The effect of air velocity on heat stress at increased air temperature

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Abstract

Increased air velocity is a frequently used method to reduce heat stress of farm animals housed in warm conditions. The main reason why the method works is that higher air velocity increases the convective heat release from the animals. Convective heat release from the animals is strongly related to the temperature difference between the surfaces of animals and the surrounding air, and this temperature difference declines when the air temperature approaches the animal body temperature. Consequently it can it by expected that the effect of air velocity decreases at increased air temperature. The literature on farm animals in warm conditions includes several thermal indices which incorporate the effect of air velocities. But, surprisingly none of them predicts a decreased influence of air velocity when the air temperature approaches the animal body temperature.

This study reviewed published investigations on different categories of farm animals to determine how the effect of air velocity depends on the air temperature. A new expression to calculate the chilling effect of increased air velocity was suggested. In addition to the parameters air velocity and air temperature this new expression included three constant. Generally usable values for two of these constants were suggested but more work is required to determine how the third constant depends on different conditions including realistic farm conditions.

1. Introduction

Increased air velocity is a frequently used method to reduce heat stress of farm animals housed in warm conditions. The main reason why the method works is that higher air velocity increases the convective heat release from the animals. Convective heat release from the animals is strongly related to the temperature difference between the surfaces of animals and the surrounding air, and this temperature difference declines when the air temperature approaches the animal body temperature. Consequently it must be expected that the effect of air velocity decreases at increased air velocity. The literature on farm animals kept at warm conditions includes several thermal indices which incorporates the effect of air velocitiy. But, surprisingly none of them predicts a decreased influence of air velocity when the air temperature approaches the animal body temperature. The aims of this work were to review published thermal indices that enable estimation of the relative significance of air velocity and temperature and to suggest a better way to include air velocity in a thermal index.

2. Materials and Methods

The review identified 8 indices which enable estimation of the relative significance of air velocity and air temperature. These indices are presented in equation 1-8. The following symbols were used:

- ***t*** ***Air temperature, ºC***
- ***t_{wb}*** ***Vet bulb temperature, ºC***
- ***t_{bg}*** ***Black globe temperature, ºC***
- ***t_{rm}*** ***Mean radiant temperature, ºC***
- ***v*** ***Air velocity, m/s***
- ***RH*** ***Relative Humidity, %***
- ***SR*** ***Solar radiation, Wm^{-2}***
- ***P_v*** ***Partial vapour pressure, kPa***

#1. The Effective Temperature, based on skin temperature and respiration rate for lactating cows exposed to different air temperatures and air velocities (Yamamoto et al., 1989) =

$$t - 10(v^{0.5})$$

.

#2. The equivalent temperature index, based on a combination of the heat storage in the body and the decline in milk production rate for dairy cows (Baeta, et al. 1989) =

$$27.88 - 0.456t + 0.010754t^2 - 0.4905RH + 0.00088RH^2 + 1.15v - 0.12644v^2 + 0.019876tRH - 0.046313tv$$

#3. The temperature, Humidity, Velocity Index, based on body temperature increase for short time exposure market size broilers to 18 combinations of temperature, dew point temperature and velocity (Tao & Xin, 2003).=

$$(0.85t + 0.15t_{wb})v^{-0.058}$$

#4. Respiration rate, determined from shaded and non-shaded feedlot cattle (Eigenberg et al., 2005). =

$$5.1t + 0.58RH - 1.7v + 0.0039SR - 105.7$$

.

#5. Adjusted THI for feed lot cattle, determined from feedlot performance of cattle (Mader et al., 2006).

$$4.51 - ((0.8t + RH(t - 14.4)) + 46.4) - 1.992v - 0.0086SR$$

.

#6. A comprehensive index for assessing environmental stress in animals, based on different physiological response in dairy cattle in yards with no solar shade (Mader et al., 2010)=

$$t + f(RH,t) + f(v) + f(SR,t)$$

where:

$$f(RH,t) = e^{(0.00182RH + 0.000018t - 0.0246)} \cdot (0.000054t^2 + 0.00192t - 0.0246)(RH-30),$$

$$f(v) = \frac{-6.56}{e^{\frac{1}{(2.26v+0.23)^{0.45(2.9+0.000001.4v^{2.5} - log_{0.3}(2.26v+0.33)^{-2})}}}} - 0.00566v^2 + 3.33, \text{ and}$$

$$f(SR,t) = 0.0076SR - 0.000002SR \cdot t + 0.00005\ t^2\sqrt{SR} + 0.1t - 2$$

#7. Index of thermal stress for cows, based on different physiological response in dairy cattle in yards with no solar shade (Da Silva et al., 2015) =

$$77.1747 + 4.8327t - 34.8189v + 1.111v^2 + 118.6981P_v - 14.7956P_v^2 + f(t_{rm})$$

#**8. Heat Load Index,** based on panting of feedlot cattle Gaughan et al. 2004).=

$$8.62 - 0.38RH - 1.55t_{bg} - 0.5u + e^{2.4-u} \quad (t_{bg} > 25)$$

$$10.66 - 0.28RH + 1.3t_{bg} - 0.5u \quad (t_{bg} < 25$$

The term "chill effect of increased air velocity" was used to compare how the different equations estimate the relative significance of air velocity and air temperature. This chill effect expresses an equivalent air temperature effect obtained by increasing air velocity, and consequently the unit is ºC. A relative humidity of 50 % was assumed in order to include the equation that considered humidity in the comparison. To include the equations that considered radiation it was assumed that the change of the air velocity did not affect the radiation. To include equation 8 in the comparison it was assumed that the air temperature changed in the same manner as the black globe temperature.

