Environmental and Management Factors Affecting the Welfare of Chickens on Commercial Farms in the United Kingdom and Denmark Stocked At Five Densities

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ABSTRACT Data from a large commercial-scale experiment in which 10 major broiler producer companies stocked whole houses of birds at 30, 34, 38, 42, and 46 kg/m^2 were analyzed to identify 1) temperature and humidity profiles achieved throughout the growth cycle, 2) management practices and equipment that contributed to observed variation in environmental conditions, and 3) the extent to which environmental variables affected bird welfare. The study involved a total of 2.7 million birds in 114 houses on commercial farms with measurement of a wide range of environmental and bird variables. Much of the variation in broiler health and welfare was associated with the percentage of time a company could maintain house temperature and RH within limits recommended by the breeder company. RH in the first week of life was particularly important to later health, suggesting that better control of humidity might lead to improved welfare. Key management factors affecting bird welfare were those relating to good ventilation and air control such as the type of ventilation, type of drinker, numbers of stockmen, and litter type.

Controlling the environment, particularly temperature, humidity, and air and litter quality, is crucial to broiler chicken welfare. This does not mean that stocking density is unimportant, but lowering stocking density on its own, without regard to the environment the birds experience, is not sufficient. Genuine improvements in bird welfare will come from setting standards that combine stocking density, safeguards on the environment, and the genetic makeup of the birds.

(*Key words*: broiler, environment, welfare, stocking density)

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INTRODUCTION

The European Union is currently considering legislation to limit the maximum stocking density of broiler chickens to 30 kg/m^2. Although a number of welfare measures have been reported to vary with stocking density (Sørensen et al., 2000; Algers and Berg, 2001; Hall, 2001), this is not consistent (e.g., McLean et al., 2002). It is now becoming increasingly clear that, at least under commercial conditions, stocking density may have less effect on welfare than its consequences, such as the deterioration in air and litter quality, unless specific measures are taken (Reiter and Bessei, 2000; Bagshaw and Matthews 2001; Feddes et al., 2002; Heier et al., 2002; Martrenchar et al., 2002; Sanotra et al., 2003 Dawkins et al., 2004). This distinction is of critical importance for the welfare of the birds themselves and for the economic future of the industry. If the problems of high stocking density can be mitigated by buildings with good indoor environmental conditions, any recommendations for limiting stocking density should take this into account (European Commission, 2000).

This conclusion was confirmed by a large, commercial-scale experiment in which 10 major broiler companies were asked to keep whole houses of birds at stocking densities of 30, 34, 38, 42, and 46 kg/m^2 (Dawkins et al., 2004). Differences among different producer companies, particularly in house temperature, humidity, and air ammonia, had more impact on key measures of bird welfare, such as mortality and leg health, than manipulation of stocking density itself. However, it was not clear why some producer companies were more successful than others in managing temperature and humidity even with high stocking densities. Nor was it clear whether temperature and humidity were acting by primarily affecting litter and air quality and, thus, indirectly influencing aspects of bird health such as foot pad dermatitis, lesioned hocks, and poor gait or whether these factors were acting more directly on bird welfare. Because answers to such questions are crucial to making recommendations for improv-

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ing bird welfare, we present here a more detailed analysis of this experiment, using within- and between-company comparisons to suggest which factors are most important. In this study only stocking density was experimentally manipulated, and so any conclusions on other factors were obtained through statistical correlations. However, the data set was sufficiently large (2.7 million birds in 114 houses, all on commercial farms, with a wide range of variables measured) that statistical regression techniques could be used to examine relationships between variables and to provide important pointers for future research. The following questions were addressed:

1. What changes in temperature and RH occur during the growth cycle of broiler chickens on commercial farms and how do these profiles vary between companies?
2. What management practices and equipment are correlated with variation in environmental conditions (temperature, RH, litter moisture, and ammonia)?
3. What impact do these environmental variables have on measures of bird welfare (gait, leg health, pad dermatitis, hock burn, mortality, corticosteroid levels, and growth rate)?

