UNIMORE
UNIVERSITÀ DEGLI STUDI DI MODENA E REGGIO EMILIA

Dipartimento di Ingegneria
“Enzo Ferrari”

# The human as a reference for assessment of livestock thermal comfort

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Heat stress and other common features of Precision Livestock Farming
*Discussion between Israeli and Italian Experts*

# Comfort (of humans)

Comfort, or well-being, is the particular psychological condition of satisfaction perceived by individuals.

It is given by multiple contributions, each one requiring specific control actions.

| | |
|---|---|
| Visual comfort | *Lighting control* |
| Acoustic comfort | *Noise control* |
| **Respiratory-olfactory comfort** | ***Air quality control*** |
| Thermal comfort | *Microclimate control* |

# Thermal comfort and microclimate

Microclimate is the set of physical environmental parameters that characterize the local environment.

In combination with metabolic activity and clothing, it determines heat transfer between bodies of the individuals and environment.

The human organism is "homeothermal", *i.e.* it works optimally in relatively narrow ranges of temperature:

- the internal body temperature is stabilized at 36.6 ± 0.6°C,
- the surface body temperature, which can undergo larger fluctuations, is stabilized at 36.6 ± 5°C.

Even modest deviations from such ranges, generally influenced by the microclimate, result in thermal discomfort.

Significant deviations lead to thermal stress.

# Body heat transfer and comfort

Thermal comfort is guaranteed when there is a balance between internal production of thermal energy (*i.e.* the metabolic heat resulting from the physical activity) and net heat transfer between body and environment.

Energy balance equation for the human body:

$$S = M - L - K - C - R - E - C_{res} - E_{res}$$

$S$ heat rate gained or lost by the body

If $S = 0 \Rightarrow$ thermal comfort (homeothermy)

If $S > 0 \Rightarrow$ warm sensation

If $S < 0 \Rightarrow$ cold feeling

# Body heat transfer and comfort

Energy balance equation for the human body:

$$S = M - L - K - C - R - E - C_{res} - E_{res}$$

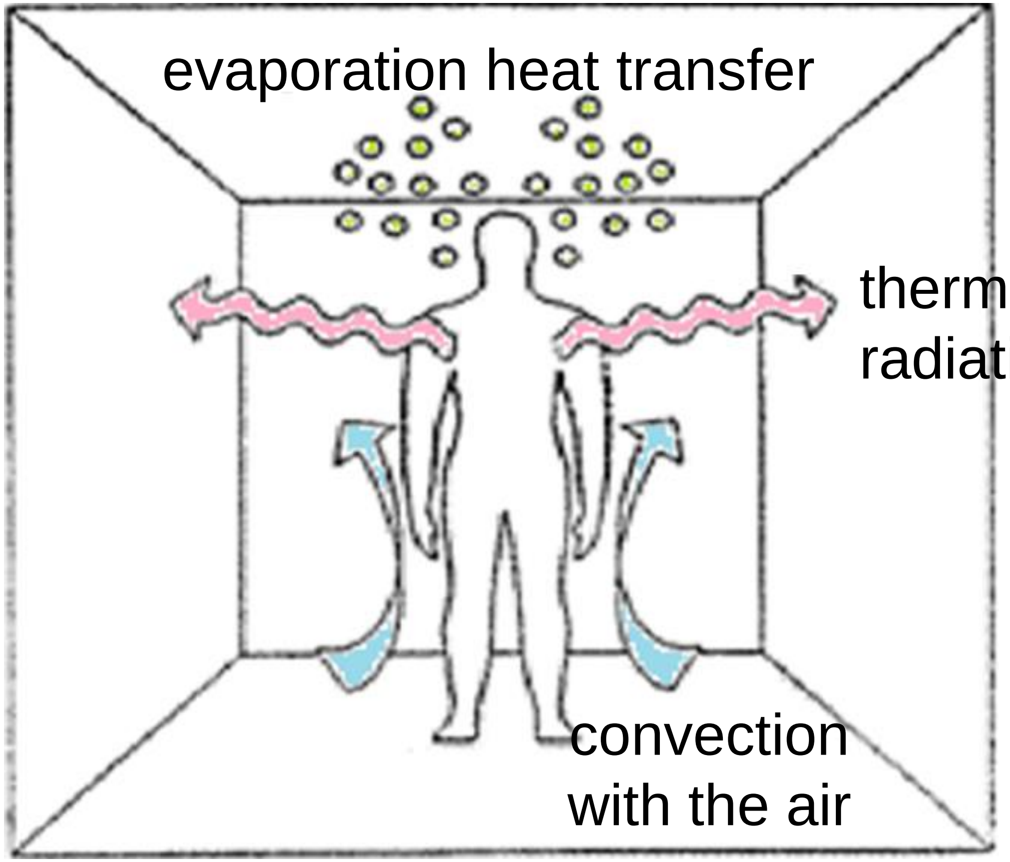
| | |
|---|---|
| $S$ | heat rate gained (*i.e.* stored, positive quantity) or lost (negative quantity) by the body |
| $M$ | metabolic heat (W) |
| $L$ | mechanical power developed by the body (W) |
| $K$ | heat rate exchanged by conduction (W) (*) |
| $C$ | heat rate exchanged by convection (W) (*) |
| $R$ | heat rate exchanged by radiation (W) (*) |
| $E$ | heat rate lost by evaporation (sweating & perspiration) (W) (*) |
| $C_{res}$ | heat rate lost for convection in breathing (W) (*) |
| $E_{res}$ | heat rate lost for evaporation in breathing (W) (*) |