Unfortunately the used data for development of the equations is available only in the article for equations 3 (Tao and Xin, 2003). Therefore literature where reviewed for additional datasets that could be used to develop an equation that predicts a reduced effect of increased velocity when the air temperature approaches the animal body temperature. The review led to data on skin temperature in laying hens (Uwagawa, 1980) and data on sensible heat loss from two pigs in each of three different weight ranches (Mount and Ingram,1965).

3. Results and Discussion

The chill effect of increasing the air velocity from 1.0 to 2.0 m/s was estimated by the 8 equation and shown in Figure 1.

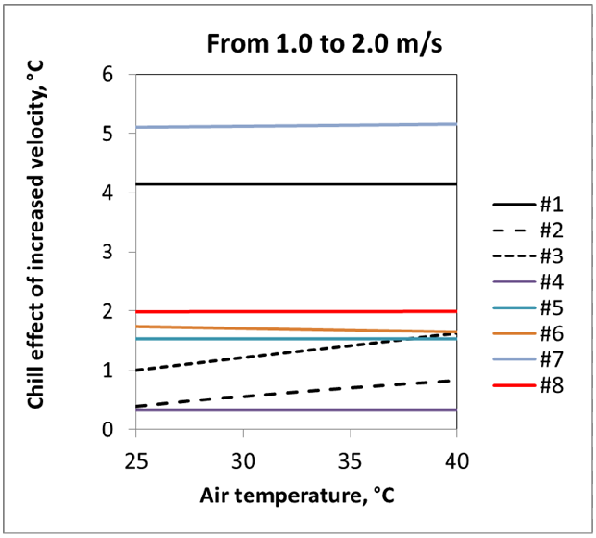

Figure 1. Chill effect of increasing air velocity from 1.0 to 2.0 m/s at increased air temperature estimated by equation 1 to 8.

It appears that the estimated chill effects are widely different between the included equations and that none of equations estimates a reduced chill effect when the air temperature approaches the animal body temperature.

Figure 2 illustrates how the 8 equation estimates the chill effect of increased air velocity at air temperature of 30 ºC when the air velocity increase from 0.2 to up to 5 m/s. All the presented curves can with good approximation be described as a power law of air velocity ($a \cdot v^b$) where the power law exponent (*b*) differ from 0.02 in equation 3 to 1.1 in equation 2.

Equation 9 illustrates a relationship where an Effective Temperature (ET) is calculated as the air temperature plus a term that adjust for humidity and minus a term that adjust for velocities above 0.2 m/s.

$$ET = t + f(RH, t) - c(d - t)(v^e - 0.2^e) \quad (9)$$

Where e corresponds to the power law exponent mentioned above,
d is the temperature where increased air velocity no longer provides any chill effect, and
c is a constant that determines the relative significance of air velocity.

An initial attempt to determine the constants from the available data gave following results

- d values between 40 to 44 reflected the data best,
- e=1.0 reflected in some cases data better than e=0.5, and in other cases it was opposite, and
- used values of d and e has significant influence on which c value that reflected data best.

Based on these results the following comparison of the available data were conducted by calculating which value of c that reflects data best when the two other constant were held constant at d=42 and c=0.7, and the results is presented I figure 3.

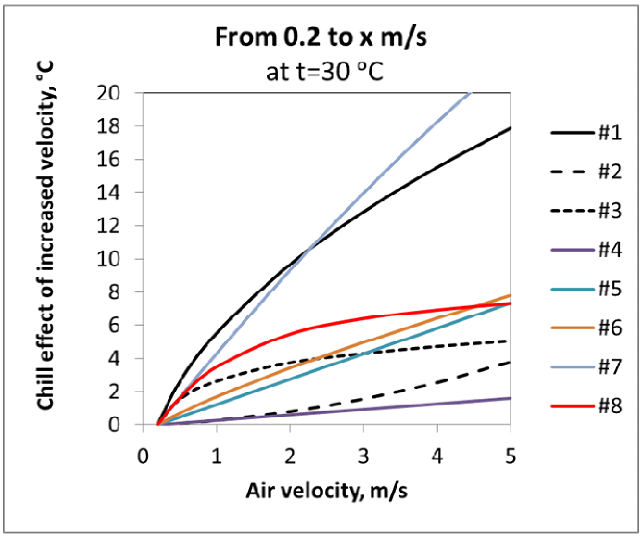

Figure 2. Chill effect of increasing air velocity from 0.2 to up to 5.0 m/s at air temperature of 30 ºC estimated by equation 1 to 8.