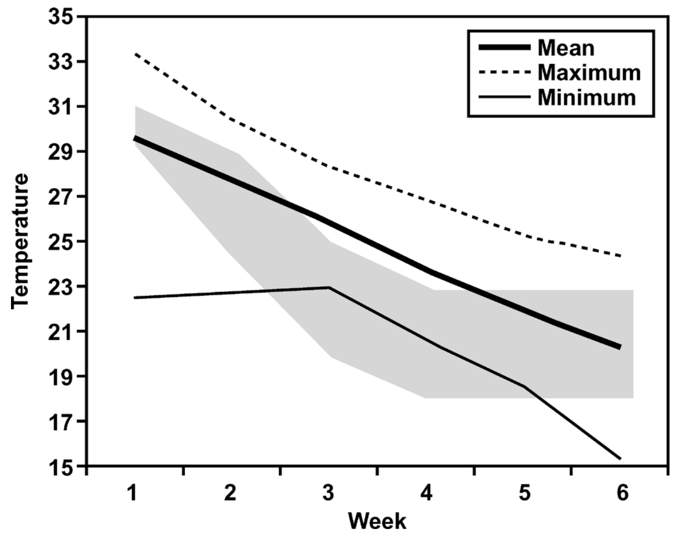

FIGURE 1. Mean, maximum and minimum weekly temperature throughout the growth cycle for the 10 companies participating in the experiment, upper and lower limits recommended by Ross (for 50 to 70% humidity) are defined by the limits of the shaded area.

MATERIALS AND METHODS

Stocking density was experimentally manipulated by each of 10 major commercial broiler producer companies in England, Scotland, Northern Ireland, and Denmark. Target maximum densities of 30, 34, 38, 42, and 46 kg/m^2 were achieved by altering the numbers of chicks placed for a given target slaughter weight. Each stocking density was replicated in at least 2 houses with each company, with random allocation of stocking density to house within a company. With 2 companies, the same 10 houses were used for flocks in the summer and winter months.

Management and husbandry data were recorded for each house. This information included house age; ownership (company or contract grower); size (m^2); orientation (north-south, east-west facing); fabric (wooden with internal struts, steel open span, or brick open span); light pattern (hours of darkness) and source (fluorescent tubes, tungsten, energy savers, or combination); dawn and dusk dimming; percentage of wheat in finishing diet; feeder type (pan or chain) and number or length; drinker type (nipple or nipple with cup) and number; heater type (space, brooder, radiant, or hired hand), number, and position (opposite ends of house, midway in the house, evenly throughout the house, or down the center of the house); ventilation control (manual or automatic); ventilation system (natural ventilation via side inlets and roof outlet, forced ventilation with side inlets and roof or side wall extraction fans, or drop down ventilation with roof inlet and side wall outlet fans); misting systems; floor and litter type (woodshavings, straw, or mix of both); number of stockpersons on farm and number of daily visits made per house to inspect the stock; vaccination program; feed withdrawal; and thinning or clearance program.

Prior to chick placement, data loggers[2] were installed at 4 predetermined, randomized points in each house at a height of 60 cm. These measured temperature and humidity at hourly intervals throughout the growth cycle of the flock. Temperature and humidity data were subsequently averaged by week and compared against a recommended profile taken from the Ross Breeders Ltd. Manual (Aviagen, 1999), which lists the dry bulb temperatures required to achieve target apparent equivalent temperatures at varying humidities. Limits on recommended RH were set at 50 to 70%, with recommended temperature decreasing over the growth cycle (see Figure 1). The proportion of hourly readings above and below the recommended limits was then calculated to indicate how well companies were controlling house environment.

At the time of chick placement we recorded the breed, sex (male, female, or as hatched), and age of parent flock. The number of chicks placed was audited by counting the number of trays and the number of chicks in at least 5 trays per house. At close to maximum stocking density as possible (at average age of 35 d and weight of 1.78 kg, house range 1.49 to 2.27 kg), in-house readings of air ammonia[3] and litter moisture [measured as (sample weight difference after drying at 80°C for 24 h/original sample weight) × 100] were taken at 4 randomly predetermined sites across the whole of each house. Birds were assessed for gait at 10 sites in each house (Table 1, n = 1,140); a single bird was chosen at random from each position and was observed walking for at least 10 paces

[2]TINYTAG PLUS (manufactured to BS EN ISO9002), Gemini Data Loggers UK, Ltd., (www.geminidataloggers.com).
[3]GASTEC pumpset (model GV-100), Gastec Corporation, Kanagawa, Japan.