(*) positive amount for net loss of energy

# Body heat transfer and comfort

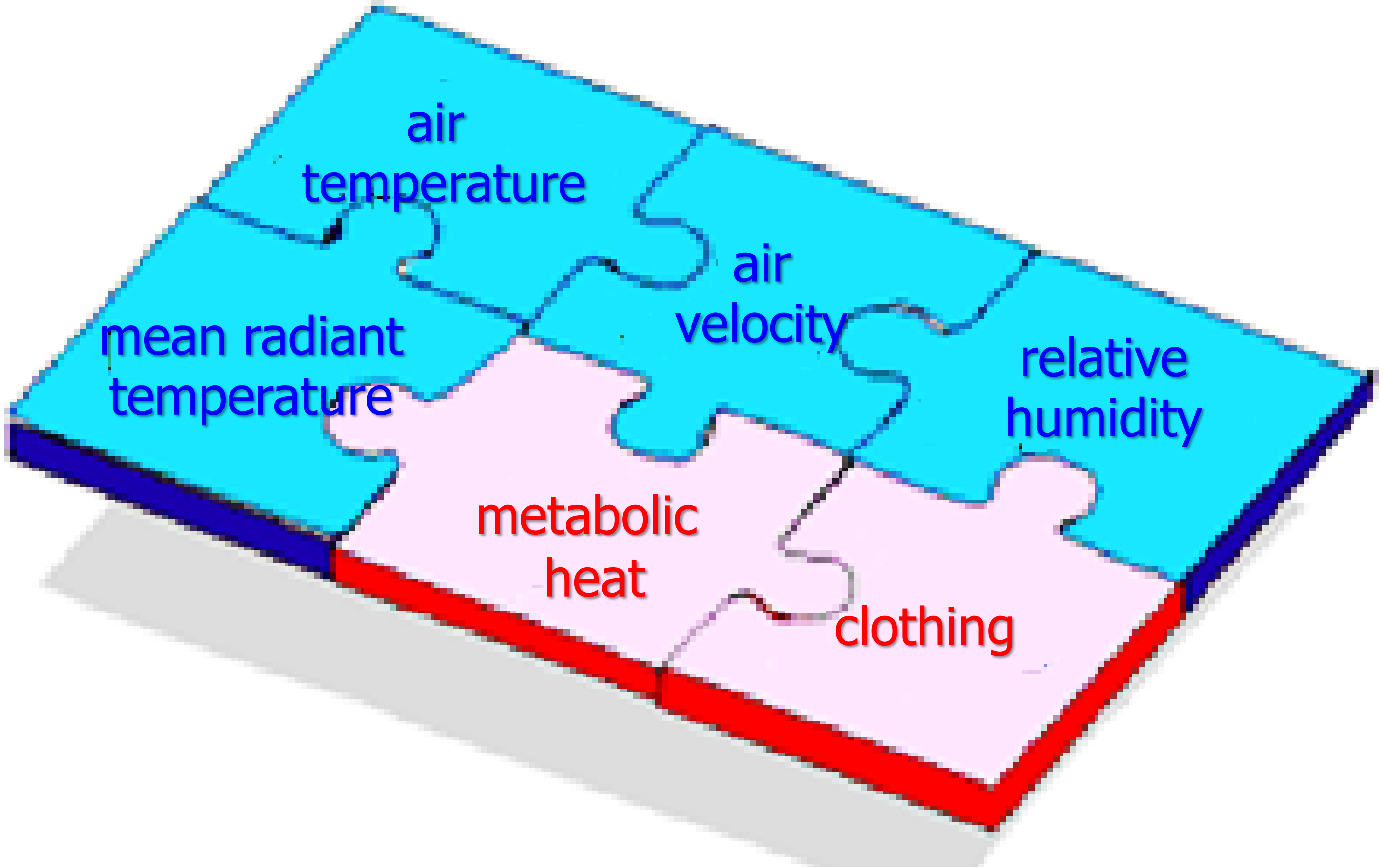
Energy balance equation for the human body:

