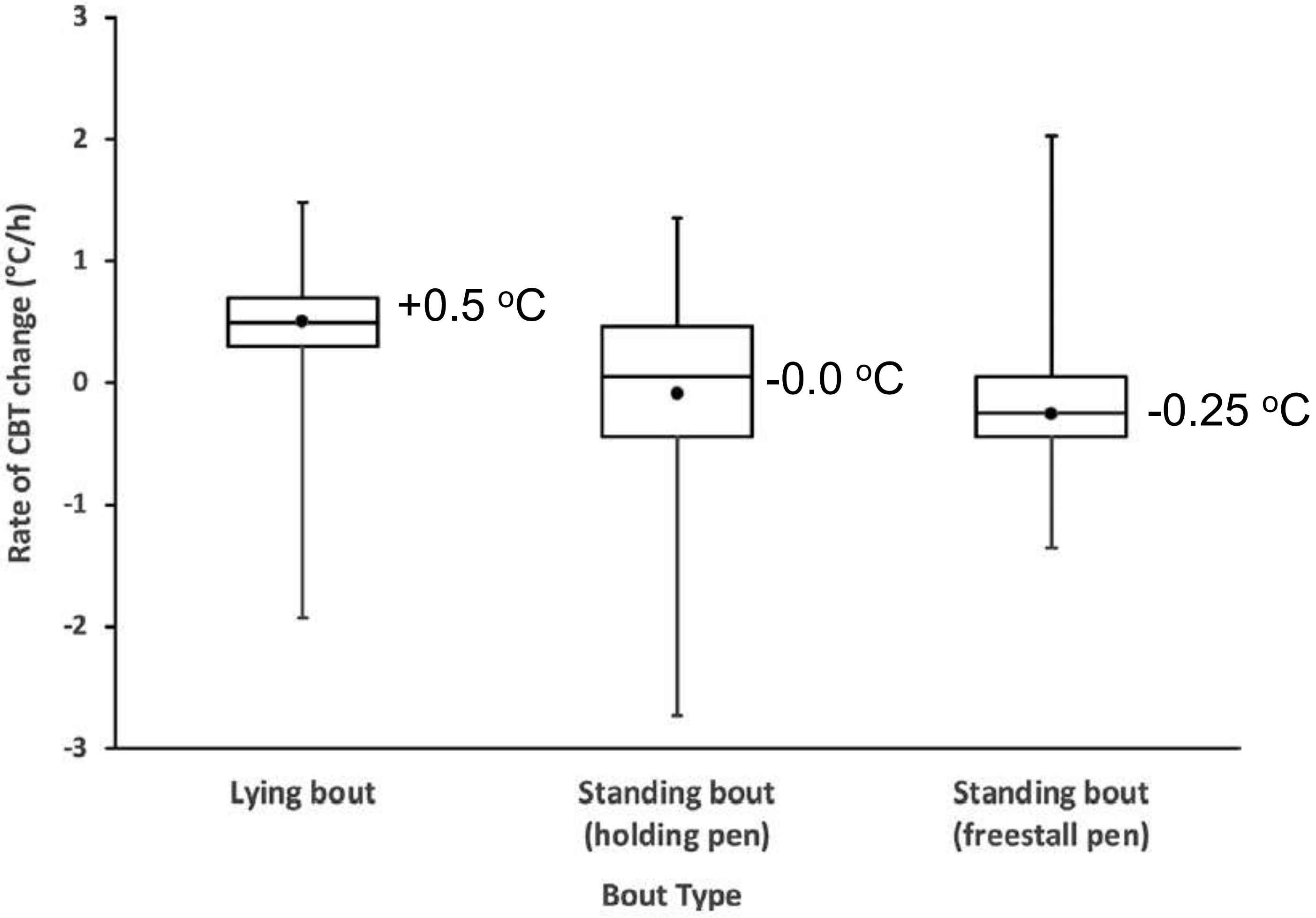
Chen (Van Os) et al., 2013, 2016, Cook et al, 2007; Tucker et al, 2008; Jensen et al, 2005; Hillman et al, 2005; Ansell, 1981; Legrand et al, 2011; Overton et al. 2002

Cows accumulate heat when they lie down and cool when they stand



Atkins et al. (2018). Transactions of the American Society of Agricultural and Biological Engineers (ASABE).61(5):1475-1485, 2018.

Rate of Temperature Change by Position



2 farms
20 cows for 6 days
6 lying bouts per day
3 standing bouts per day (stall)
3 standing bouts per day (parlor)

Cows cool while standing in the pen at half the rate that they accumulate heat while lying down

Nordlund et al. J. Dairy Sci. 102:6495, 2019

Effect of THI on Lying Bout Thermodynamics

Lying Bouts

THI (±2.5) categories at start of lying bout	N	Observed start CBT (°C)	Observed end CBT (°C)	Model-predicted end CBT (°C)	Observed lying-bout duration (min)	Observed bout rate of CBT change (°C/h)	Observed net change of lying-bout CBT (°C)
60	91	38.6 (0.04)	39.0 (0.04)	39.0	70.5 (4.1)	0.28 (0.04)	0.40
65	123	38.6 (0.03)	39.1 (0.03)	39.1	56.3 (2.6)	0.43 (0.03)	0.44
70	160	38.7 (0.03)	39.1 (0.03)	39.1	53.1 (2.1)	0.46 (0.03)	0.45
75	146	38.8 (0.04)	39.3 (0.04)	39.3	44.2 (2.0)	0.58 (0.04)	0.48
80	124	39.2 (0.05)	39.6 (0.04)	39.6	35.2 (1.8)	0.63 (0.03)	0.40
85	26	39.2 (0.10)	39.6 (0.09)	39.7	28.7 (3.3)	0.76 (0.09)	0.40

Cows appear to end their lying bouts after a net CBT change of ~0.4-0.5 ^{o}C

Nordlund et al. J. Dairy Sci. 102:6495, 2019

Bunching Behavior

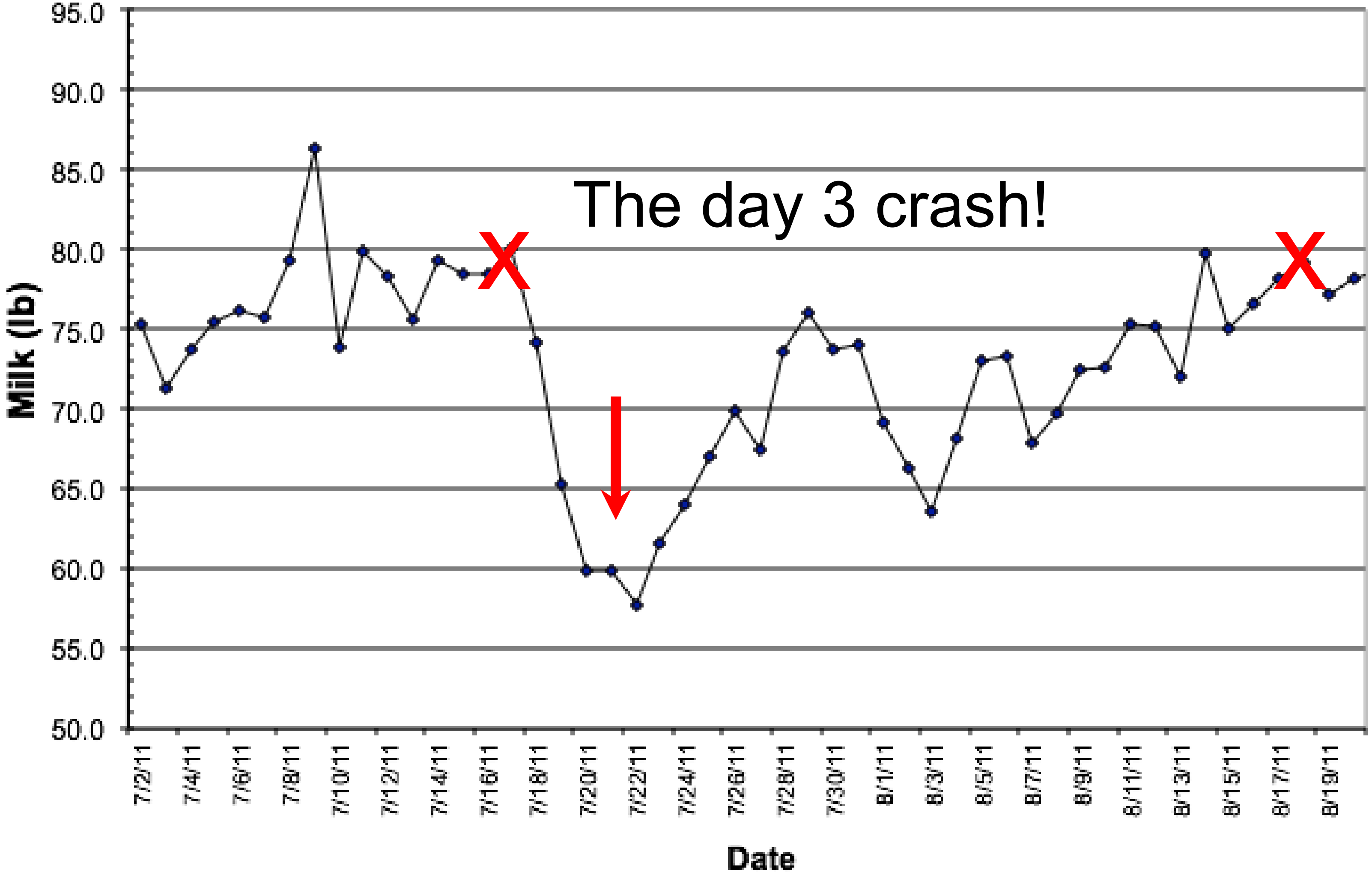
Bunching Behavior

- Due to heat and flies!
- Remember cows seek shade at pasture when heat stressed – they do the same thing in buildings (“go some where dark”)
- Cows move away from the side and end walls of the barn (worse situation in NS oriented barns)
- Cows also seek faster moving air and move away from dead air
- Close the end wall doors, spray for flies, shade cloth/close curtains, ensure sufficient air exchange, enhance cooling

Herd Level Signs

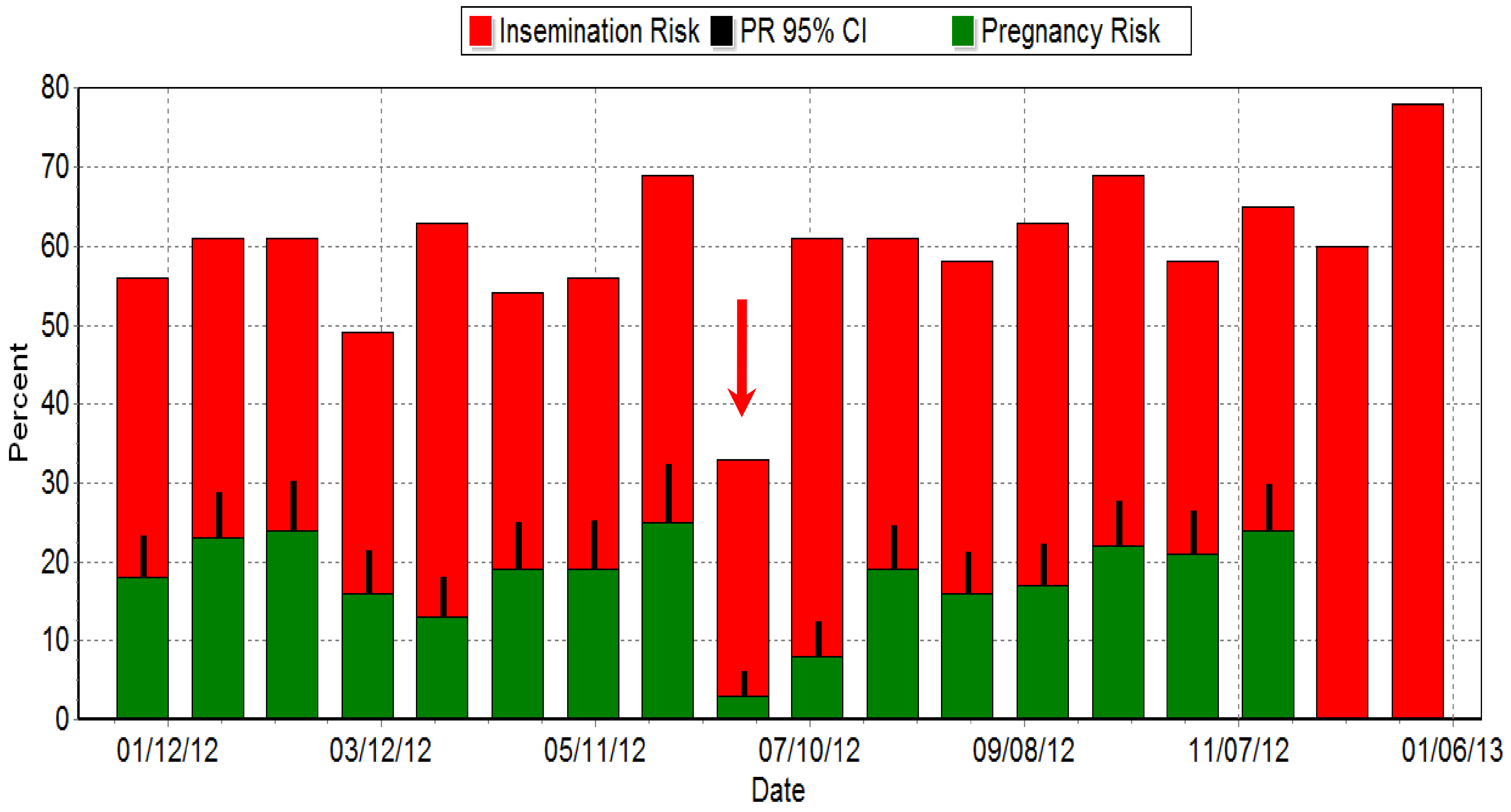
- Milk yield crash in the summer
- Fertility crash in the summer
- Elevated SCC in the summer
- Elevated rates of health events – variable timing:
  - Mastitis in the summer
  - Lameness <u>in the fall</u>
  - Pneumonia <u>in the winter</u> (problem of definition!)