TABLE 1. Scoring system for gait, hockburn, pad dermatitis, and leg deviations

Leg health measure	Score 0	Score 1	Score 2
Gait	Bird walks with ease, has regular and even, strides, and is well balanced	Bird walks with irregular and uneven strides and appears unbalanced	Bird is reluctant to move, is unable to walk many strides before sitting down
Hockburn[1]	No discoloration or lesions	< 10% hock with lesion	> 10% hock with lesion
Pad dermatitis[2]	No lesions	< 5mm lesion on pad	> 5mm lesion on pad
Angle–in	Legs straight	Inward bow at intertarsal joint so that the 2 legs meet > 22°	
Angle–out	Legs straight	Outward twist at intertarsal joint with > 30° between the legs	
Rotation	Legs straight, pads facing away from handler	Rotation of the tibia shaft so that pads face each other > 15°	

[1]Pink hocks were also recorded.

[2]Pervasively dirty pads (leading to papillae formation on the metatarsal pad) were also recorded.

before being scored. Groups of 10 birds were subsequently caught at 4 random points per house. Individuals were inverted (ventral side facing handler) and held by the legs with the handler's thumbs just below the intertarsal joint pointing upward and were visually assessed for leg straightness (Table 1, n = 4,370), weighed, and then released. Growth rate was calculated as [(individual weight − average chick weight)/age in days], and actual stocking density was calculated to allow analysis separately from the target stocking density. Fresh fecal samples were taken from 5 predetermined random points in each house and later analyzed for corticosteroid levels (n = 535; Cockrem and Rounce, 1994; Denhard et al., 2003).

Company production records were audited. Mortality (numbers of birds found dead plus numbers of birds culled because of illness or leg problems), feed conversion ratio, numbers and weights of birds removed from the house (thinned or cleared), and number of birds rejected at the processing plant were recorded for each house.

Statistical Analysis

The independent statistical unit was house. When multiple measurements were made within a house, a single house-specific mean was used in the analysis. Variables were first analyzed for effects of target stocking density, actual stocking density, and company by analysis of variance. When actual density effects were significant, they were further examined by regression analysis (fitted line model) and post hoc Tukey comparison.

Univariate linear correlations were examined between outcome variables and predictors treated as continuous variables. Multivariate linear models were constructed using a stepwise model selection procedure (starting from a model with no predictors) with possible predictors including those continuous predictors with linear correlations <–0.2 or >0.2 as well as categorical predictors. Models with and without effects of company are presented to allow within-company differences to be clearly identified while giving insight into the extent to which between-company differences could be explained by the recorded variables.

An important point to note with a study such as this is that a large number of statistical tests have been carried out, which increased the likelihood that one or more of these would produce a significant result merely by chance. Unadjusted *P*-values have been reported in order to allow the reader access to the raw test results independent of a specific correction method; as such, results of borderline significance should be interpreted with caution. For this reason, we discuss only effects where $P < 0.01$.

RESULTS

Chicken houses were predominantly company owned (74.4%) and built of wood (80.9%). On average the floor area was 1,144 m^2 (ranged from 455 to 1,901m^2), and 42.5% of houses were less than 10 yr old, whereas 29.8% were older than 30 yr. Most houses (81.9%) had some form of automatic control over the environment, which increased or decreased ventilation rates and switched heaters on and off in relation to house temperature and a programmed temperature profile; the controller also operated the light and feed programs. Forty-one percent of the houses were naturally ventilated, whereas 47% had fan-assisted forced ventilation systems, and 12% had drop-down ventilation. Twenty-one percent of houses operated misting systems, and approximately 60% of houses were orientated in a north-south direction.