$$S = M - L - K - C - R - E - C_{res} - E_{res}$$



# Thermal comfort and microclimate

In has been found that the deviation of the net heat balance of the human body from thermal neutrality ($S$) is a complex function of 6 environmental and individual parameters:



# Thermal comfort and microclimate

In has been found that the deviation of the net heat balance of the human body from thermal neutrality ($S$) is a complex function of 6 environmental and individual parameters:

$$S = S\,(T_a, T_{mr}, w_a, RH, M, I_{cl})$$

where

| | |
|---|---|
| $T_a$ | air temperature |
| $T_{mr}$ | mean radiant temperature |
| $w_a$ | air velocity |
| $RH$ | relative humidity |
| $M$ | metabolism |
| $I_{cl}$ | clothing thermal resistance |

# PMV index of global thermal comfort

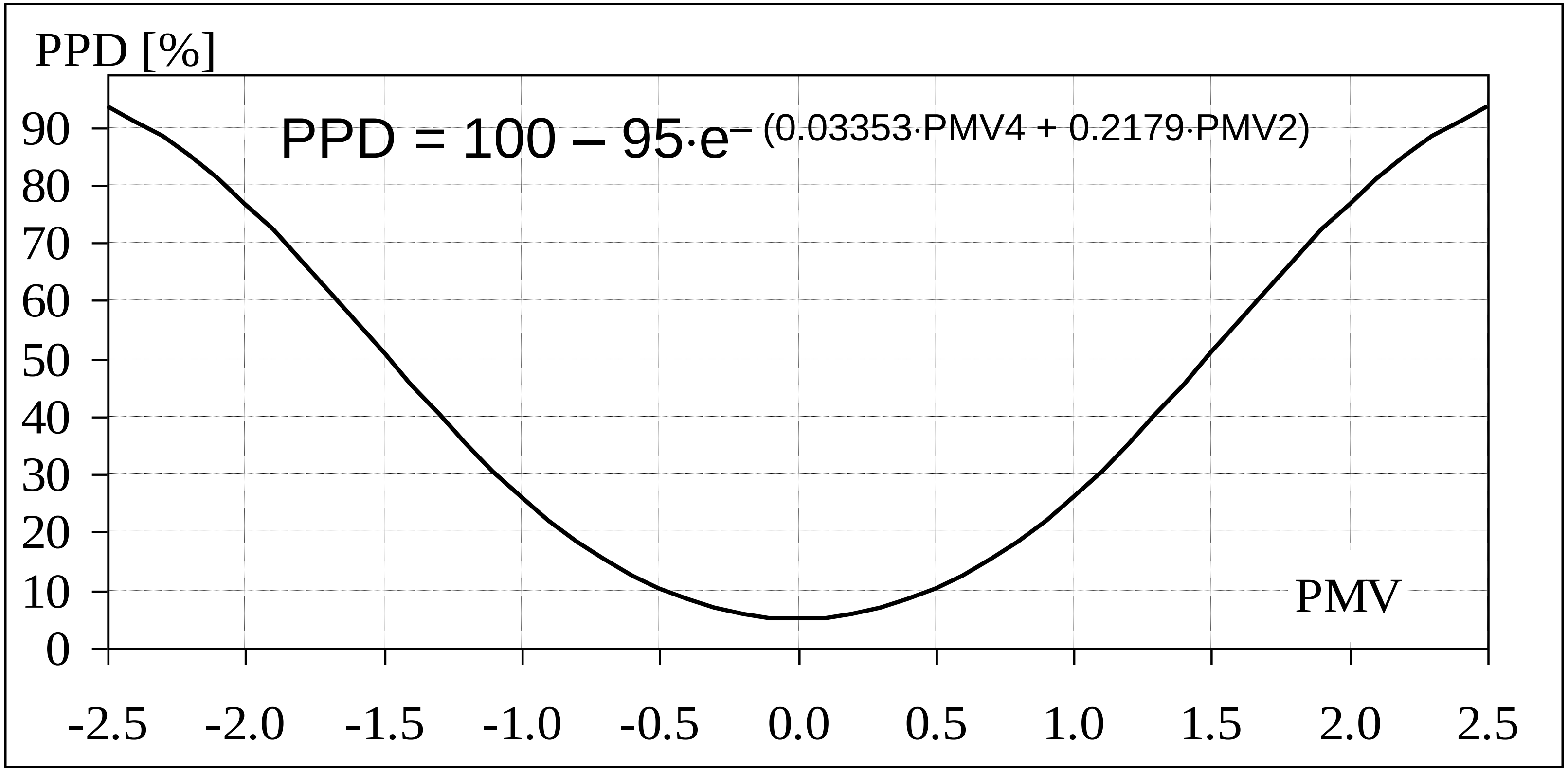
The PMV index (predicted mean vote) has been developed to predict the thermal sensation for the body as a whole on a 7-point thermal sensation scale, obtained interviewing large groups of people exposed to the same environment:

$$PMV = PMV\,(T_a,\ T_{mr},\ w_a,\ RH,\ M,\ I_{cl})$$

+ 3 very hot
+ 2 hot
+ 1 slightly warm
0 neutral
– 1 slightly cold
– 2 cold
– 3 very cold

# PPD index of global (dis)comfort

The PPD index (predicted percentage of dissatisfied) is related to the PMV index ad provides a quantitative forecast of the percentage of people dissatisfied from the thermal point of view.




cold | slightly cold | neutral | slightly hot | hot

# Indexes of global thermal comfort

(EN ISO 7730)

$$PPD = 100 - 95 \cdot e^{-(0.03353 \cdot PMV^4 + 0.2179 \cdot PMV^2)}$$

$$PMV = (0.303 \cdot e^{-0.036 \cdot M} + 0.028) \cdot$$
$$\cdot \{ (M - L) - 3.05 \cdot 10^{-3} \cdot [5733 - 6.99 \cdot (M - L) - p_v] -$$
$$- 0.42 \cdot [(M - L) - 58.15] - 1.7 \cdot 10^{-5} \cdot M \cdot (5867 - p_v) -$$
$$- 0.0014 \times M \times (34 - T_a) - 3.96 \cdot 10^{-8} \cdot f_{cl} \cdot [(T_{cl} + 273)^4 -$$
$$- (T_{mr} + 273)^4] - f_{cl} \cdot h_c \cdot (T_{cl} - T_a) \}$$

$$RH = p_v / p_{sat}(T_a)$$

$$T_{cl} = 35.7 - 0.28 \cdot (M - L) - I_{cl} \cdot$$
$$\cdot \{ - 3.96 \cdot 10^{-8} \cdot f_{cl} \cdot [(T_{cl} + 273)^4 - (T_{mr} + 273)^4] - f_{cl} \cdot h_c \cdot (T_{cl} - T_a) \}$$

$h_c = 2.38 \cdot (T_{cl} - T_a)^{0.25}$ per $2.38 \cdot (T_{cl} - T_a)^{0.25} > 12.1 \cdot \sqrt{w_a}$

$\quad\; 12.1 \cdot \sqrt{w_a}$ per $2.38 \cdot (T_{cl} - T_a)^{0.25} < 12.1 \cdot \sqrt{w_a}$

$f_{cl} = 1.00 + 1.290 \cdot I_{cl}$ per $I_{cl} < 0.078\ m^2\,°C/W$ (< 0.5 clo)