Milk yield crash – daily milk vs monthly tests

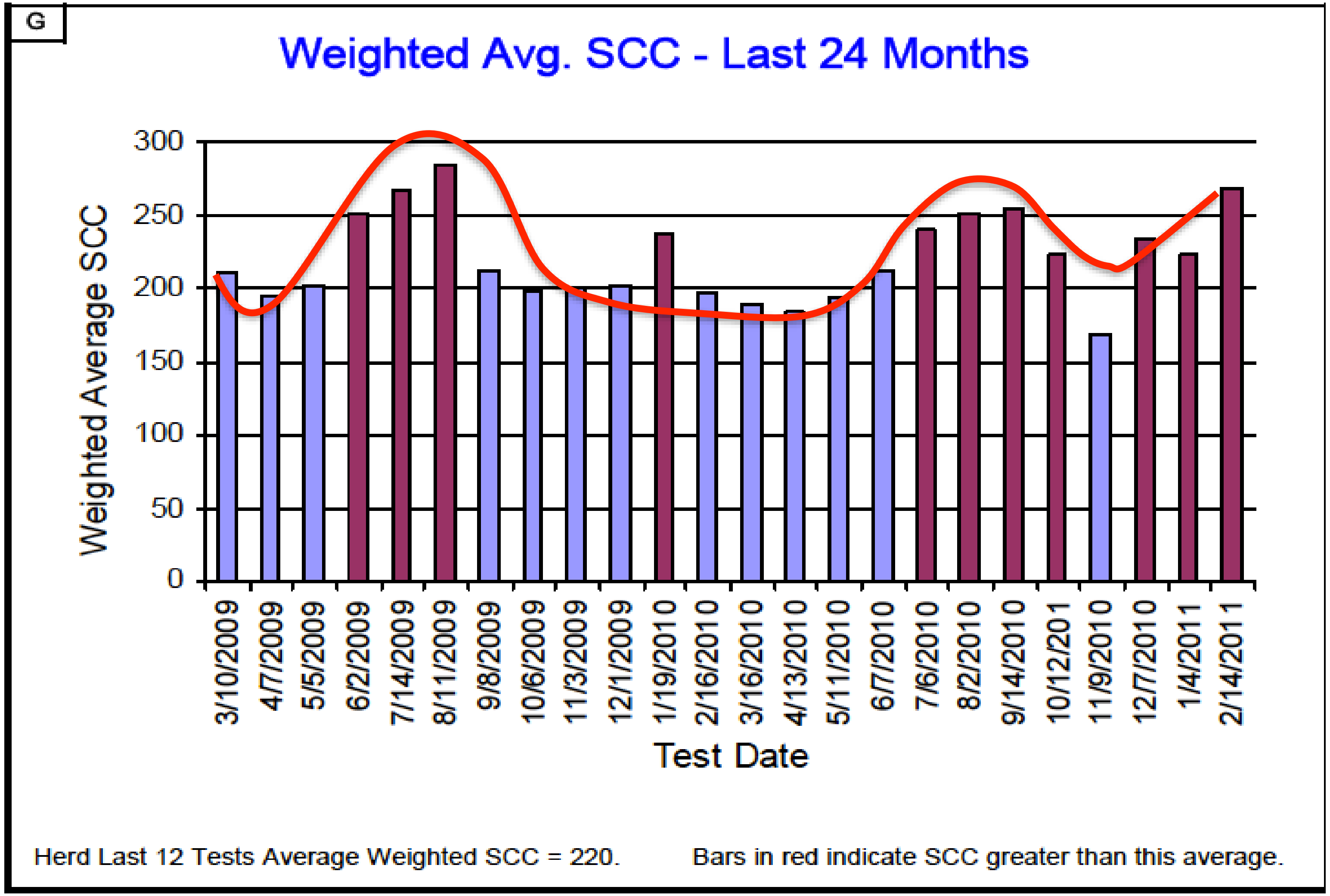


Monthly milk tests may miss or drastically underestimate the lost milk production from episodic heat stress!

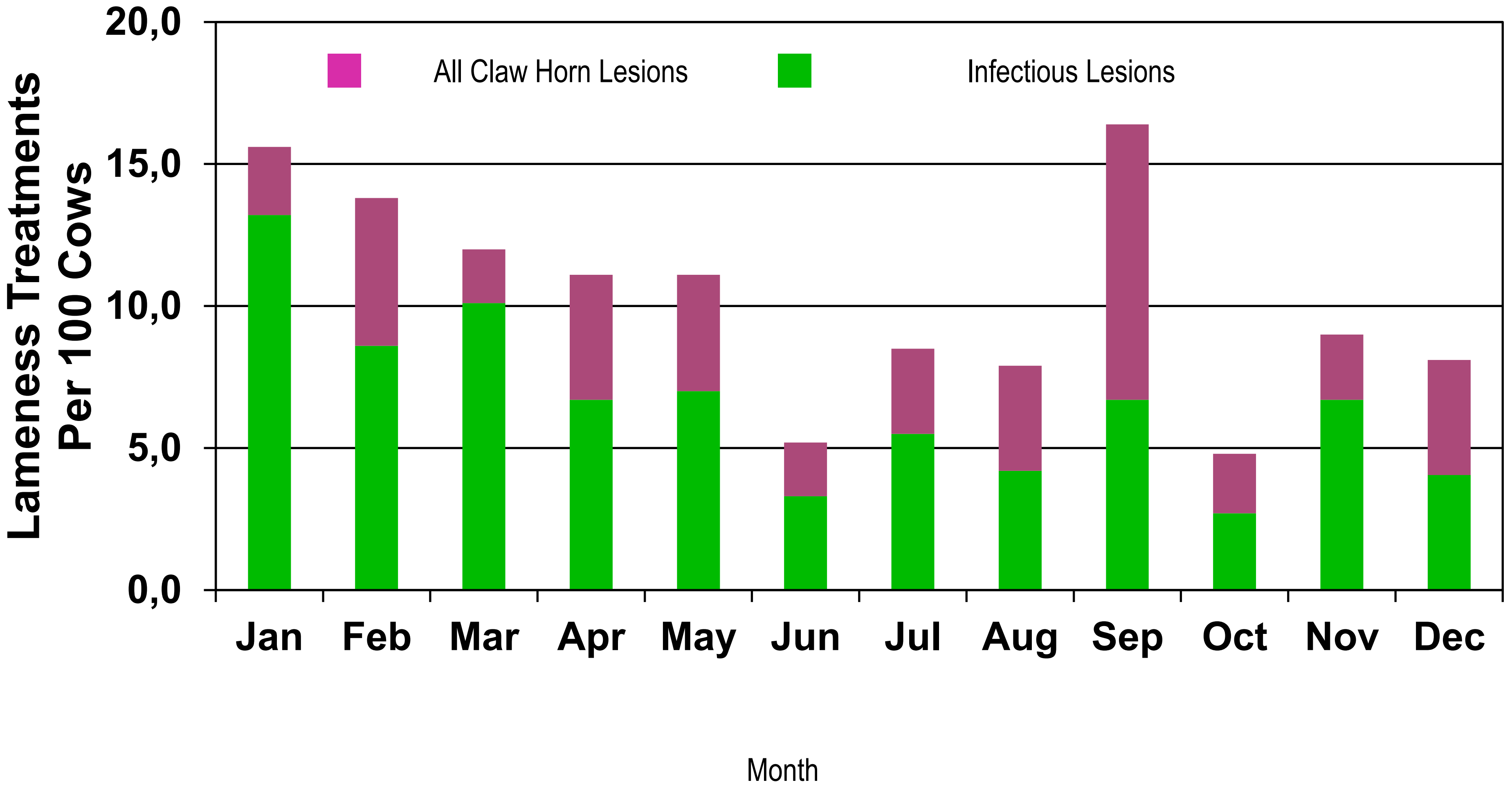
Impact of heat on reproductive performance



