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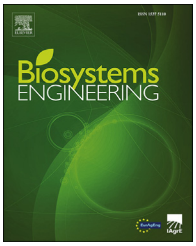

Research Paper

Optimising the design of confined laying hen house insulation requirements in cold climates without using supplementary heat

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Supplementary heat is required when birds do not produce enough heat to maintain adequate air temperature in confined poultry houses in cold climates, and this consists of the largest proportion of building energy consumption. Thus, it is becoming increasingly apparent that the poultry houses need more insulation to retain heat in cold climates. With a well-insulated structure, the thermoneutral temperature can generally be maintained using sensible heat from the birds. Here, the effects of stocking density, indoor temperature set-point, and ceiling insulation level on ventilation rate, balance temperature, and thermal resistance were described, based on the fundamental heat balance equations for livestock buildings using models. Results illustrated that ventilation rate was influenced by stocking density, and it reduced less than 7.1% when increasing stocking density from 133% to 166% at the outdoor temperature of <-35 °C. The effect of increased stocking density on ventilation rate was greatest when stocking density changed from 33% to 66%. Ventilation rate was not appreciably affected by the indoor temperature set point while the outdoor temperature was <-12.5 °C. Every 1 °C increase in the indoor temperature set point led to a 1.5 °C reduction in balance temperature. Increasing the roof insulation from 110 to 400 mm reduced the balance temperature by 1 °C. The model was validated with measured indoor air temperature in two commercial poultry houses located in the North and Northeast China. The difference between the predicted and measured indoor temperature was found to be less than 5%.

1. Introduction

The basic requirement of a poultry house is to provide and maintain a comfortable environment for hens (Reece & Lott, 1982). Environmental parameters such as air temperature, relative humidity, and air quality are essential to ensure the hen's well-being, maximum productivity and efficient feed utilisation (Dawkins, Donnelly, & Jones, 2004; Vits, Weitzenbürger, & Distl, 2005; Kocaman, Esenbuga, Yildiz, &

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Nomenclature

ρ_w	air density, $\rho_w = 353\cdot(t_0+273)^{-1}$, kg m^{-3}
C_p	special heat of air, $C_p = 1.0056$ kJ kg^{-1} °C^{-1}
V	ventilation rate, m^3 h^{-1}
t_o	outside air temperature, °C
t_i	inside air temperature, °C
R_j	thermal resistance of the poultry house outer-building envelope of part j, m^2 K W^{-1}
A_j	surface of building components (wall, ceiling) of part j, m^2
Q_s	sensible heat production of the poultry, W
V_i	poultry house building content, m^3
h_x	heat transfer coefficient of the indoor air and internal wall, feeding equipment in the house, W m^{-2} °C^{-1}
s_x	surface area of the internal wall and feeding equipment inside the poultry house, m^2
t_x	internal thermal mass temperature, °C
Q_t	total heat production of the poultry, W
m	body mass of the bird's, kg
R_W	thermal resistance for walls, m^2 K W^{-1}
R_C	thermal resistance for the ceiling, m^2 K W^{-1}
v	theory minimum ventilation rate, m^3 h^{-1} hen^{-1}
N	stocking density, hen
θ	coefficient factor for orientation
Qv	sensible heat drawn out by the ventilation system, W
Q_w	sensible heat transferred through the building, W
Qe	sensible heat produced by the equipment and manure, W
Q_{sr}	sensible heat from solar radiation, W
ΔQ_i	sensible heat changes of indoor air, W
Q_x	heat storage of indoor equipment (feeding, manure equipment), W
0.278	unit conversion factor 1 kJ h^{-1} = 0.278 W
$R_{o,min}$	minimum thermal resistance, m^2 K W^{-1}
α	temperature difference correction factor
Δt_y	the allowable temperature difference between the indoor temperature and the inner surface temperature of the building envelope, °C
R_n	thermal resistance of the building inner surface envelope, m^2 K W^{-1}
$\Delta t_{y,w}$	the allowable temperature difference between the indoor temperature and the inner surface temperature of the building walls, °C
$\Delta t_{y,R}$	the allowable temperature difference between the indoor temperature and the inner surface temperature of the ceiling, °C
t_1	dew point temperature at indoor temperature and relative humidity, °C
CO_2	carbon dioxide production rate, W kg^{-1}
O_2	oxygen consumption rate, W kg^{-1}
RQ	respiratory quotient of the animals
$[CO_2]_e$	the CO_2 concentration of the exhaust air, ppm
$[CO_2]_o$	the CO_2 concentration of the outside air, ppm
V_t	building ventilation rate for temperature control, m^3 h^{-1} hen^{-1}
Vco_2	building ventilation rate for carbon dioxide control, m^3 h^{-1} hen^{-1}

Lacin, 2006; Xin et al., 2011). Air temperature stability is significantly affected by the thermal insulation performance of the building envelope. Previous research on poultry buildings showed that the room temperatures could be lower than the required and recommended minimum temperature in cold climate or/and in winter (Li, Zhan, Liu, & Chen, 2012). This is usually caused by poor design on the thermal insulation of the building, for example, using inappropriate insulation materials, lower bird stocking density, and higher minimum ventilation rate than suggested in the literature (Esmay, Dixon, & Flegal, 1979; Olgun, Çelik, & Polat, 2007). Otherwise, designs and insulation materials can be used in vastly different climatic regions and no standards comply with the cold climate (Wang, Cao, Wu, Wang, & Zhang, 2011). Consequently, the temperatures of laying hen houses can be lower than required and have large temperature fluctuations. Lower temperatures have been shown not only to reduce the productivity by 5%–10% but also increase the daily feed consumption by 3–5 g for every hen in cold weather (Yu, Li, Shi, & Ma, 1997). Nevertheless, use of thermal insulation in confined laying hen houses has been erratic in both design and construction, and standards are not often complied with in cold climates.

Additional heating system are generally required to provide suitable air temperature conditions in poultry houses when lower bird stocking density and thus lower sensible heat production in the house in cold climate or/and in winter (Zhao, Xin, Shepherd, Hayes, & Stinn, 2013). Berry and Miller (1988) developed a spreadsheet model to describe broiler, building and environmental interactions which confirmed that fuel consumption could be greatly reduced by increasing insulation levels. Reece and Lott (1982) presented general mathematical equations used for the design of broiler houses which described that the climate condition affected the poultry house operation, but the results could neither validate its effectiveness nor give the minimum allowable insulation requirement. Zhao et al. (2013) developed a spreadsheet model to delineate ventilation rate, balance temperature, and supplementary heat in alternative hen housing systems (aviary and enriched colony housing) as compared to the conventional cage system under cold weather conditions. The supplementary heating system would use a large amount of energy and increase the associated carbon emissions, of which, most of the energy comes from non-renewable fossil fuels such as coal, oil, wood and natural gas. However, throughout the world space heating demands make up the largest proportion of building energy consumption and this is a rapidly increasing trend (Papadopoulos & Giama, 2007). The desire to achieve satisfactory performance in poultry house thermal environment and in energy conservation has led to research into passive saving measures and technologies (Yang & Guo, 2016; Yang & Zhang, 2015). Reece and Lott (1982)