Gas burning space heaters were the most common form of heating (81.9%) with heaters placed at opposite ends of the building (63.8%). Woodshavings (48.9%) or straw (35.1%) were used as litter, and a woodshaving-straw mix was used in 16% of the houses. Approximately 51% of houses were equipped with chain feeders (49% had pan

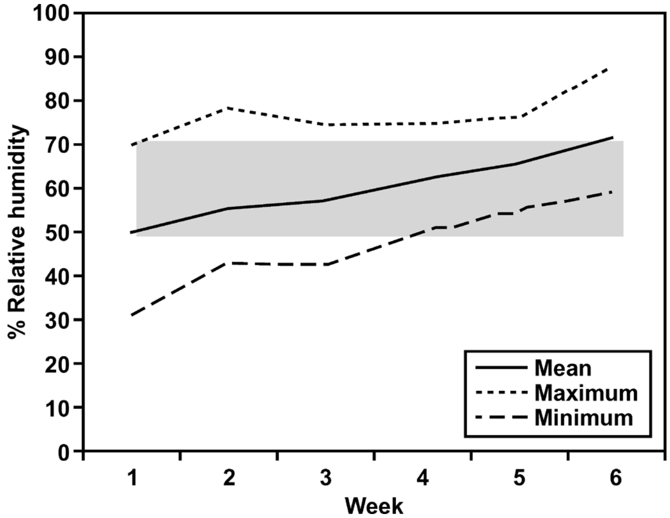

FIGURE 2. Mean, maximum and minimum weekly relative humidity through the growth cycle for the 10 companies participating in the experiment, upper (70%) and lower (50%) limits recommended by Ross are defined by the limits of the shaded area.

feeders) and 54.3% with nipple drinkers (47.5% had nipple drinkers with cups). Most houses were stocked with Ross birds (74.6%); 16.7% were stocked with Cobb birds and 8.8% were stocked with a mix of the 2 breeds. Most houses were managed by 2 stockpersons (67%), making 3 daily inspections (visits) of the flock (55%); 25% of houses were inspected 5 times per day.

Temperature and Relative Humidity Changes Through the Growth Cycle

Mean weekly temperature decreased as expected during the growth cycle, from 29.6°C in wk 1 to 20.3°C in wk 6 (Figure 1), whereas RH increased from 49.9% in wk 1 to 71.5% in wk 6 (Figure 2). Between companies, there were highly significant differences at all stages in the growth cycle in temperature and RH ($P < 0.001$) and little effect of stocking density (target or actual). RH in wk 6 was significantly affected by actual ($P < 0.01$) and target density ($P < 0.001$) so that average RH was significantly lower in houses stocked at 30 kg/m^2 (Table 2).

Across companies, mean weekly temperature was highly correlated to the within-house temperature of the previous week (r > 0.7, $P < 0.001$). Temperatures in wks 4 and 5 were also correlated to that in wk 2 (r = 0.3, $P <$ 0.001), and temperature in wk 5 was also correlated to that in wk 3 (r = 0.64 $P < 0.001$). Mean weekly RH was correlated to all previous weeks except for wk 5 and wk 1 (r = 0.32 to 0.89, $P < 0.001$).

The percentage of weekly readings above and below limits taken from the Ross Breeder Manual (Aviagen, 1999) are given in Table 3. Temperature in wks 2 to 5 (particularly wk 3 and 4) tended to be higher rather than lower than that recommended (for 50 to 70% RH), whereas a high percentage of temperature readings in wk 1 were below the lower recommended limit of 29°C. The RH tended to be lower than that recommended in wk 1 to 3 and higher in wk 4 to 6. This indicates a lower than anticipated apparent equivalent temperature for the youngest birds and higher apparent equivalent temperatures for older birds, especially if temperature was lower or higher than that recommended when young or old respectively. Interestingly, temperature in wk 1 was above the upper recommended limit of 31°C for 27.5% of the time, which may have been to compensate for low RH.