Impact of Heat on Bulk Tank SCC

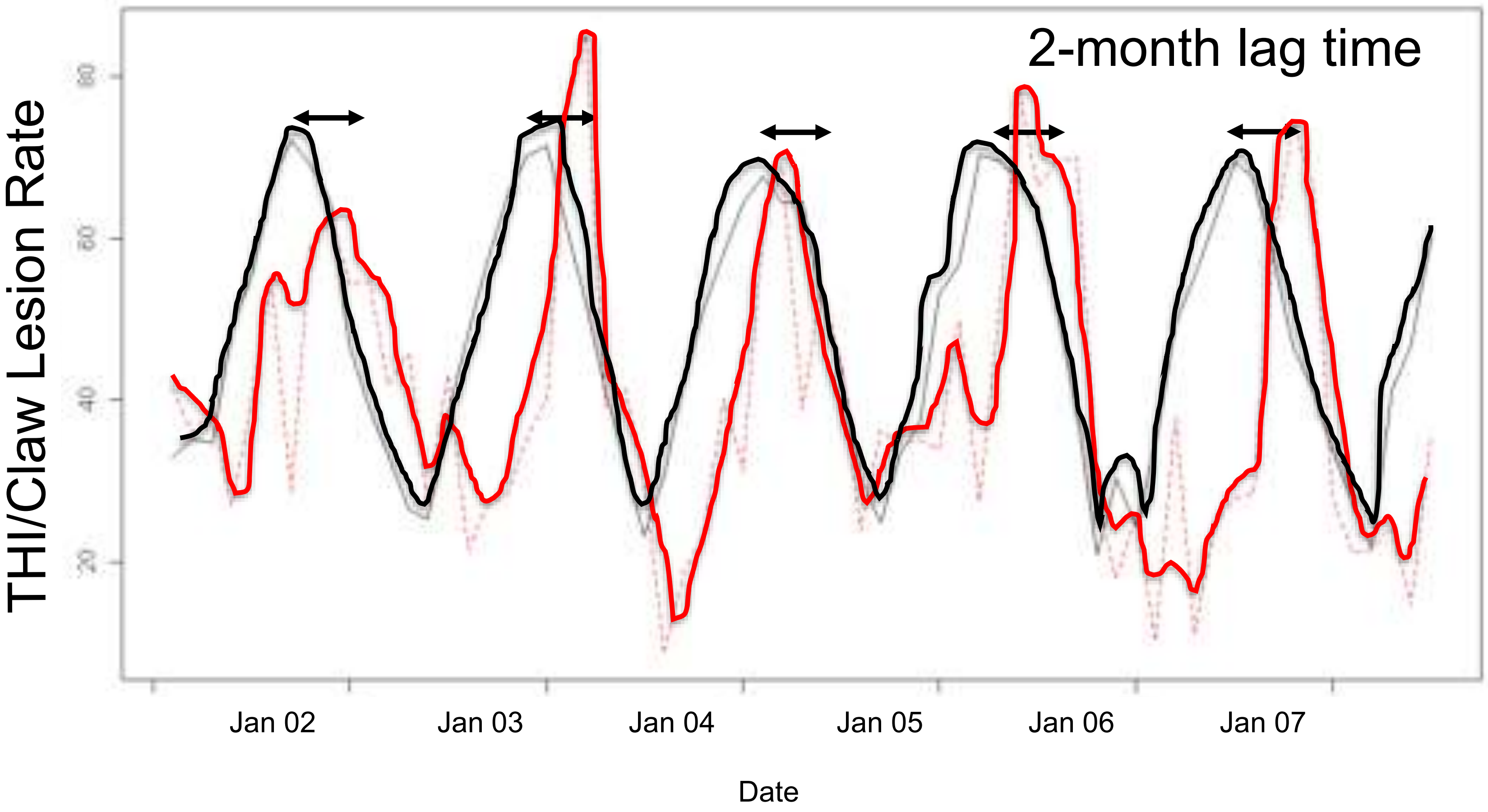


Seasonal Influence on Lameness Treatment Rate in 10 Wisconsin Dairy Herds



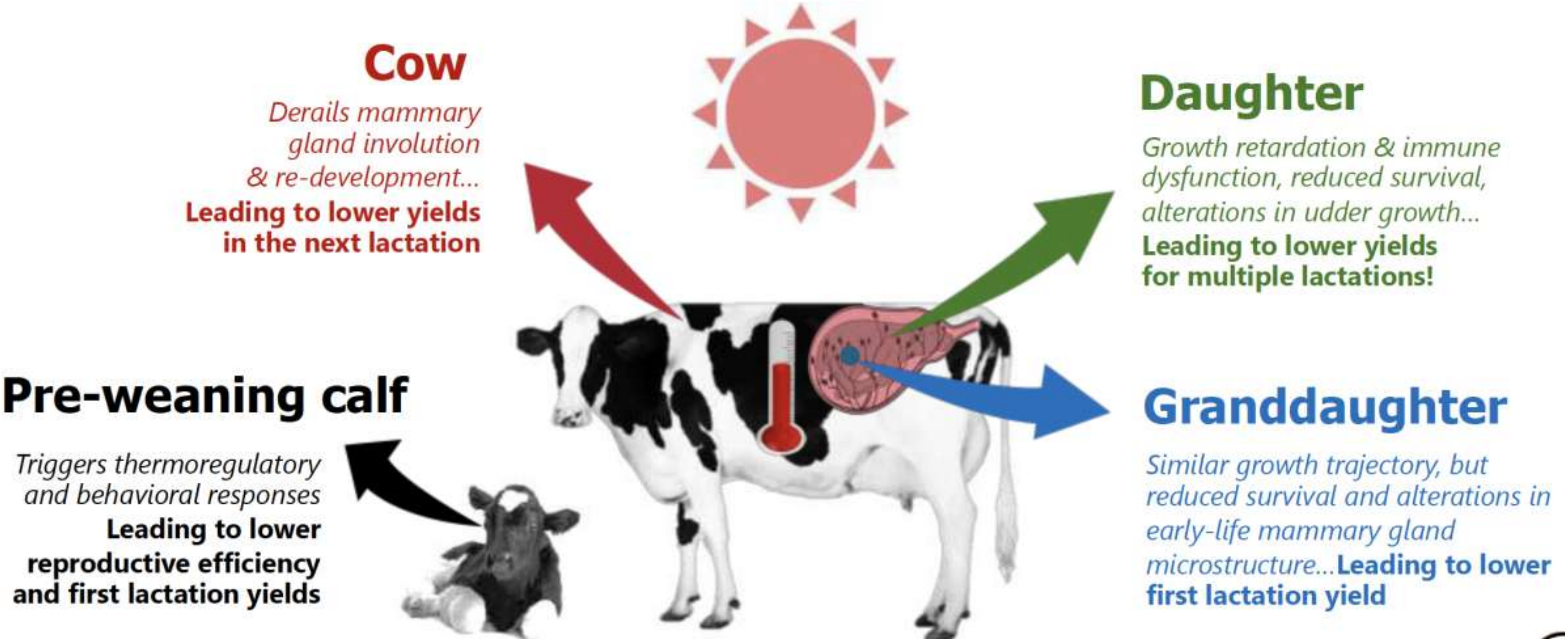
Cook, 2004. Proc. of the 13th Int. Conf. Lameness in Ruminants, Maribor, Slovenia.

Time Series of Temperature Humidity Index and Claw Lesion Rate



Cook et al., Proc. 14th Int. Lame. Symp. 2006

Heat Stress – Not just lactating cows ….



From Jimena Laporta Lab, UW-Madison

Milk Loss in the Next Lactation Following Dry Period Heat Stress

Reference	Dry period length (d)	Milk production measured in the subsequent lactation (d)	Milk loss in the subsequent lactation (kg/d)
Collier et al. (1982)	60	100	1.2
Collier et al. (1982)	60	305[1]	2.6
Wolfenson et al. (1988)	60	150	3.5
Avendaño-Reyes et al. (2006)	60	100	2.6
Urdaz et al. (2006)	28[2]	60	1.4
Adin et al. (2009)	60	90	2.1
do Amaral et al. (2009)	46	210	7.5
do Amaral et al. (2011)	46	140	2.3
Tao et al. (2011)	46	280	5
Tao et al. (2012)	46	294	6.3
Thompson et al. (2014)	46	280	3.8

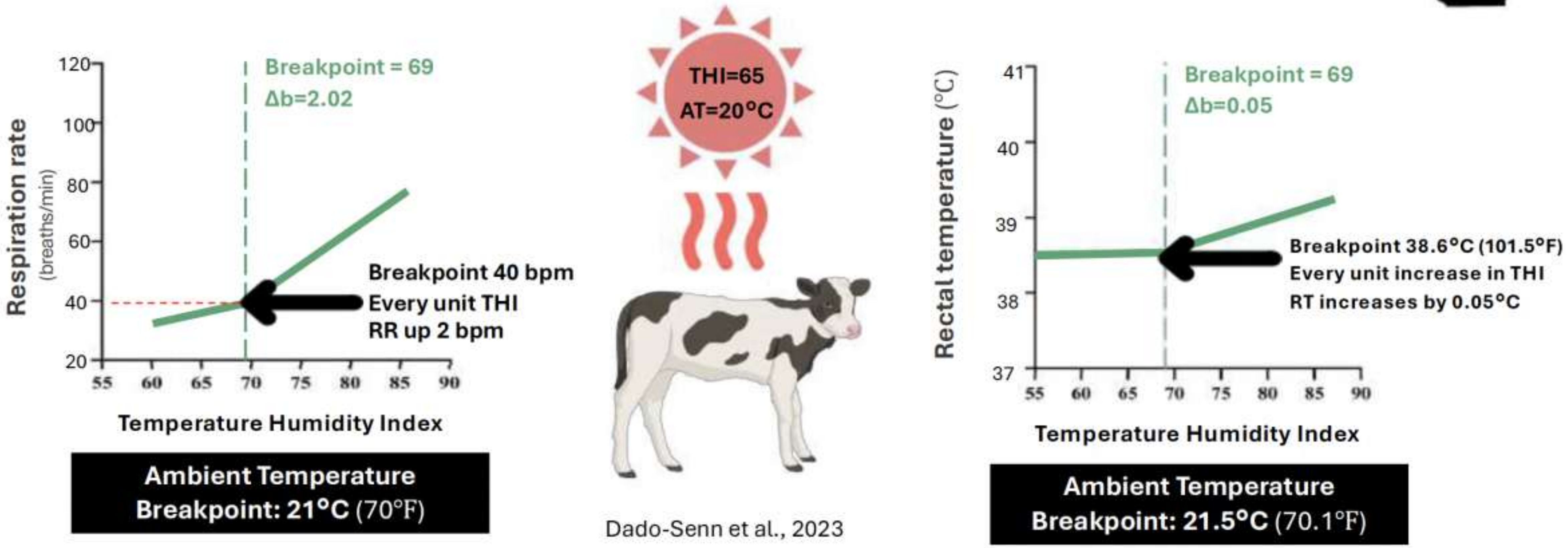
[1]305-d predicted yield adjusted for age, month of calving, and estimated relative producing ability.

[2]Cooling in the close-up period only.

Average milk loss is **7.7 lb** (3.5 kg) per cow per day

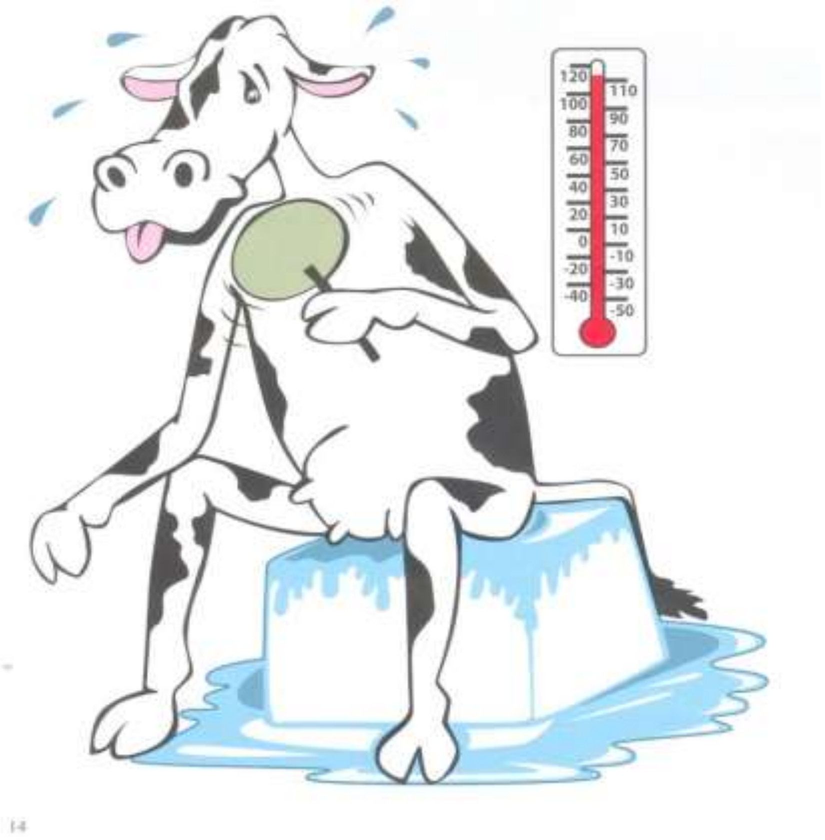
Calves and heifers impacted at similar THI to adult cows ….

To prevent the onset of HS, monitor calves *before* THI of 69 and ambient temperature of 21°C (69.8°F)



Cooling Strategies for Cows

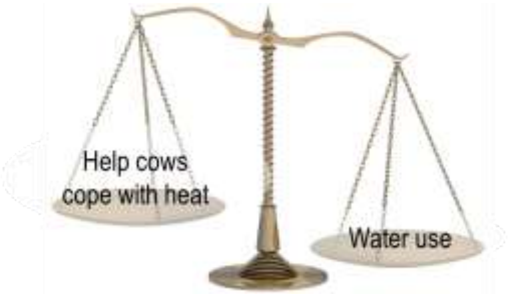
- Use water:
  - To soak the cow
  - To cool the air
    - Misting
    - Evaporative Cooling Pads



- Use conduction
  - Conductive cooling mattress
- Use ventilation and air movement
  - Exhaust the heat and humidity
  - Create air movement to maintain a favorable heat loss gradient


8

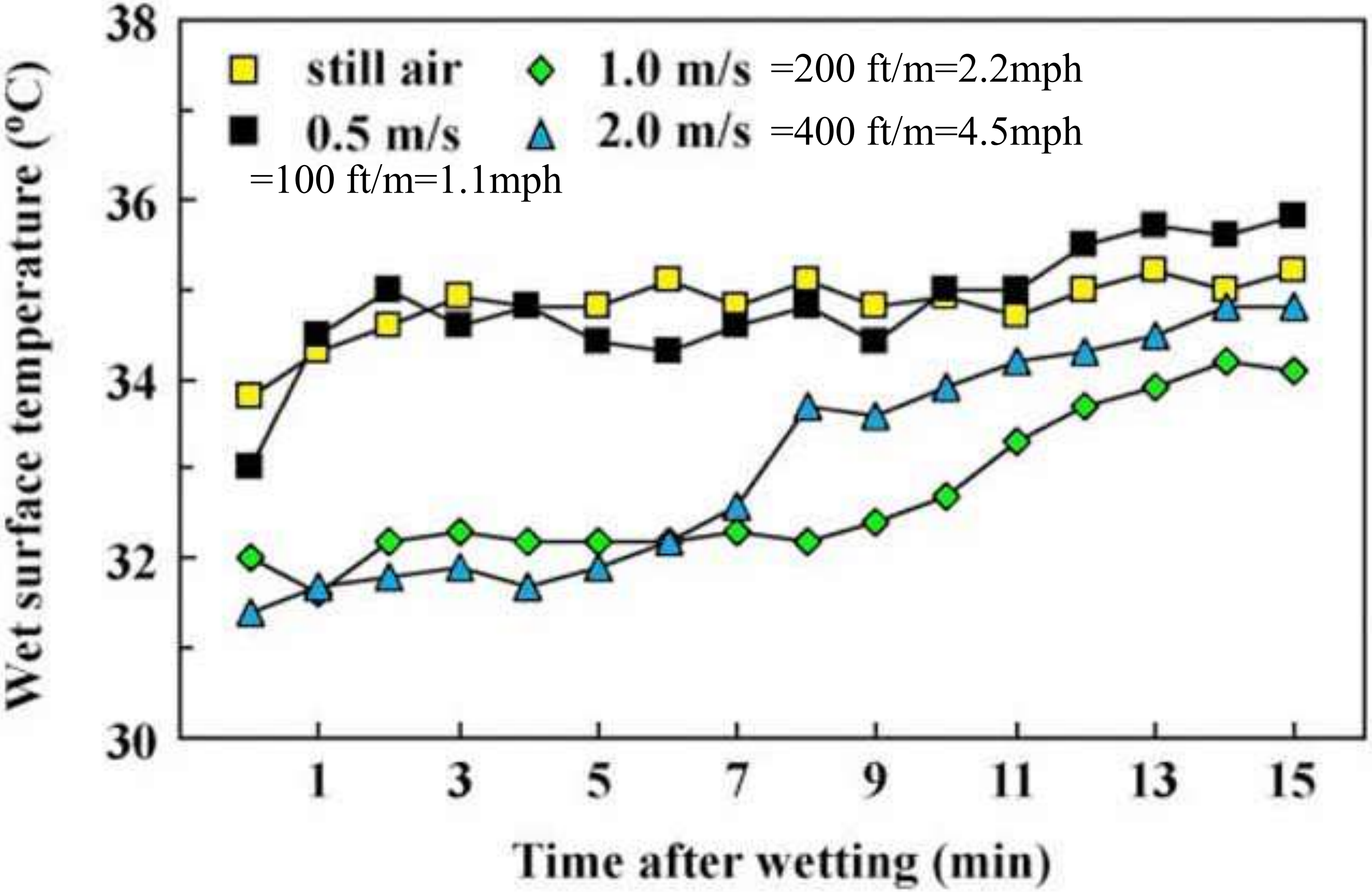
Use water *efficiently*



- Enough water should be applied to generate effective cooling
- Too little water is not effective, and therefore not efficient!
- After a certain point, applying more water → diminishing returns for cooling
- In a lower humidity climate, optimal volume ~ 1 gallon (4L) per spray application (which can cool 2–3 adjacent cows at the feed bunk), at least 4-5×/hour
- Adjust based on region / responses of cows on specific farms
- Low pressure systems, don't worry about droplet size!