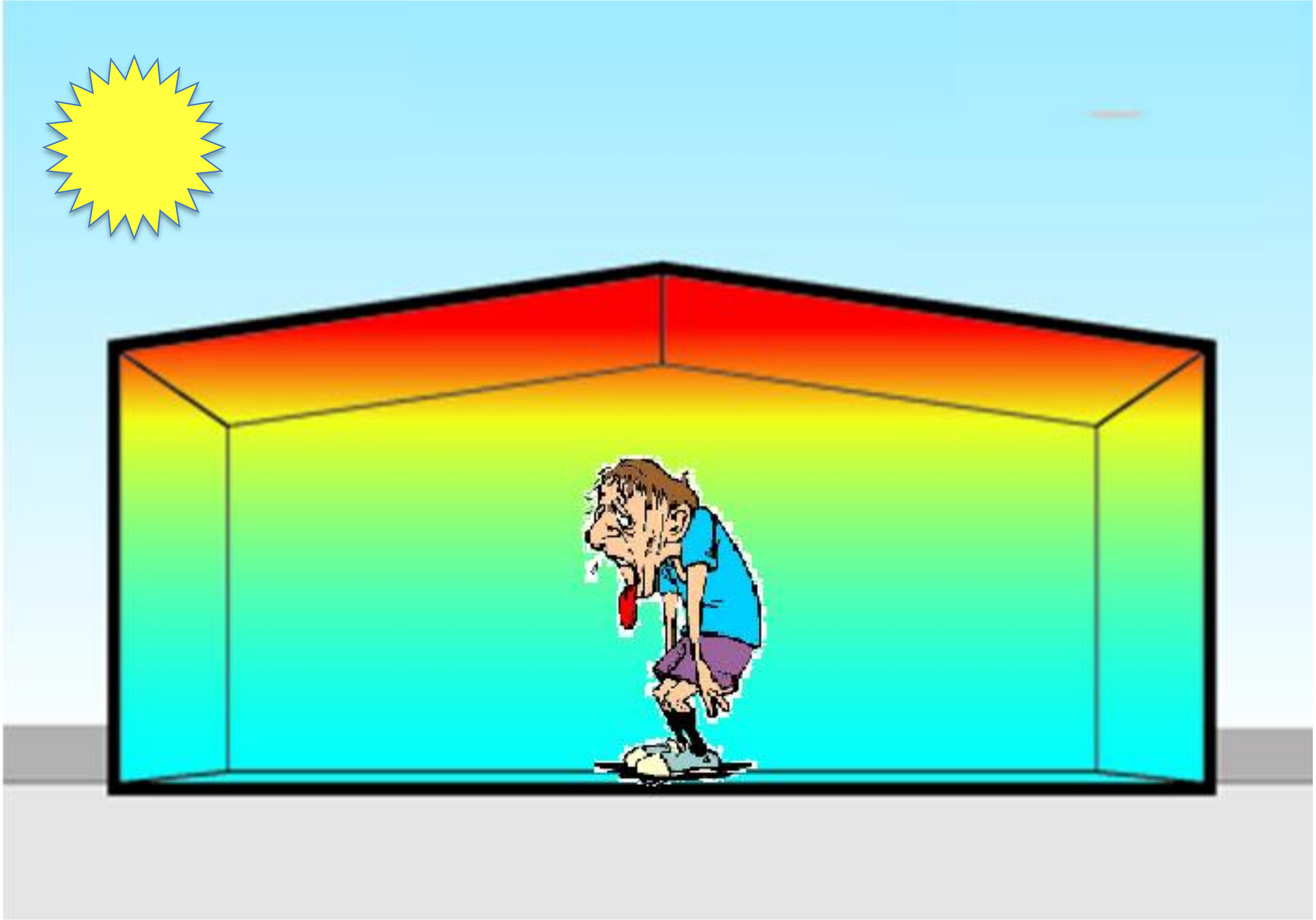
$\quad\; 1.05 + 0.645 \cdot I_{cl}$ per $I_{cl} > 0.078\ m^2\,°C/W$ (> 0.5 clo)

# Local thermal (dis)comfort

There are numerous factors of local discomfort, related to inhomogeneous heating or cooling of portions of the body surface. Each of these factors can be associated with a specific index of local comfort.