Large differences between companies existed in the percentage of readings above and below the recommended limits; there were only a few small effects of target or actual stocking density. In wk 2, houses stocked at target density of 42 kg/m^2 had fewer RH readings of less than 50% than houses stocked at 30 kg/m^2 (22% compared with 36.7%), and in wk 4, houses stocked at 42 kg/m^2 had fewer readings below 50% RH than houses stocked at 38 kg/m^2 (3.5% compared with 8.3%).

The percentage of time that weekly temperature was out of the recommended range was highly correlated from one week to the next, (r = 0.30 to 0.73, $P \leq 0.002$ in all cases). Out of range temperature in wk 5 was also strongly correlated to that in wk 3 (r = 0.53, $P < 0.001$). Similarly, the percentage of time that weekly RH was out of the recommended range was also highly correlated from one week to the next in wk 2, 3, and 4, (r = 0.36 to 0.81, $P < 0.001$ in all cases). Out of range RH in wk 5 was also correlated to that in wk 2 and 3 (r = 0.51 to 0.54, P < 0.001).

TABLE 2. The effect of target stocking density on relative humidity in week 6

Target stocking density (kg/m^2)	Mean	SE	Minimum	Maximum	Houses (n)	*P*-value
30	68.53[a]	1.33	58.98	77.16	15	
34	70.89[b]	1.40	63.95	78.99	12	<0.05
38	71.21[b]	1.51	60.75	79.04	14	<0.05
42	72.81[b]	1.27	65.73	82.84	15	<0.01
46	73.17[b]	1.77	65.3	87.83	12	<0.01

[a,b]Values with different superscripts are significantly different, Tukey test, and *P*-values pertain to differences from 30kg/m^2. Values are from 60% of the flocks; the remaining flocks had depopulated or were thinned prior to the sixth week.

TABLE 3. Percentage of time above and below recommended limits of temperature and relative humidity and the effects of company, target stocking density, and actual stocking density

Variable	Mean (%)	SE	Minimum	Maximum	Company	Target density	Actual density
Time above upper temperature limit (%)							
Week 1 >31°C	27.49	3.43	0	99.40	$P < 0.001$	NS	NS
Week 2 >29°C	15.56	2.24	0	94.05	$P < 0.001$	NS	NS
Week 3 >25°C	66.47	3.16	0	100	$P < 0.001$	NS	NS
Week 4 >23°C	58.62	3.10	0	100	$P < 0.001$	NS	$P < 0.05$
Week 5 >23°C	22.79	2.78	0	100	$P < 0.001$	NS	NS
Week 6 >23°C	12.37	2.49	0	62.5	$P < 0.001$	NS	NS
Time below lower temperature limit (%)							
Week 1 <29°C	38.43	4.52	0	100	$P < 0.001$	NS	NS
Week 2 <24°C	1.10	0.93	0	94.05	NS	NS	NS
Week 3 <20°C	0.07	0.026	0	1.79	$P < 0.05$	NS	NS
Week 4 <18°C	0.03	0.16	0	1.19	NS	NS	NS
Week 5 <18°C	1.16	0.30	0	24.41	$P < 0.001$	NS	NS
Week 6 <18°C	15.33	3.00	0	95.83	$P < 0.001$	NS	NS
Time above 70% humidity (%)							
Week 1 >70%	2.17	0.79	0	56.55	$P = 0.001$	NS	NS
Week 2 >70%	6.29	2.08	0	97.62	$P < 0.001$	NS	NS
Week 3 >70%	7.03	1.87	0	100	$P < 0.001$	NS	NS
Week 4 >70%	11.86	1.77	0	98.81	$P < 0.001$	NS	NS
Week 5 >70%	29.78	2.32	0	97.02	$P < 0.001$	NS	NS
Week 6 >70%	61.17	3.28	4.17	100	$P < 0.001$	NS	NS
Time below 50% humidity (%)							
Week 1 <50%	52.14	3.62	0	100	$P < 0.001$	NS	NS
Week 2 <50%	30.42	3.34	0	100	$P < 0.001$	$P < 0.05$	NS
Week 3 <50%	19.65	2.57	0	100	$P < 0.001$	NS	NS
Week 4 <50%	7.07	1.11	0	50.00	$P < 0.001$	$P < 0.05$	NS
Week 5 <50%	2.35	0.35	0	19.64	$P < 0.001$	NS	NS
Week 6 <50%	0.83	0.26	0	10.00	$P < 0.001$	NS	NS