Chen (Van Os) et al, 2015, 2016a,b

Duration of heat loss effect after soaking



Berman, JDS 91:4571, 2008

Soaking Smarter:

Lo Range at ~ 70-75^{o}F (21-24^{o}C)
Shower time 0.3-0.5 min
Interval 12-15 min

Hi Range at ~ 82-85^{o}F (28-29^{o}C)
Shower time 0.3-0.5 min
Interval 6-10 min

Is this an efficient use of water and the best location for soaking cows?


Cool Sense™
Motion Cooling System
• Control the amount of water used by adjusting the shower time – Minimize wasted water.
We need to make sure that the water lands on the cow!

Intelligent Soaker

- Soaks only when the cow is present – ultrasonic sensor to detect the cow at the feed bunk
- Reduces the amount of water used (up to 70% less?)
- Probably too expensive right now?

The Future: Precision Livestock / biofeedback

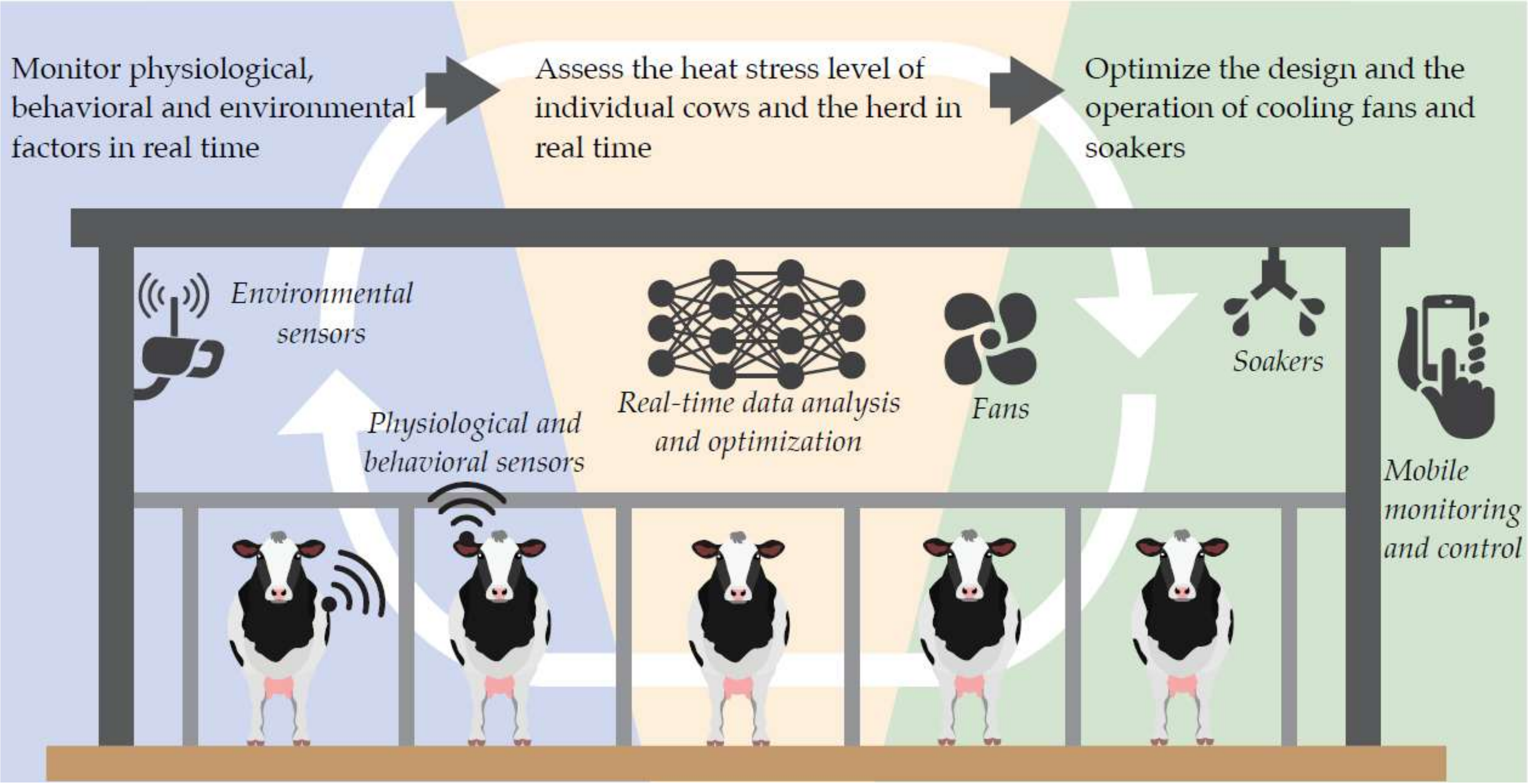


Figure: Kim, Choi, Van Os, Brounts (2021-2024 NSF-CPS/USDA grant); see review on precision cooling by Zhang et al. 2024 (https://doi.org/10.1016/j.compag.2024.109248).

Soakers counteract production losses

- Modeled production losses from heat stress:
  - > $1.5 billion/yr with shade alone
  - estimated losses ⇩ 43% with soakers

- ⇧ Feeding time, DMI
- ⇧ Milk yield (3.3 to 8.2 lbs/d ~ 1.5 to 3.7 kg/d)

Chen (Van Os) et al, 2013, 2016; St-Pierre et al, 2003; Gaughan et al, 2004; Strickland et al, 1989; Morrison et al, 1981; Flamenbaum et al, 1995; Her et al, 1988

Feed line soakers do not significantly increase lying times!

Study	Soaker Lying Time (h/d)	Control Lying Time (h/d)
Legrand et al., JDS 94:3376, 2011	11.1	11.5
Chen et al., JDS 96:5035, 2013	11.3	11.0
Chen et al., JDS 99:4607, 2016	12.1	11.9

This makes sense – water lands on the cows…

IWOB #17 nozzle 10 pound pressure reducer with 0.5 lb (1kg) weight 9’ (2.75m) above ground for 30’ (9.0 m) spread


Lely Astr

Misting systems (High Pressure Fogging)

Usually only low humidity environments …. But some efficacy under moderately humid situations ..

What about evaporative cooling pads?

Predicted Cooling of Air Temperature - Effect of RH% on Evaporative Cooling

Ambient Temperature	Relative Humidity %				
^oF (^oC)	15	25	35	45	55
93 (34)	-24 (13)	-18 (10)	-12 (7)	-7 (4)	-1 (0.6)

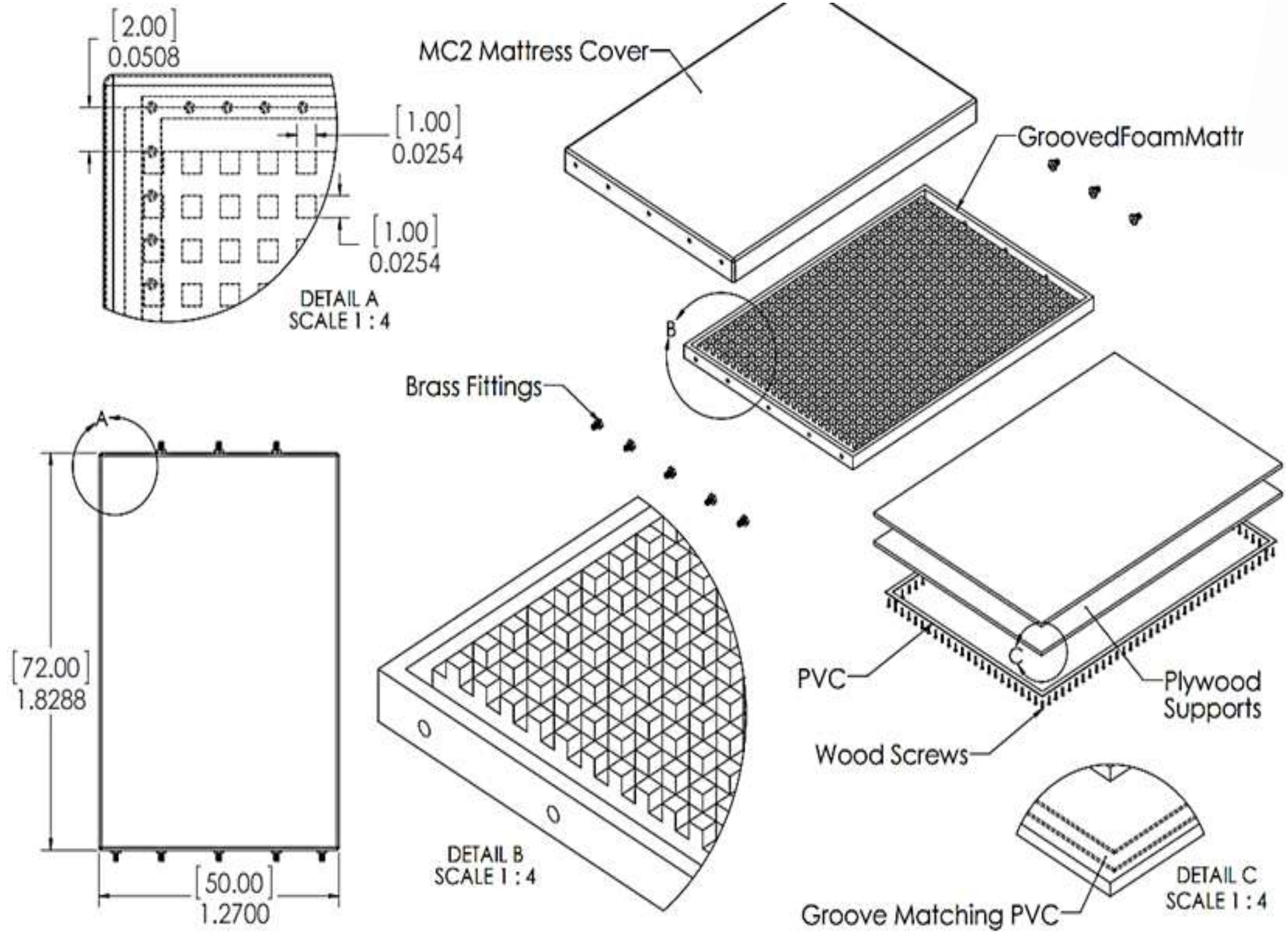
Cooled air is at 65% RH

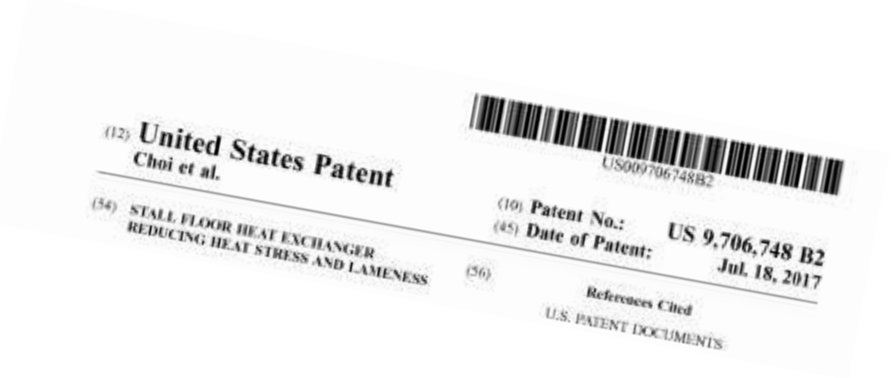
Berman, JDS 89:3817 2006


Maintenance ….

Issues with cooling pads….

- Constant cleaning and maintenance
- Some blockage of the inlet is common
- Limits incoming air speed to ~ 420 ft/min (2.1m/s) – less mixing of incoming air

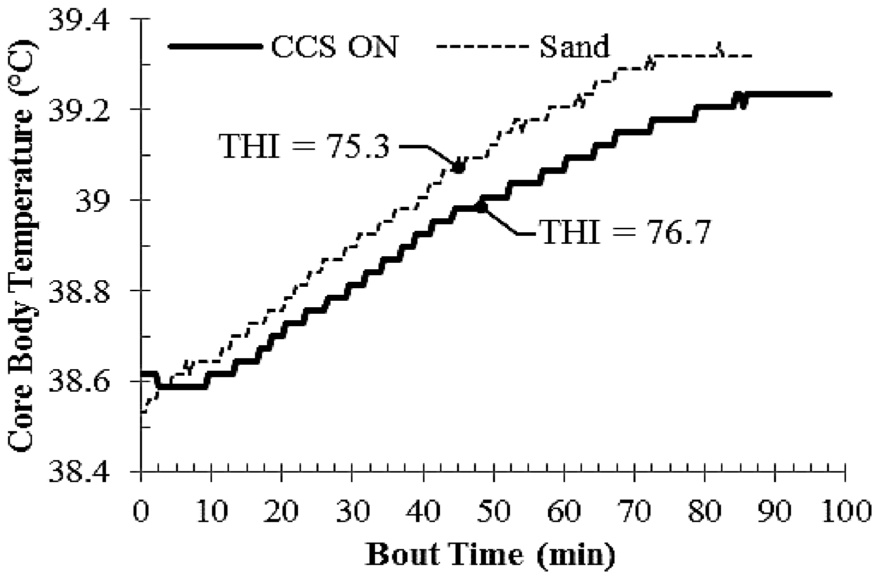




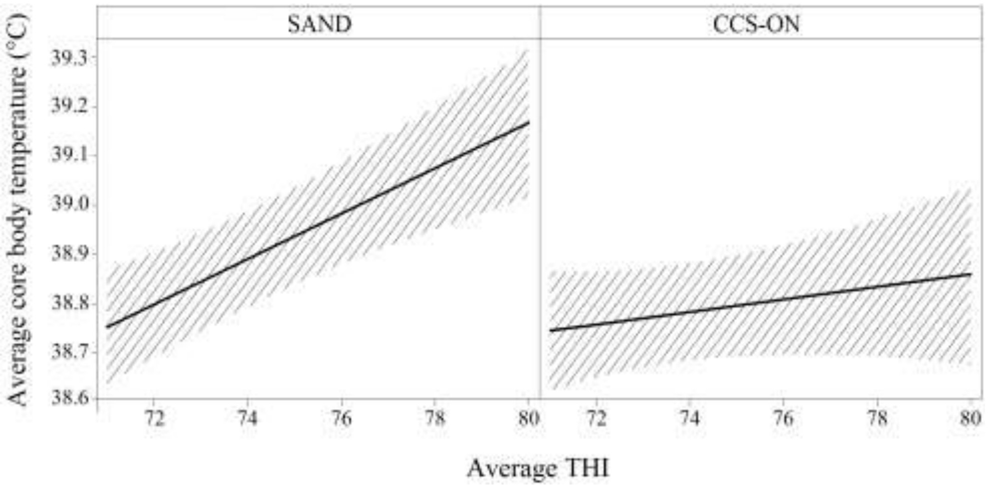
A mattress we use for ~3 months in the summer

Conduction Cooling System

(Mondaca et al.)