- air flow ⇒ Draught rate (DR)
- vertical gradients of air temperature ⇒ percentage of dissatisfied (PD)
- too cold or too hot floor ⇒ percentage of dissatisfied (PD)
- radiant asymmetry (too cold or too hot ceiling/wall) ⇒ percentage of dissatisfied (PD)

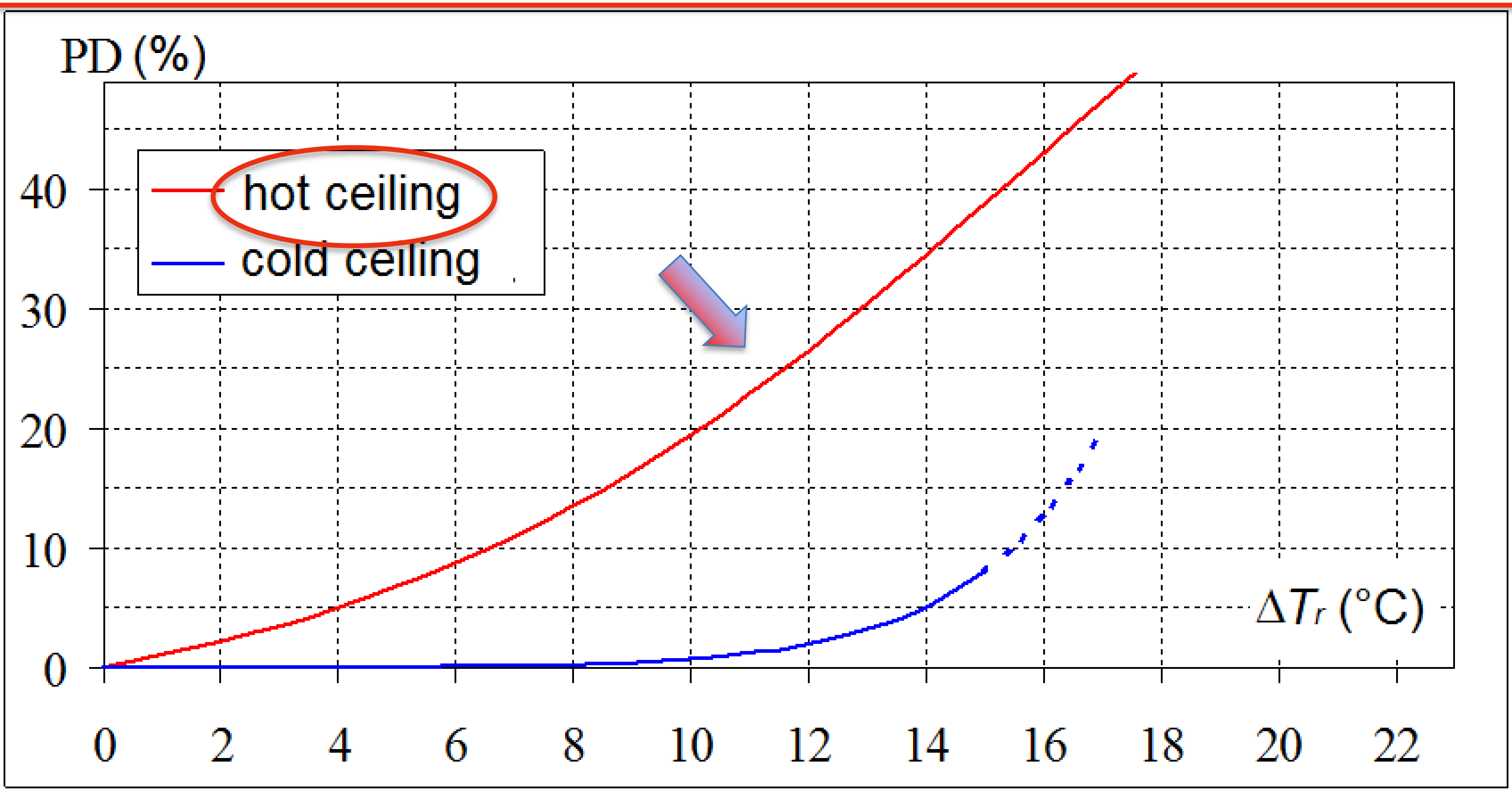
# Example: the 'hot head' effect



# Vertical radiant asymmetry (ceiling)

$$PD = 100 / [1 + \exp(2.84 - 0.174 \cdot \Delta T_r)] - 5.5 \quad \text{(hot ceiling)}$$

$$PD = 100 / [1 + \exp(9.93 - 0.50 \cdot \Delta T_r)] \quad \text{(cold ceiling)}$$




$\Delta T_r$ is acceptable if PD<5% (*i.e.* dissatisfied below 5%).