Management Practices and Equipment Contributing to Variation in Environmental Conditions

Companies controlled house temperature according to their own protocols and with different sorts of equipment, including heaters, fans, and sometimes misters. Some systems were operated manually, others automatically. No company controlled or even measured RH. The percentage variation in temperature, RH, litter moisture, and air ammonia that could be explained by the measured equipment or management variables are given in Tables 4, 5, and 6, respectively.

Between-Company Variation. Companies that allowed house temperature to go above the upper recommended limits were those that had fewer stockpersons [partial R^2 (pR^2) 4.6%], a woodshavings/straw mix for litter (pR^2 1.2%), and newer houses (pR^2 1.0%). On the other hand, lower than recommended temperatures were associated with naturally ventilated houses (pR^2 3.6%) and houses with fewer drinkers per unit area (pR^2 1.2%). Higher litter moisture was associated with more drinkers per unit area (pR^2 29.1%) and heaters spread evenly throughout the house (pR^2 6.2%), whereas litter moisture was lower in houses with manual control over temperature (pR^2 7.2%). Ammonia levels were less in winter and summer (pR^2 11.0%) and in houses with fan-assisted ventilation (pR^2 11.3%).

Companies with older houses (pR^2 6.3%), using a woodshavings/straw mix (pR^2 3.5%) as litter and fans as well as side inlets (pR^2 2.0%), were better able to maintain RH below 70%. RH less than 50% increased with increasing number of daily stockperson visits (pR^2 14.0%), in wooden houses (pR^2 1.9%), and houses with larger floor areas (pR^2 1.1%), and decreased with woodshavings litter (pR^2 6.4%). Variation in RH was greater in newer houses (pR^2 9.4%), with nipple and cup drinkers (pR^2 1.4%), and with a woodshavings/straw mix litter (pR^2 1.2%).

Within-Company Variation. Week was the main explanatory predictor of the temperature and humidity variables (e.g., average temperature pR^2 78.4%, average RH pR^2 42.4%). There were fewer temperatures above the upper recommended limits in winter and spring (pR^2 4.9%) and in houses with nipple drinkers (pR^2 3.1%).

Environmental and Management Effects on Measures of Bird Welfare

The effect of variation in management and environmental conditions on various measures of bird welfare are shown in Tables 7 and 8.

Between-Company Variation. There were fewer birds with dirty pads when there was more variation in wk 2

TABLE 4. A summary of the explanatory predictors for temperature variation[1]

Variable	Explained model 1 (%)	Explained model 2 (%)	Company explains (%)	Predictors for between-company variation	Partial R^2	Predictors for within-company variation	Partial R^2
Mean Temperature	86.2	86.9	4.7	Less with woodshavings	1.5	Reduces with increasing week	78.4
				Greater with more drinkers/unit area	1.0	Less in winter and spring	2.2
	{7.8%}	{3.8%}		Greater with concrete floor	0.5	Greater with NS orientation	1.0
				Greater with fewer visits (≤3/d)	0.6	Less with fans and side inlets	0.3
						Increases with increasing numbers placed in house	0.1
						Greater with 1 to 2 stockpersons	0.2
Temperature above upper limit (%)	69.9	69.9	13.2	Greater with 1 to 2 stockpersons	4.6	Less in wk 1, 2; more in wk 3, 4	47.0
				Less with no misters	0.8	Less in winter and spring	
	{22.9%}	{9.8%}		Greater with concrete floor	0.7	Less with nipple drinkers	4.9
				Less with manual control	0.5	Less with increasing stockpersons	3.1
				Less with woodshavings or straw litter	1.2	Increases with increasing numbers placed in house	0.9
				Less with older houses	1.0		
				Greater with more drinkers/unit area	0.7	Increases with NS orientation	0.7
Temperature below lower limit (%)	48.8	49.0	8.6	More with natural ventilation	3.6	Greater in wk 1	38.5
				More with fewer drinkers/unit area	1.2	More in winter and spring	1.9
	{10.2%}	{1.9%}		Less in wooden houses	0.3		
SD temperature	32.5	32.6	5.5	Less with fewer visits (≤3/d)	2.3	Less in wk 1 to 4	12.1
				Less with woodshavings or straw litter	1.1	Less in winter	9.1
	{20.4%}	{15.0%}		Increases with increasing area of house	1.5	Less with increasing drinkers/unit area	4.1
				Greater with manual control	0.8	Less with 1 to 2 stockpersons	1.1
				Less with more drinkers/unit area	1.1	Less with fans and side inlets	0.7