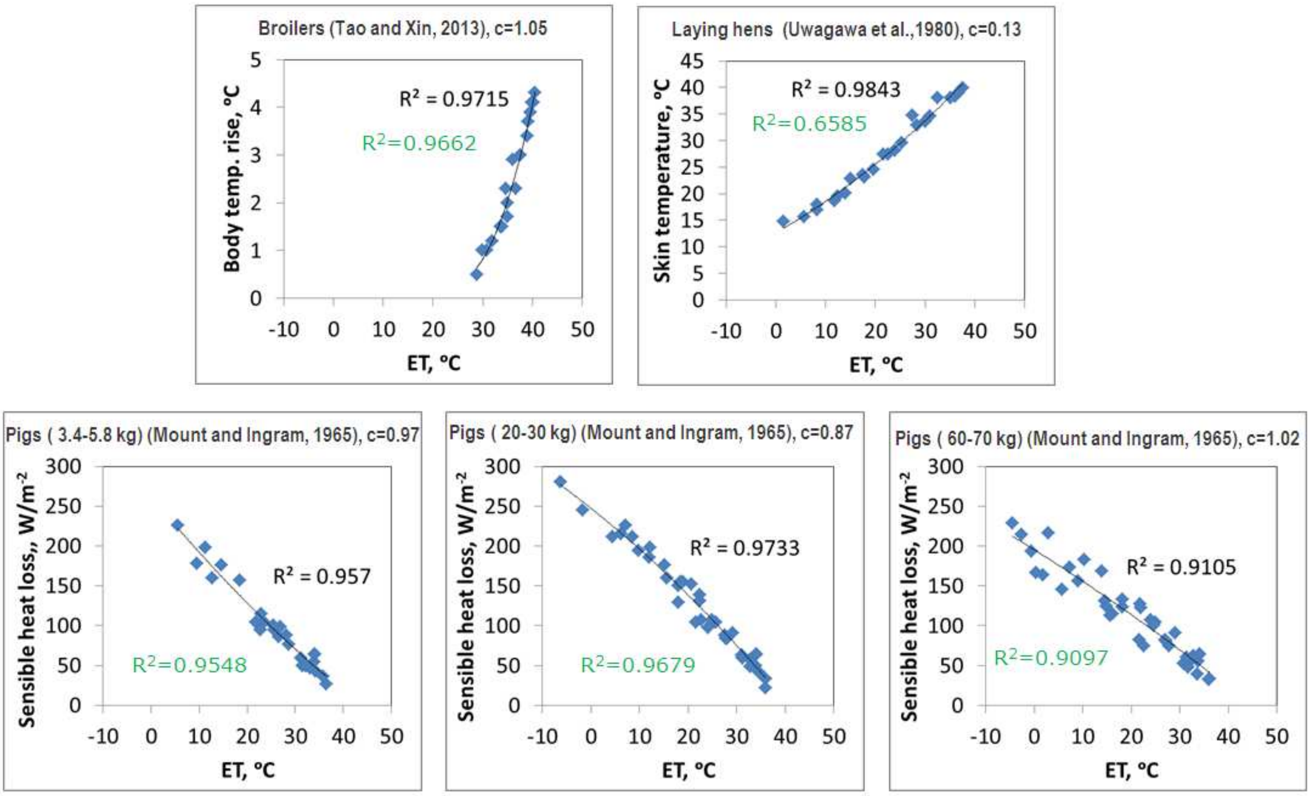

Figure 3. Correlations between data and ET calculated by equation 9 assuming d=42, e=0.7 and the c equal the value that best reflected the data. These c-values are mentioned in the heading of each graph and the corresponding coefficients of determination are printed in black. Green text shows the coefficients of determination if the c-value was set to 1.00.

The five graphs in figure 3 shows generally very good correlations between data and ET and the coefficient of determination were in all cases above 0.91 if d=42 and e=0.7 were assumed. In addition it appears that a value of c near 1.0 reflected data best in the four of the five graphs and that it did not in these cases significantly degraded the coefficient of determination if a c-value of 1.0 where used. The data on skin temperature in laying hens differed by that a significant lower value of c reflected data best. The results indicates that d values around 42 and e values around 0.7 may be generally usable, but that it is likely that the c-value depends significantly on conditions as animal species, animal size, production level, group sizes, the length of the periods the animals are exposed to heat stress and on the methods used to determine the air velocity.

4. Conclusions

Eight published thermal indices to assess heat stress in production animals were reviewed and none of them did consider that the effect of increased air velocity should decrease at increased air temperature. A new expression to calculate the chilling effect of increased air velocity was suggested. It included the parameters air velocity and air temperature, and three constants. Generally usable values for two of these constants were suggested but more work is required to determine how the third constant depends on different conditions including realistic farm conditions.

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