Using well water (~55^{o}F, ~13^{o}C), we can mitigate the effects of THI on core body temperature during the lying bout



At THI 80, CCS cooled cows by 0.4^{o}C vs sand

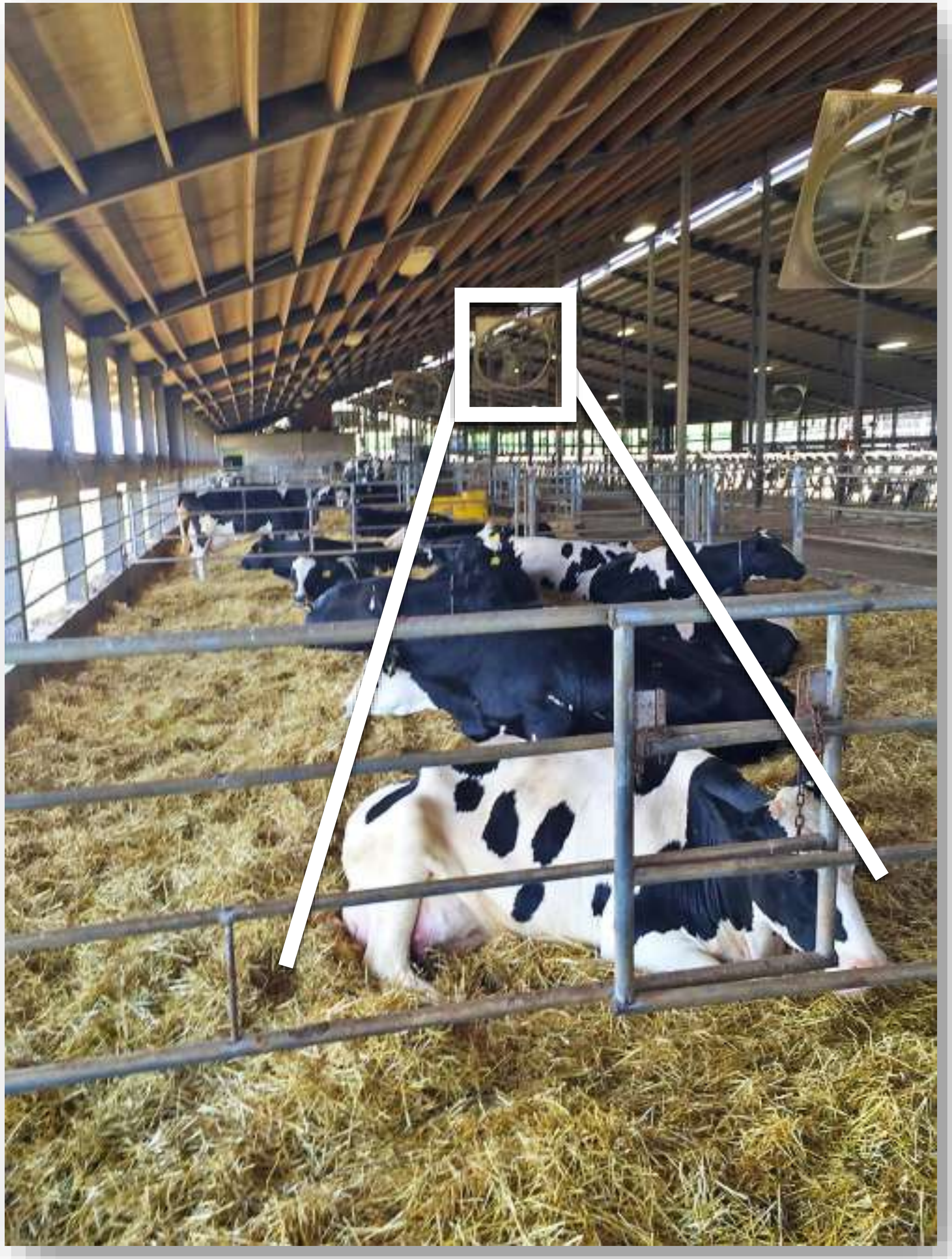

TLC200 PRO 2014/06/18 12:35:37

Cows heat and humidify the air

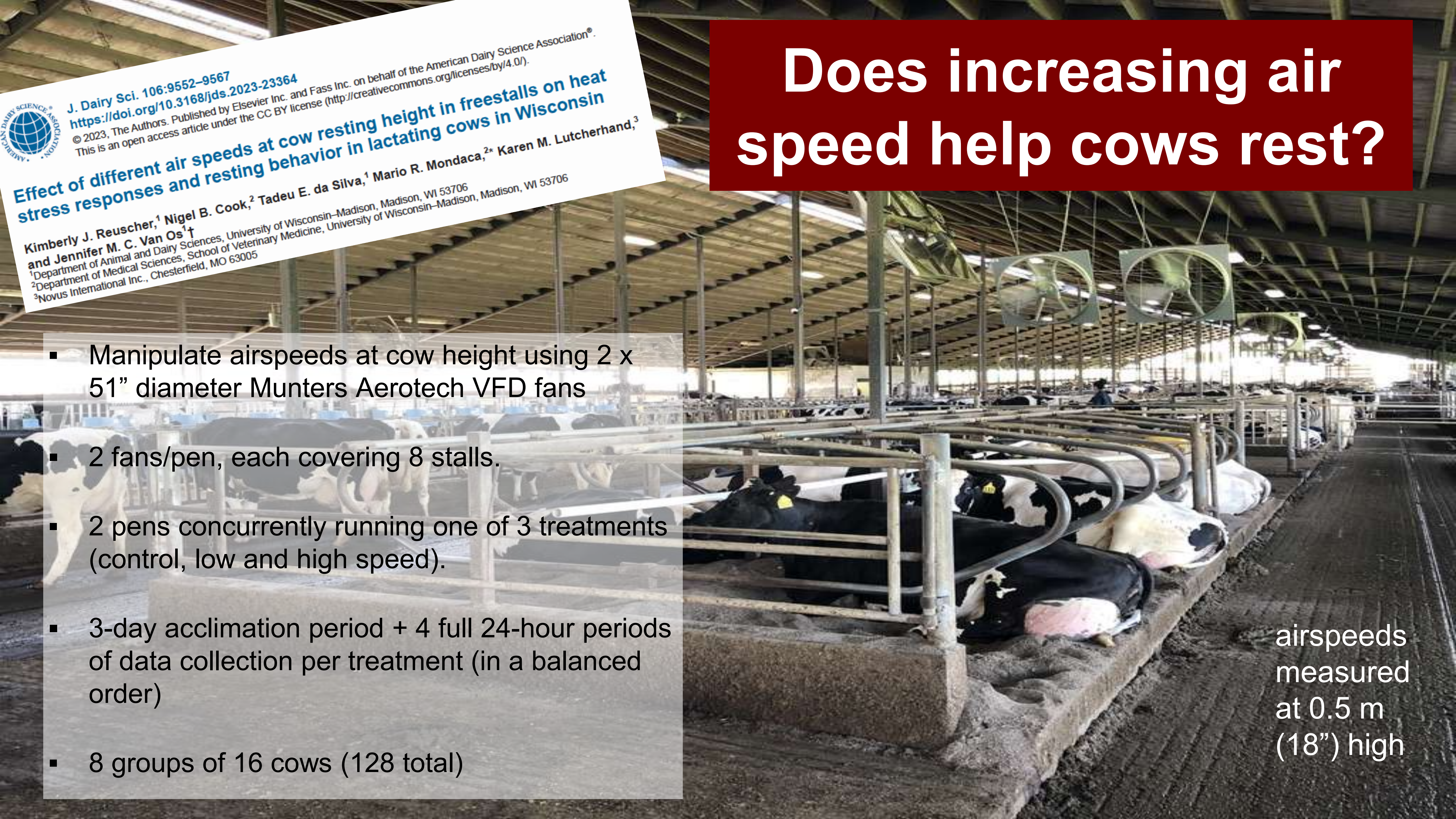
- Replacing the hot and humid air with fresh air helps maintain a favorable heat transfer gradient – just like blowing on your morning coffee!

- Air speed DOES have a significant effect!

Cows prefer fast moving air when they are hot!



This is likely a behavioral effect rather than a physiological effect



J. Dairy Sci. 106:9552–9567
https://doi.org/10.3168/jds.2023-23364

Effect of different air speeds at cow resting height in freestalls on heat stress responses and resting behavior in lactating cows in Wisconsin

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[3]Novus International Inc., Chesterfield, MO 63005

Does increasing air speed help cows rest?

- Manipulate airspeeds at cow height using 2 x 51” diameter Munters Aerotech VFD fans
- 2 fans/pen, each covering 8 stalls.
- 2 pens concurrently running one of 3 treatments (control, low and high speed).
- 3-day acclimation period + 4 full 24-hour periods of data collection per treatment (in a balanced order)
- 8 groups of 16 cows (128 total)

airspeeds measured at 0.5 m (18”) high

Air Speed Map at 0.5 m height by treatment

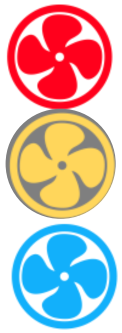
Low Speed (Fans @ 60% Max)

1.4	2S	3S	4S	**1.9**	6S	7S	**1.4**
1.0	2N	3N	4N	**1.8**	6N	7N	**1.1**

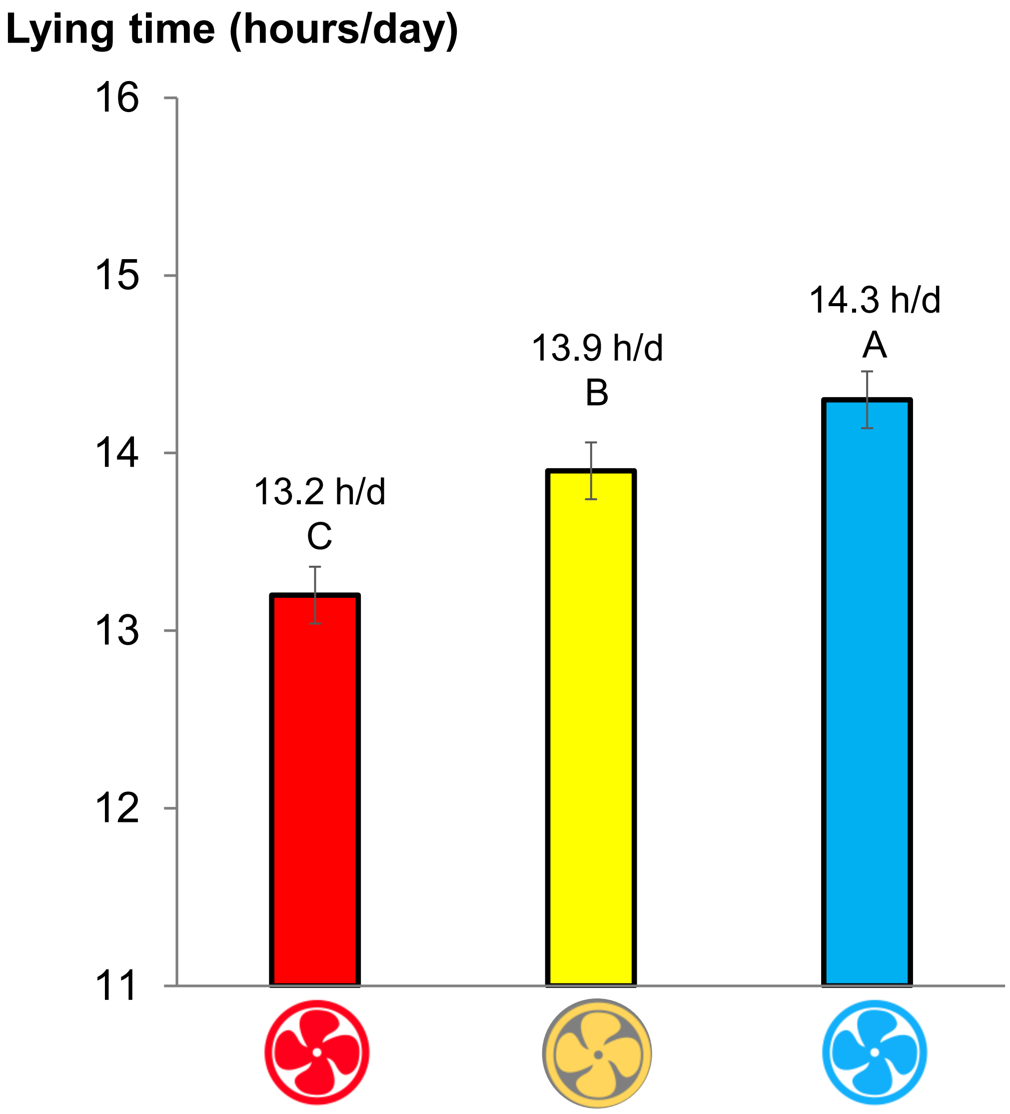
High Speed (Fans @ 100% Max)