[1]Model 1 with environment and management covariates; model 2 plus company effects. {percent explained by covariates}.

[AUTH QUERY: no data for "Less in winter and spring" in last column?]

TABLE 5. A summary of the explanatory predictors for relative humidity variation[1]

Variable	Explained model 1 (%)	Explained model 2 (%)	Company explains (%)	Predictors for between-company variation	Partial R^2	Predictors for within-company variation	Partial R^2
Mean humidity	74.5	74.6	28.4	Less with straw/woodshaving mix litter	1.4	Increases with week	42.4
				Less with wooden structure	1.6	Lower in spring	2.1
	{32.1%}	{3.9%}		Less with older houses	1.2	Less with heaters at mid point in house	1.0
				Decreases with increasing area	0.6	Increases with increasing numbers placed in house	0.6
						Decreases with increasing visits/day	0.2
Humidity above upper limit (%)	49.3	48.8	18.7	Greater with younger houses	6.3	Increases with week	28.3
				Less with straw/woodshaving mix litter	3.5	Less in winter and spring	1.8
	{20.8%}	{1.8%}		Less with wooden structure	1.5		
				Less with fans and side inlets	2.0		
				Less with NS orientation	0.6		
Humidity below lower limit (%)	62.4	62.6	25.0	Increases with increasing number of visits per day	14.0	Reduces with week	32.7
						Less in winter, greater in spring	2.7
	{29.7%}	{4.9%}		Less with woodshaving litter	6.4	Less in concrete floors	0.5
				Increases with increasing house area	1.1	Treatment effect at group level	1.0
				Decreases with increasing numbers placed in the house	0.5	Less with heaters at opposite ends of shed	0.7
				Greater in wooden houses	1.9		
				Greater with natural ventilation	0.7		
SD humidity	44.5	44.5	11.23	Greater with newer houses	9.4	Less with wk 1 to 3	22.3
				Greater with nipple and cup drinkers	1.4	Less in winter	8.7
	{22.3%}	{11.0%}		Greater with straw/woodshaving mix litter	1.2	Increases with increasing stockpersons	1.6
						Greater with manual control	0.7
				Drinker ratio effect at group level	0.9		

[1]Model 1 with environment and management covariates; model 2 plus company effects, {percentage explained by covariates}.

TABLE 6. A summary of the explanatory predictors for litter moisture and air ammonia variation[1]

Variable	Explained model 1 (%)	Explained model 2 (%)	Company explains (%)	Predictors for between-company variation	Partial R^2	Predictors for within-company variation	Partial R^2
Mean litter moisture	48.2	56.3	45.5	Less with fewer drinkers/unit area	29.1	Greater in treatments 3 and 4	4.1
				Greater with heaters spread evenly through house	6.2		
				Less with manual control	7.2		
Average Ammonia levels	22.3	73.7	72.8	Less in winter and summer	11.0		
				Less with fans and side inlets	11.3		
				Less with fewer visits (≤3/d)	0.1		

[1]Model 1 with environment and management covariates; Model 2 plus company effects. {percent explained by covariates}.

temperature (pR^2 8.1%) and more birds with pad 0 (best) in houses with no misters (pR^2 11.9%). For the study as a whole, only 2.8% (range 0 to 47.5%) of birds were recorded with severe foot pad lesions, whereas 19.5% (range 0 to 75%) had pervasively dirty pads.