# Comfortable environment

Overall, an environment can be considered comfortable, with $PPD_{global} < 20\%$, if a set of limits are respected on several indexes (EN ISO 7730):

- $-0.5 < PMV < +0.5$ $\Rightarrow$ $PPD < 10\%$
- Air velocity: $\Rightarrow$ $DR < 15\%$
- Vertical gradient of air temperature: $\Delta T_{av} < 3°C$ $\Rightarrow$ $PD < 5\%$
- Floor temperature: $19°C < T_f < 26°C$ $\Rightarrow$ $PD < 10\%$
- Radiant asymmetry:
  - vertical (ceiling): $\Delta T_r < 10°C$
  - horizontal (walls): $\Delta T_r < 5°C$
  
  $\Rightarrow$ $PD < 5\%$

All indexes and limits were assessed interviewing large groups of people over decades!

# Animals are not easy to interview…

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Up to now, simpler (and maybe simplistic) indexes have been developed:

- Temperature Humidity Index (THI)

$$THI = a \cdot T_{db} + b \cdot T_{wb} + c$$

$T_{db}$ dry-bulb (*i.e.* air) temperature
$T_{wb}$ wet bulb temperature (depending on relative humidity)
a,b,c constants depending on animal species

- Black Globe Temperature Humidity Index (BGTHI)

$$BGTHI = a \cdot T_{bg} + b \cdot T_{wb} + c$$

$T_{bg}$ black-globe temperature (including radiative effects)

- Temperature Humidity Velocity Index (THVI)

$$THVI = (a \cdot T_{db} + b \cdot T_{wb}) \cdot v^{-c}$$

v air velocity

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- Temperature Humidity Velocity Index (THVI)

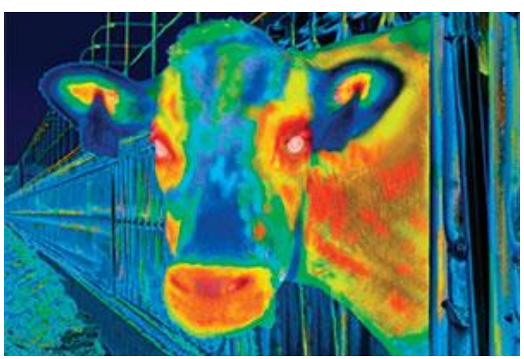
$$THVI = (a \cdot T_{db} + b \cdot T_{wb}) \cdot v^{-c}$$

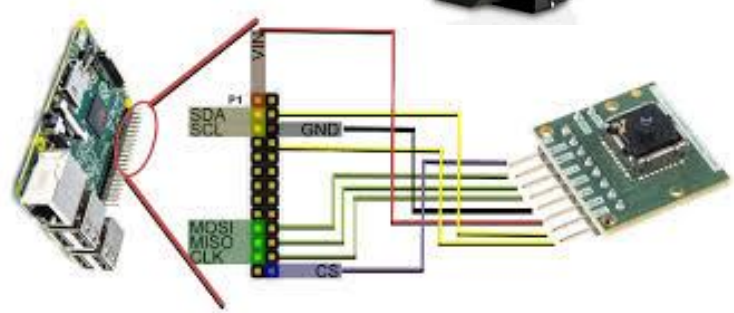
Critical values of THI / BGTHI / THVI / etc. have been identified from rectal temperature or vaginal temperatures, or from growth rate, fecundity, productivity, etc.

However, a poor gain of information is often observed compared to measurement of the mere (dry bulb) air temperature ($T_{db}$).

# Room for improvement? Ample…

- A set of environmental and individual parameters as large as that considered for humans can be taken into account.
- Their impact on comfort, both global (whole body) and local (body portions) can be analyzed.
- The correlation between considered parameters and perceived comfort level can be investigated by artificial intelligence.
- A.I. can be exploited to automatically perform both the acquisition of relevant data (on microclimate, and comfort) and the identification of correlation formulas.



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# THANK YOU
# FOR THE ATTENTION!