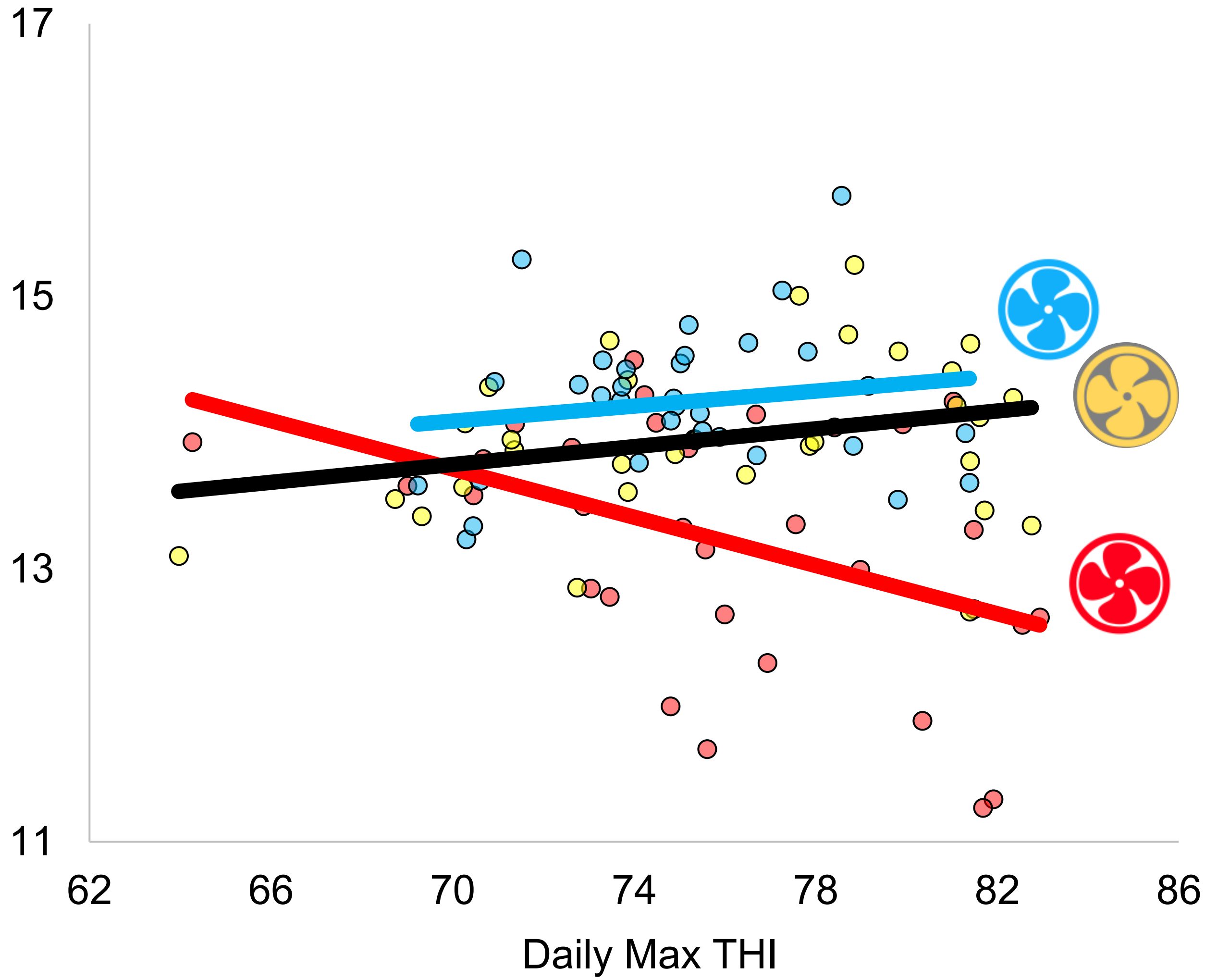
2.5	2S	3S	4S	**3.4**	6S	7S	**2.5**
1.4	2N	3N	4N	**3.0**	6N	7N	**2.0**

- Control (no fans): 0.4 m/s ± 0.2 m/s
- Low airspeed: 1.7 m/s ± 0.5 m/s
- High airspeed: 2.4 m/s ± 0.8 m/s



