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# Smart Indoor Climate Control in Precision Livestock Farming

**Guoqiang Zhang [a,*], Bjarne Bjerg [b], Xiaoshuai Wang [a]**

[a] Department of Engineering, Aarhus University, Aarhus, Denmark

[b] Production Animal Science, University of Copenhagen, Copenhagen, Denmark

* Corresponding author. Email: guoqiang.zhang@eng.au.dk

**Abstract**

One of the major objectives of precision livestock farming (PLF) is to provide an optimal thermal climate control in the animal occupant zones for promoting animal production and wellbeing. To achieve this goal, smart climate models that reflect the needs of different animal species and ages or feasible sensor techniques that can measure animal felt thermal environment are essential. Ideally, such a model should be able to integrate the effects of air temperature, humidity, air speed (including turbulence) and thermal radiation on animal thermal comfort/wellbeing, and consequently, animal productions. In this paper, models defined as effective/equivalent felt temperature for different farm animals are introduced and discussed. Using such a felt temperature would be valuable for control of ventilation, cooling facilities, and air speed in animal occupant zone (AOZ) to achieve desired thermal condition in AOZ. In addition, the paper presents a fundamental principle of development of an integrated indoor climate sensor to reflect animal thermal wellbeing and techniques that could be used for a smart system design and control are discussed.

**Keywords:** Thermal index; farming animals; climate control; effective temperature; convection; radiation

## 1. Introduction

In conventional indoor climate control of farming animal housing, it is common to use indoor air temperature at a chosen location as a reference for system regulating of ventilation, heating or cooling facilities or units. A major disadvantage of such a reference is that it ignores the possible effects via force convection, evaporation or thermal radiation between the animals and the surroundings. Those effects could be very important for both monitoring and control of the thermal condition in animal occupant zone to ensure it is remained within the thermal neutral levels for the animals. However, the information and knowledge of the integrated effects due to the varied air speed and thermal radiation together with air temperature and humidity is not directly available in literature.

The objective of this paper is to establish a concept of such an integrated thermal index model and introduce a form of such a model based on literature review and theoretical analysis.

## 2. Model concept & developments

For a given weight/age of housing animal, the heat loss is determined by a combination of air temperature, air humidity, air speed and thermal radiation. The effects of air speed is important for ventilation system design and control, since it is linked directly with airflow rate and airflow patterns in the ventilated room space. A model that can directly describe the effects of the air speed in around animals on the effective temperature that animal may responds could provide fundamental knowledge for smart design and control of ventilation for an optimal thermal condition for animals in houses.

In farming animal production, a temperature-humidity index (THI) is often used for expressing the combined effect of air temperature and air humidity, where a dry bulb and a wet bulb temperature were used in calculation:

$$THI = at_{db} + (1 - a)t_{wb} \tag{1}$$

where $a$ = weighting of dry-bulb temperature.

$t_{db}$ = dry-bulb temperature, ℃;

$t_{wb}$ = wet-bulb temperature, ℃

In the proposed model, the integration term of the thermal effects of varied climate factors are convert to natural convection effects of the given temperature difference between animal body and the local air in AOZ, effective temperature, ET.

$$ET = at_{db} + (1-a)t_{wb} + f(v)(t_a - t_{db}) + g(t_a - t_r) \quad (2)$$

where

$f$ is function that related to force heat convection: air speed, animal species and ages

$g$ is a function that related to radiation heat loss

$t_a$ is a temperature that related to animal skin surface temperature and evaporation potential in room; it is temperature where increased velocity no longer results in increased heat release, ℃

$t_r$ is radiant surface temperature, ℃

Considering the differences of poultry, pigs and cattle, the modelling of the integrated effect of the aforementioned climate parameters has been recently reported by Bjerg et al (2015) and Wang et al. (2016) based on literature review, analysis of the data available and theoretical consideration.

Based on literature review and data analysis, Bjerg et al. (2015) has developed an ET model for poultry and pigs without considering thermal radiation effects:

$$ET = ET_{v=0.2} - c(d - t_{db})(v^e - 0.2^e) \quad (3)$$

where,

$$ET_{v=0.2} = 0.794t_{db} + 0.25\ t_{wb} + 0.70 \quad (4)$$

and

$c$ is a constant that may depend on animal species, sizes and animal density

$d$ is the temperature where ET no longer can be reduced by increased air velocity, ℃

e is a constant that control the influence of velocity.