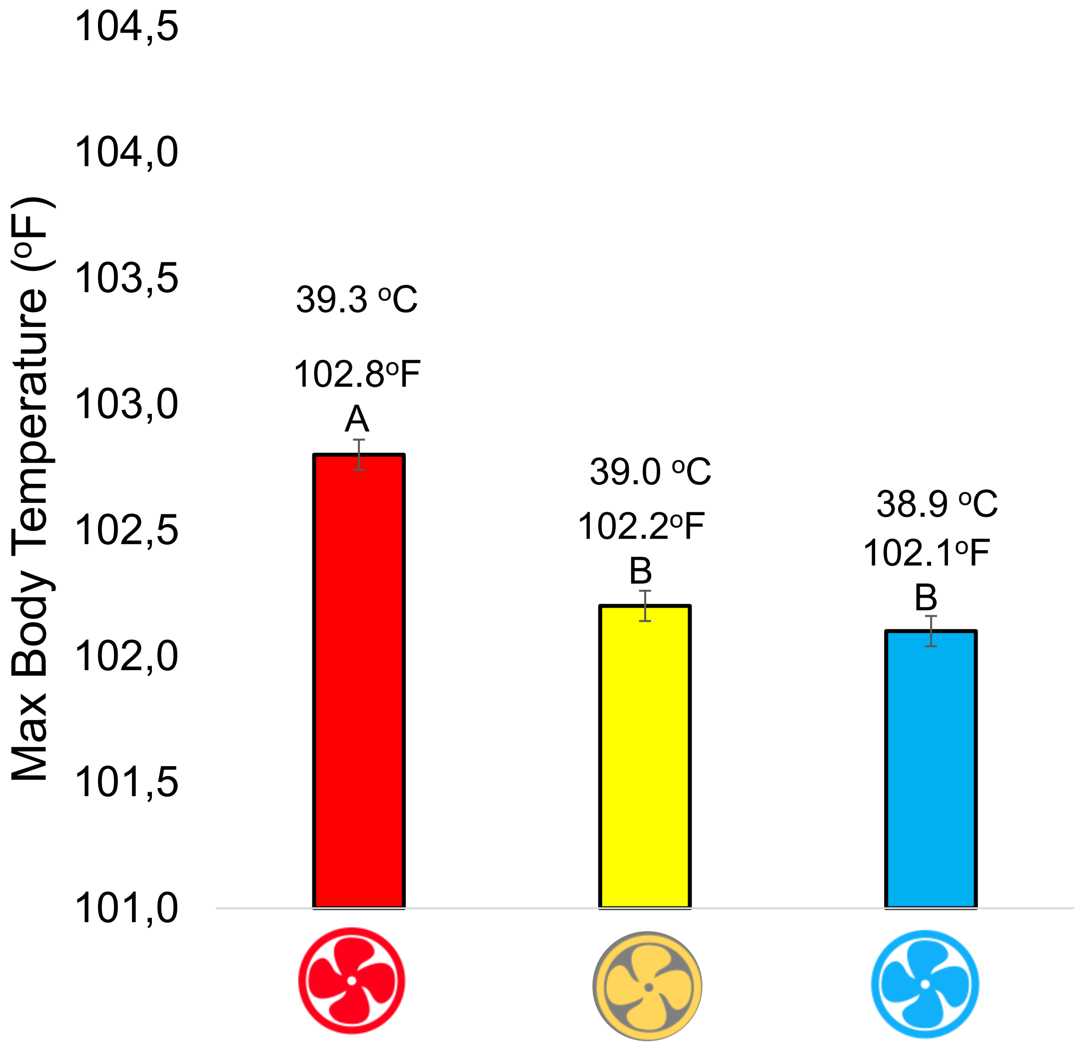
Fans protected lying time

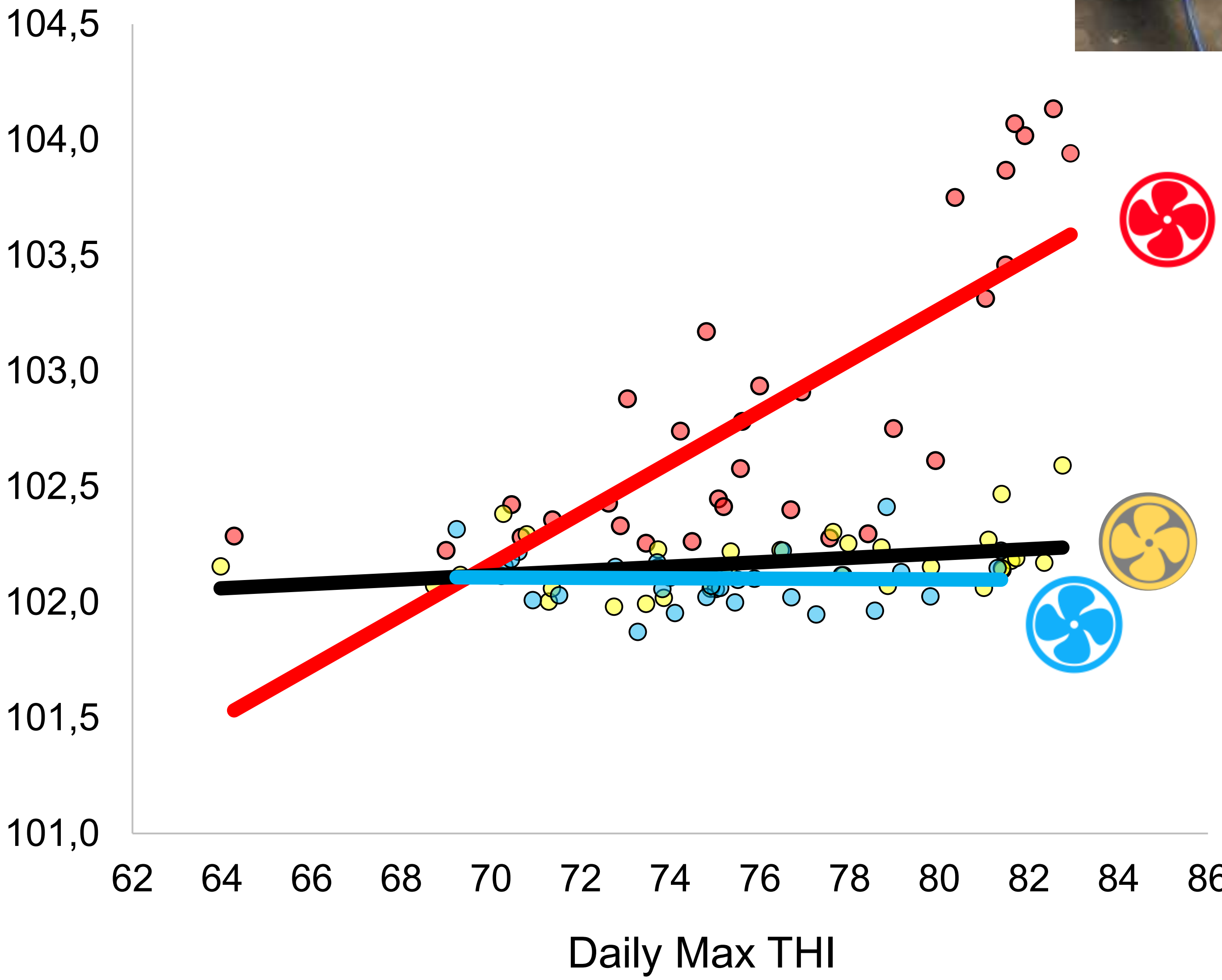




Reuscher et al., JDS 106:9552, 2023

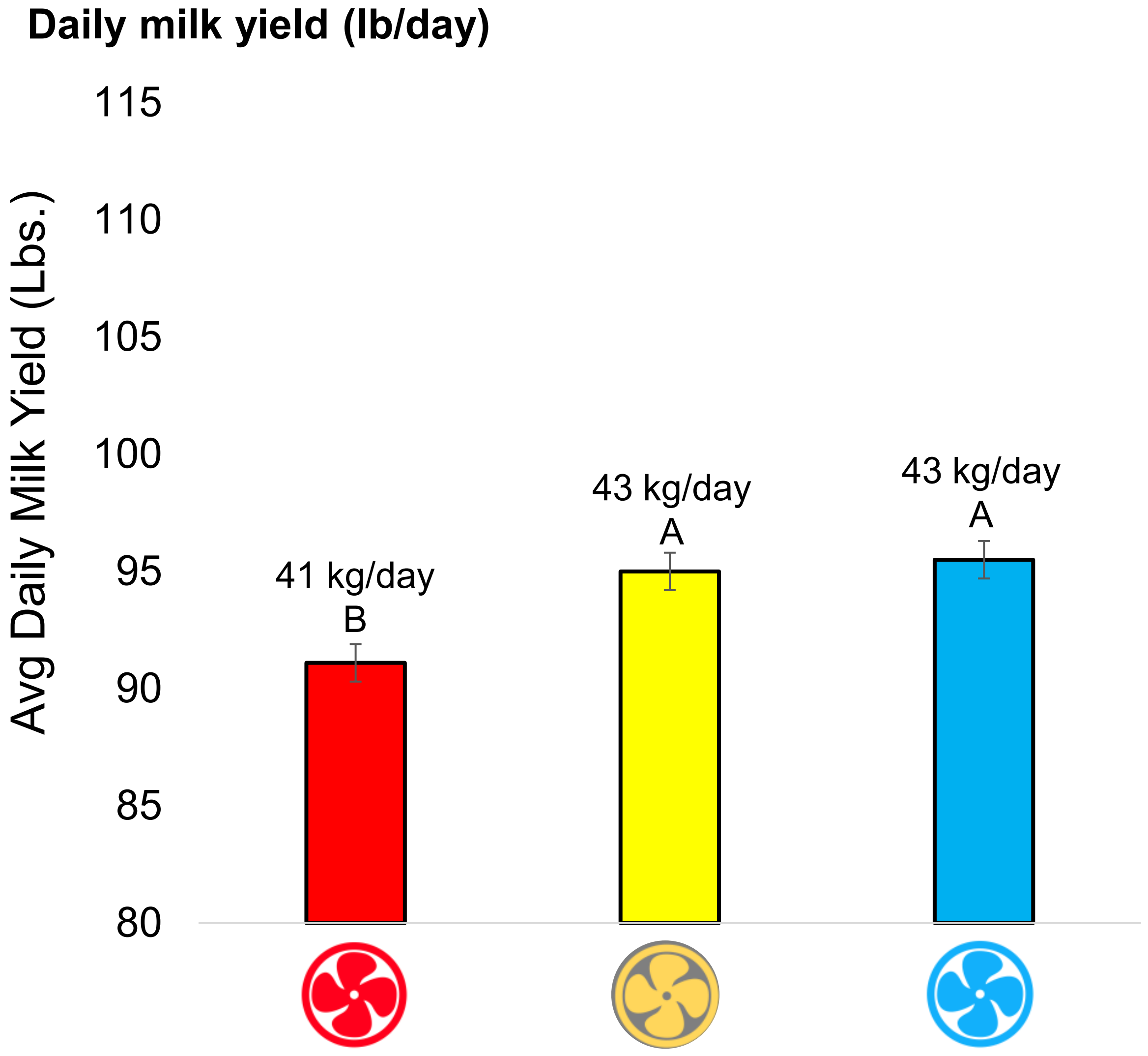
Fans kept body temperature normal

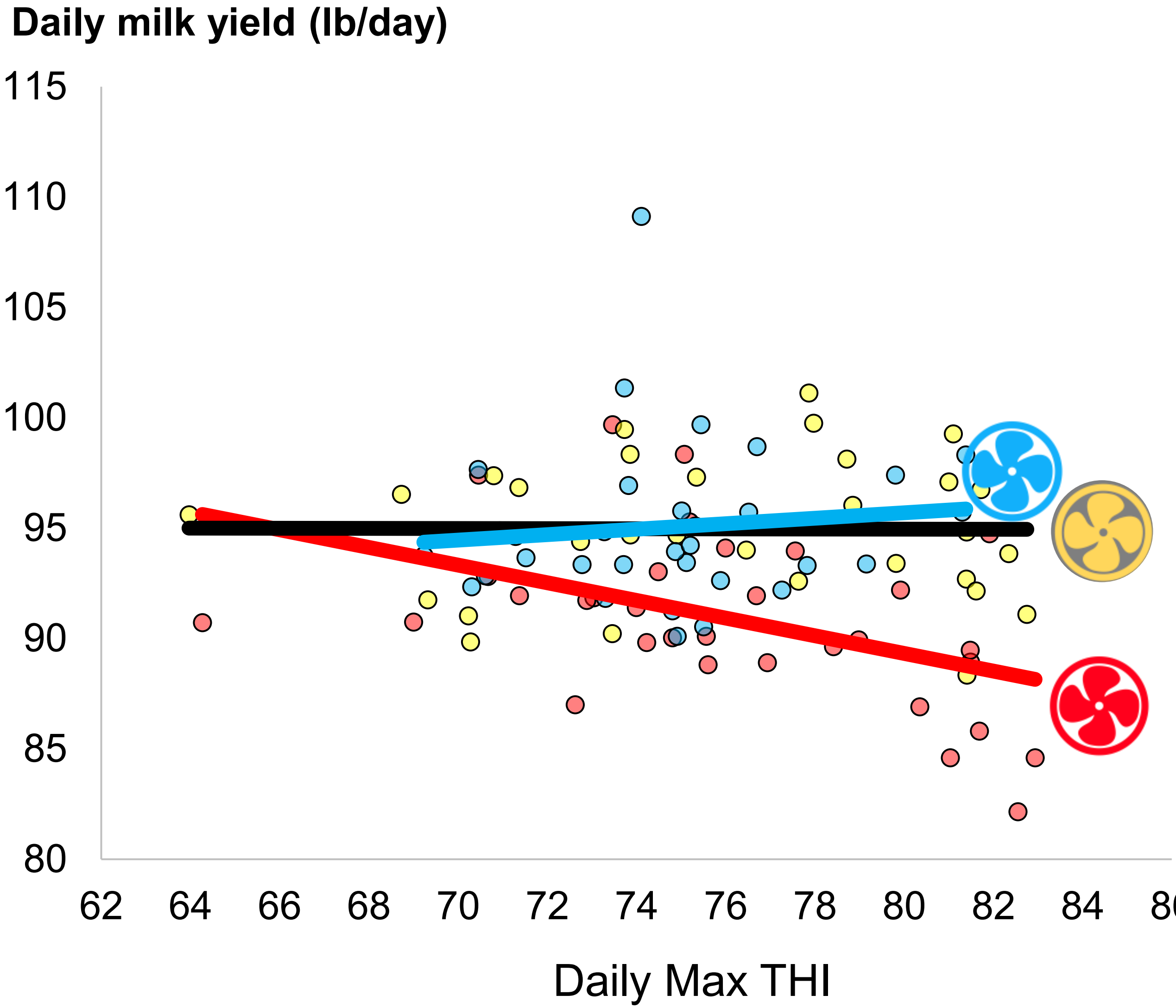




Reuscher et al., JDS 106:9552, 2023

Fans protected milk yield





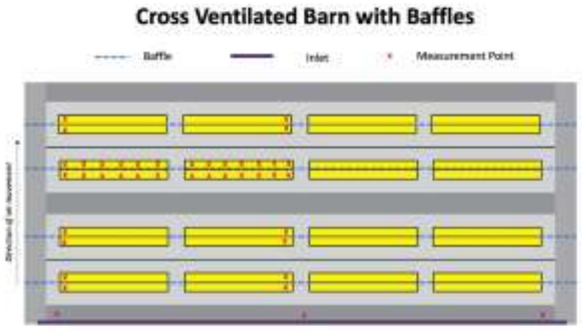
Reuscher et al., JDS 106:9552, 2023

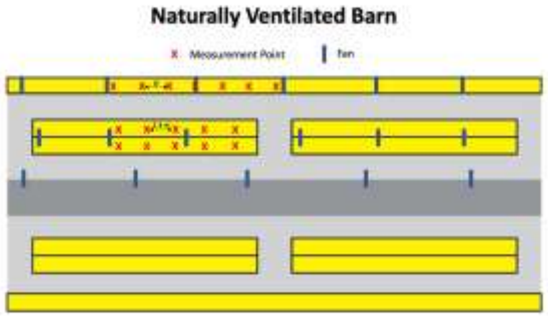
- Air speed at cow resting height influenced daily lying time, vaginal temperature, and milk yield under conditions of heat stress
- These results indicate the need to provide a **Minimum Cooling Air Speed (MCAS)** in the cow resting microenvironment (1-2 m/s at 0.5 m above the stall)
- Increasing fan speed from 60% to 100% more than doubled the electricity cost for little improvement in cow outcomes

Air Speed Mapping

- Propeller anemometer
  - 1.5’ (0.5m) off the ground = resting height airspeed

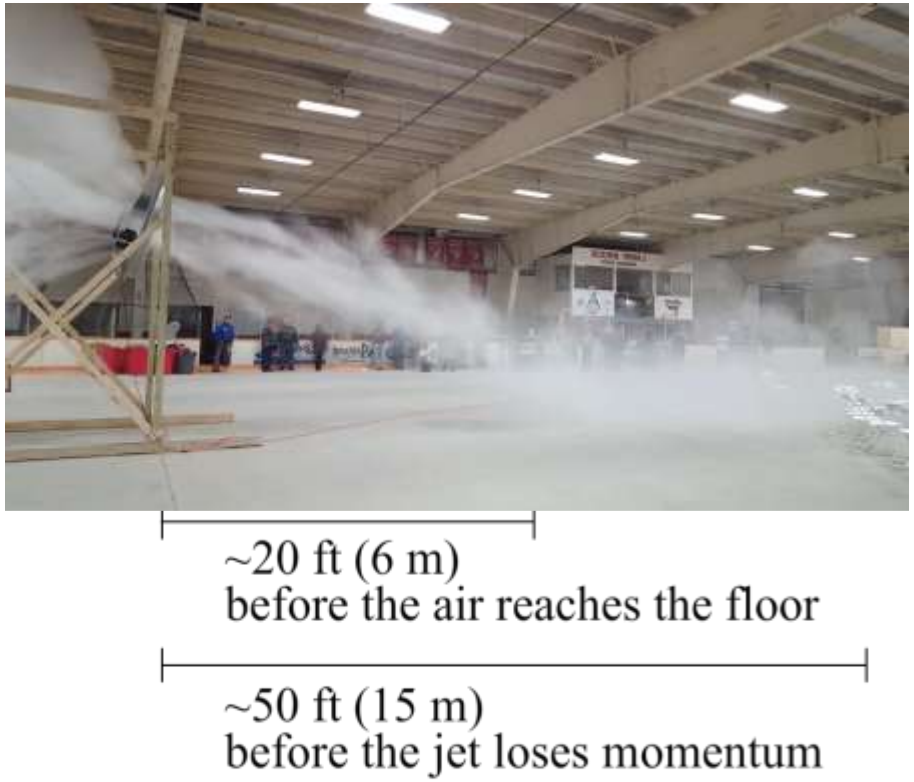
- 1 min per location

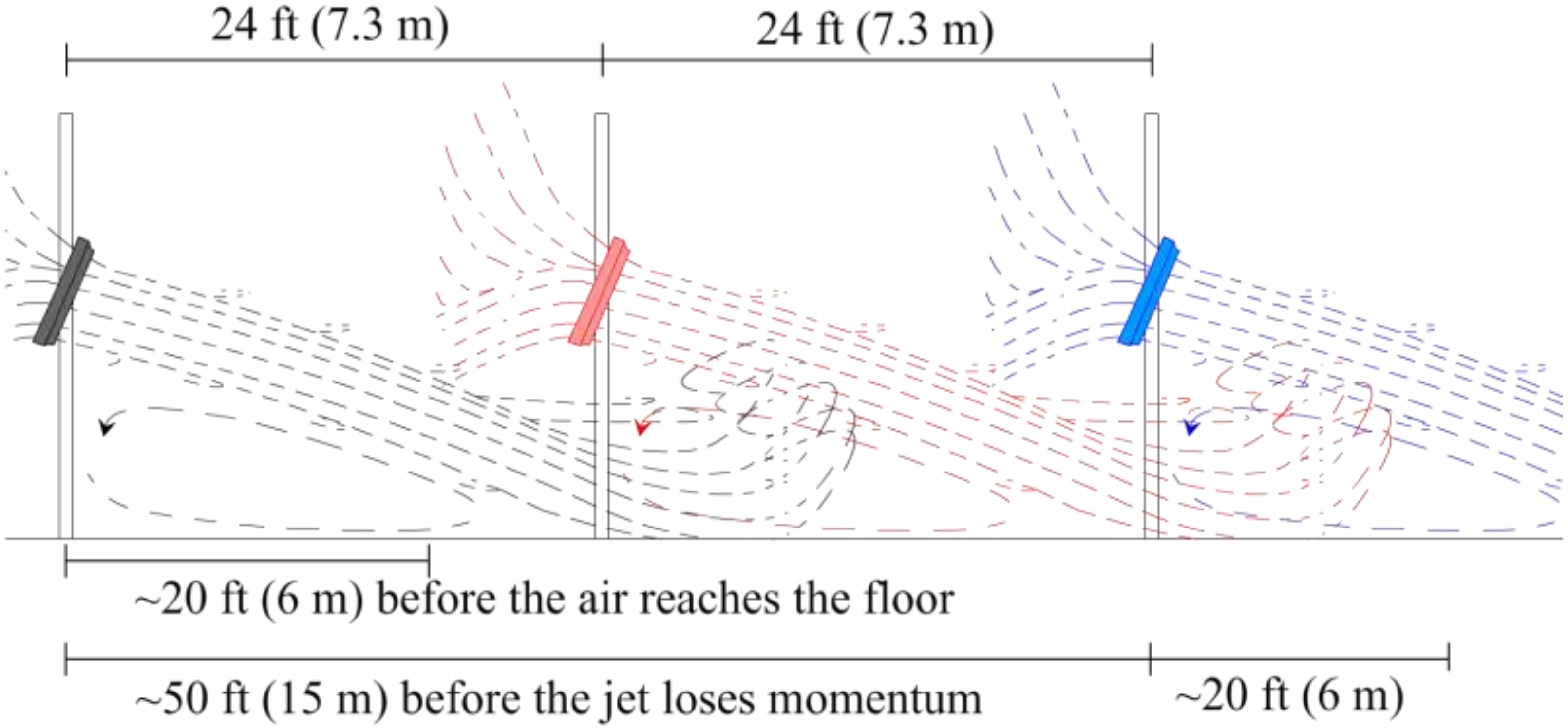




Fan Spacing

(Typical 48-55” (122–140 cm) diameter panel fans)