Similarly, Wang et al. (2016) has developed an ET model for housed cattle by considering the thermal radiation:

$$ET = ET_{rad=0,v=0.2} + k(v^{0.53} - 0.2^{0.53})(t_a - t_{db}) + j(t_r - t_{db}) \quad (5)$$

where

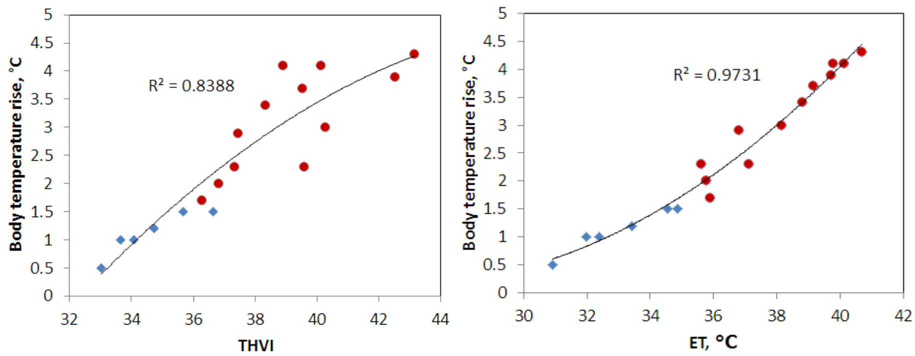
$k$ is a constant that is dependent of animal sizes and animal density

$t_a$ is a temperature that related to animal skin surface temperature and evaporation potential in room; it is temperature where increased velocity no longer results in increased heat release, ℃

$t_r$ is the average radiant temperature of surroundings, ℃

## 3. Feasibility and application of the Model

Bjerg et al. (2015) found that using ET give better description on bird body temperature rising in hot environments by using the data used of Tao and Xin (2003) comparing a THVI, a temperature, humidity and velocity index, defined by Tao and Xin (2003).

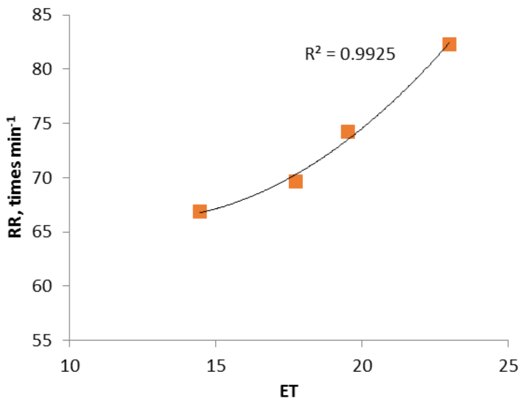



(a) (b)

Figure 1. Comparison of measured and predicted body temperature rise for broilers exposed to 18 different combinations of dry-bulb temperature, dew point temperature and air velocity as function of (a) THVI ($THVI = (0.85t_{db} + 0.15t_{wb})v^{-0.058}$ $(0.2 \leq v \geq 1.2)$) and (b) ET (in Equ. (3), with c = 0.7, d = 43 ℃ and e=0.5**).**

Wang et al. (2016) showed that using ET instead of THI (adjusted) (Medor et al., 2006) can better describe animal bio-responds in hot climate conditions and defined ET as $ET_{hc}$. Following is the example of reparation rates of cows versus $ET_{hc}$ or THI.

Figure 2 shows the ET model is better than the Adjust THI model, however only little data was available to be used. The suitability and accuracy of ET need be verified with more data.



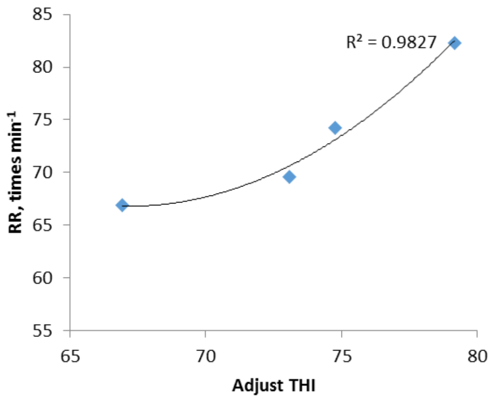



Figure 2. The comparison of the respiration rate (RR) in the $ET_{hc}$ model and adjust THI model; symbols in figure, experimental data was by Yamamota et al (1994); −, trend line of regression

Advantage of using ET model to estimate the thermal environment directly effect on animal in houses is that it can provide a direct measure of how the animals is expected to perceive the climate. Such a measure can be used to regulating the ventilation and cooling system for further proper action to bring the climate within / close to the thermal neutral zone for the animals.

## 4. Conclusions

The dependence of velocity is treated as an additional term in the suggested ET equation. This term is assumed to be proportional to the difference between animal body temperature and the room air temperature, and reported data were analysed to determine whether a linear or a square root relationship with velocity best reflected the data.

Published data has been selected to improve and validate ET. A better correlation was observed comparing with other heat stress indices based on the limited available published data. The ET need to be further improved with further experimental data from both laboratory or field measurement.

The data from studies on animals in groups is less clear, but indicated that the wind shading among the animals reduces effect of air velocity.

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