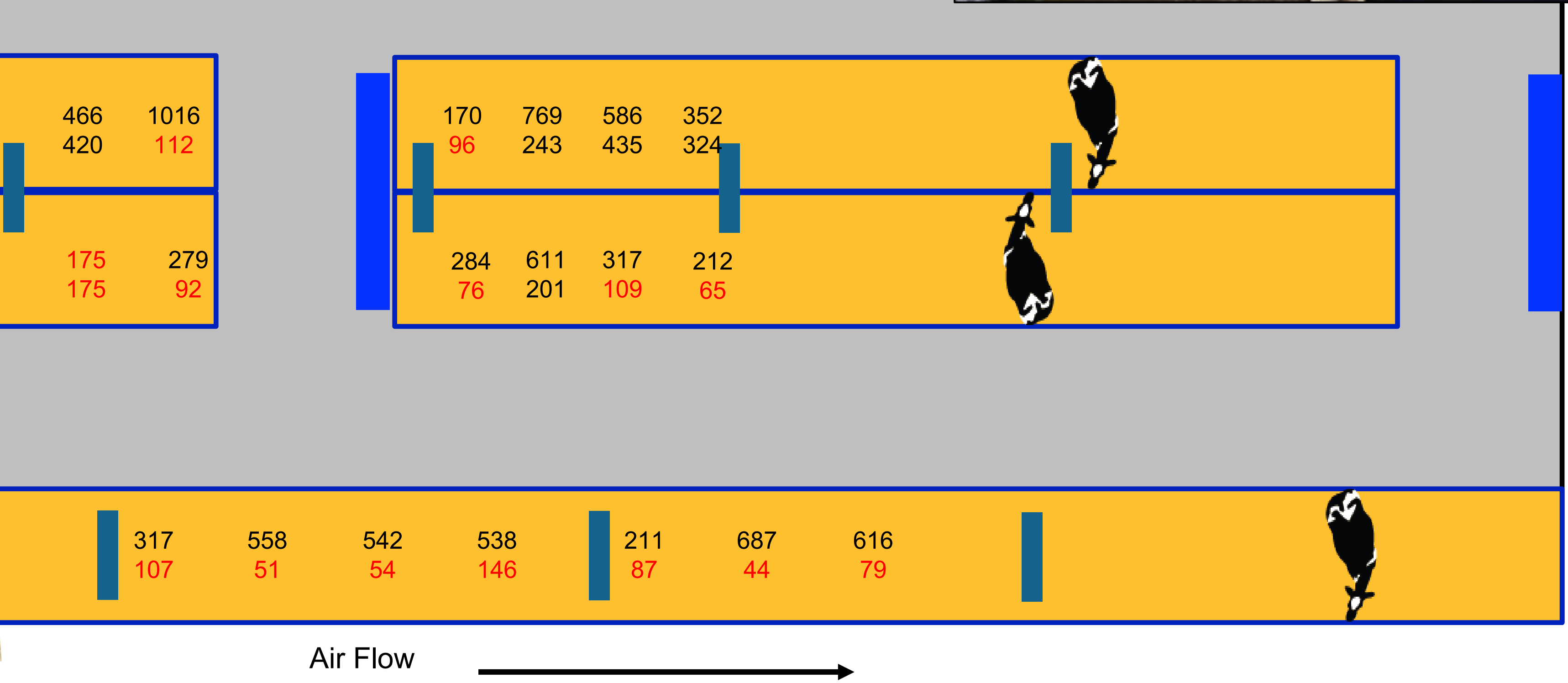


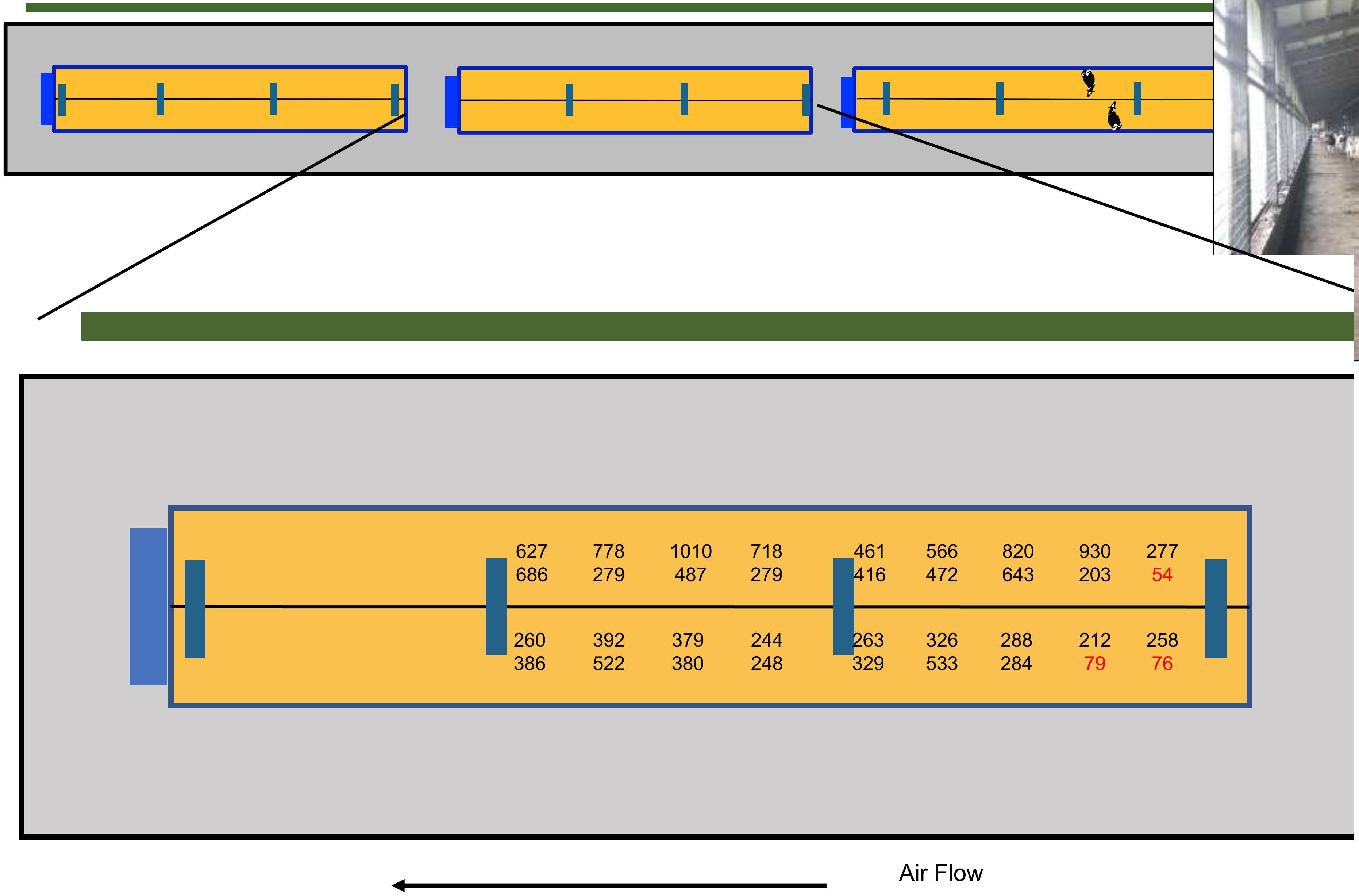
Target one fan per stall platform spaced 24-30’ (7-9 m) apart activated at ~68^{o}F (20^{o}C)

The air needs to be directed DOWN!

Single panel fans spaced 7 m on center (head-to-head), spaced 11 m side wall – insufficient angle and compromised direction

*colored red if <200 ft/min or 1 m/s





Single panel fans spaced 11 m on center – good angle and placement!

Adjust cooling strategies by observing cows

Why observe the cows?

- Farms vary in facilities and management
- Within the same environment, individual cows respond differently, depending on:
  - breed, milk production, pregnancy or health status, coat characteristics
  - social status (which could affect access to drinking water, cooler microclimates, heat abatement)

Bianca, 1968

Respiration rate: an early indicator of heat stress

Rule of thumb: intervene at ≥60 breaths per minute

- 60 breaths/min threshold suggested in older literature
- After being deprived of cooling, cows preferred soakers when respiration rate reached 60 breaths/min
- Cows with 24-hour access to soakers: 50 breaths/min on average
- Easy to count

Legrand et al, 2011; Chen (Van Os) et al, 2013, 2016; Atkins, Cook et al 2018; Webster, 1993

How to measure respiration rate – an early indicator

Rule of thumb: intervene at ≥60 breaths per minute

Method:

1. Watch the cow and record 10 complete breaths counting ‘1’ as the cow inspires and ‘and’ as the cow expires

2. Get the rhythm first by counting ‘1 and’ ‘1 and’ ‘1 and’… then start the timer before the next ‘1 and’ and count all the way to ‘10 and’ and stop the timer

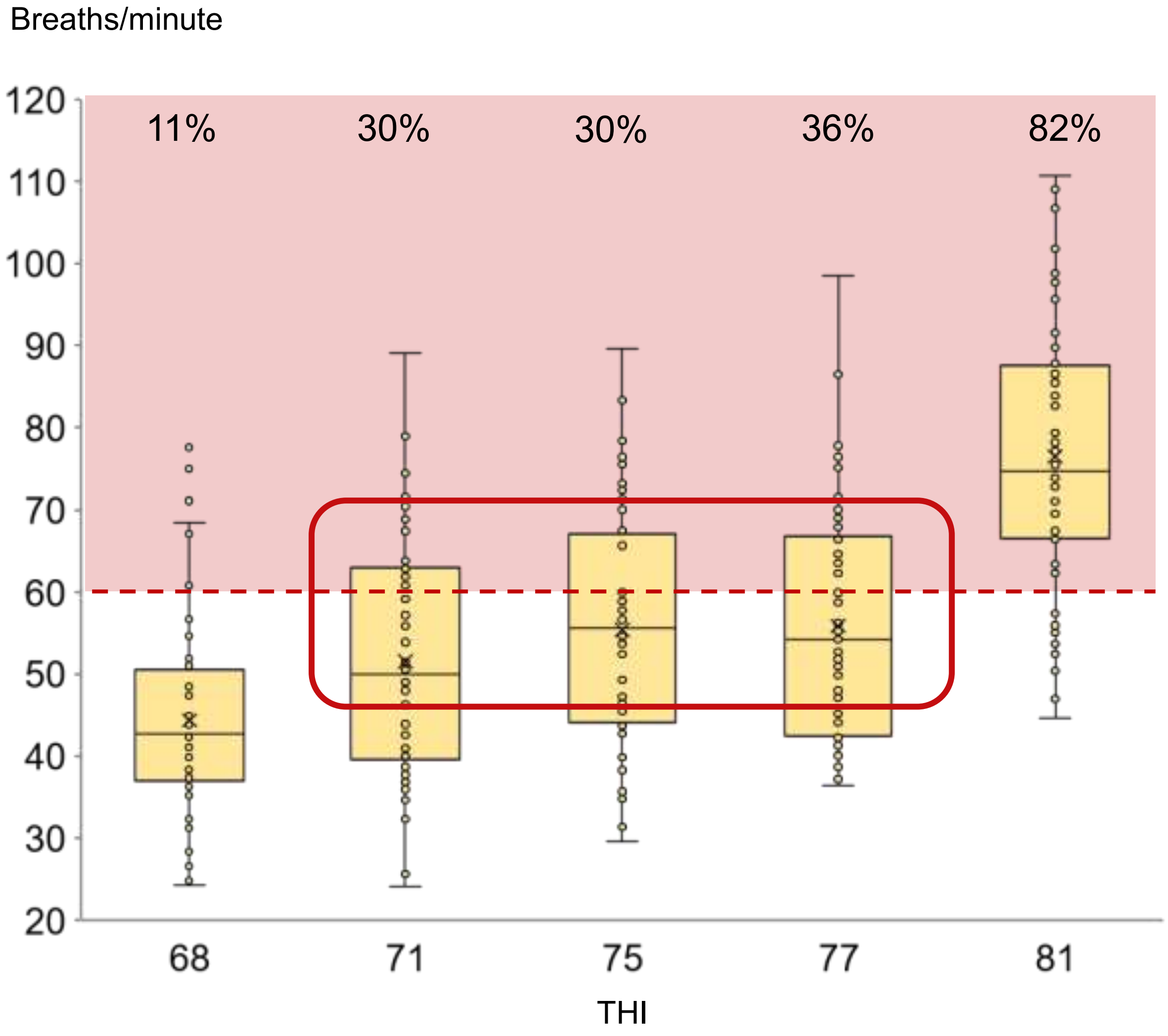
3. Divide 600 by the number of seconds that it took to record 10 complete breaths = breaths per minute

e.g. 10 seconds to take 10 breaths = 600/10 = 60 breaths per minute,
so if it takes 10 seconds or less to record 10 breaths = >60!

Watch the following video: https://youtu.be/rtKJk6EFxNA

Slide provided by Dr. Jennifer Van Os

How many cows ≥ 60 breaths/minute?



The top quartile tells a different story than the average. From an **animal welfare** perspective, intervening earlier is better.

Target <25% of cows **≥ 60 breaths/minute**

da Silva, Cook, Van Os et al. (in preparation); see also Chen (Van Os) et al. (2016); Atkins et al. (2018)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Thank you!