Fewer birds had pink hocks or worse with smaller numbers of drinkers per unit area (pR^2 31.9%), whereas more of them had pink hocks or worse with houses in a north-south orientation (pR^2 12.1%), and more hock 2 (worst) in houses with manual control over temperature (pR^2 3.2%). The occurrence of birds with hock 2 was less in houses with no misters (pR^2 6.0%). Fewer birds were scored with angle-out leg deviation with increasing daily stockperson visits (pR^2 8.6%), whereas more birds showed rotation with nipple drinkers (as opposed to nipple drinkers with cups; pR^2 8.2%), and less rotation with no misting systems (pR^2 11.6%).

Corticosteroid levels were lower in houses with drop-down ventilation (pR^2 30.7%), and increasing mean temperature in wk 1 (pR^2 2.2%), and greater with increasing RH in wk 5 (pR^2 2.8%). Growth rate was less in houses with fewer daily stockperson visits (≤3 inspections) (pR^2 27.4%) and with natural ventilation (pR^2 10.9%). Mortality had a positive relationship with fecal corticosteroid levels (pR^2 21.8%), and was less with no misters (pR^2 11.4%), and more with increasing variation in RH in wk 4 (pR^2 3.6%).

Within-Company Variation. There were fewer birds with dirty pads the more RH varied in wk 3 (pR^2 23.0%) and with manually controlled systems (pR^2 7.8%) but more birds with dirty pads with increased mean RH in wk 3 (pR^2 6.0%). **[AUTH QUERY: Previous sentence unclear; please adjust]** There was greater incidence of birds with pad 2 (worst) and fewer with pad 0 (best) with increasing mean RH in wk 2 (pR^2 4.9 and 26.9%, respectively).

More birds showed the worst gait (gait 2) in the last week of the growth cycle, the more the house RH had been out of recommended range when they were very young (in wk 1; pR^2 5.6%), whereas more birds showed

TABLE 7. A summary of explanatory predictors for gait, hockburn and pad dermatitis[1]

Variable	Explained model 1 (%)	Explained model 2 (%)	Company explains (%)	Predictors for between-company variation	Partial R^2	Predictors for within-company variation	Partial R^2
Gait 0	23.3	51.9	36.8	Less with manual control systems	4.2	More in newer houses	7.7
						Reduces with increasing target stocking density	7.3
Gait 2	5.6	10.3	4.8			Increases with increasing % of time RH out of range W1	5.6
Hock 0	24.4	44.5	37.8	Higher in older houses	17.3	Increases with increasing stocking density	4.6
Hock 2	17.4	28.0	25.4	Less with fewer drinkers/unit area	8.2		
				More with manual control systems	3.2		
				Less with no misters	6.0		
Hock pink or worse	46.1	60.5	54.9	Increases with NS orientation	12.1		
				Less with fewer drinkers/unit area	31.9		
				Increases with increasing W3 temperature	2.1		
Pad 0	51.5	58.9	23.2	More with no misters	11.9	More with concrete floors	5.4
				Increases with increasing growth rate	6.3	Less with higher W2 RH	26.9
						Less in winter	2.6
Pad 2	7.9	26.6	19.4			More with higher W2 RH	4.9
Dirty pads	45.4	56.3	17.3	Less with more variation in W2 temp	8.1	Less with manual control	7.8
						Less with more variation in W3 RH	23.0
						More with higher W3 RH	6.0

[1]Model 1 with environment and management covariates; model 2 plus company effects. **AUTH QUERY: Define W1, W2, and W3 used in table]**

TABLE 8. A summary of explanatory predictors for leg deviation (total of angle in, angle out, rotation), fecal corticosteroid, mortality and growth rate[1]

Variable	Explained model 1 (%)	Explained model 2 (%)	Company explains (%)	Predictors for between-company variation	Partial R^2	Predictors for within-company variation	Partial R^2
Angle in	26.5	35.4	6.3			More with no mister	12.0
						More with greater lying stretched out	5.6
						More with higher % of W5 temperature out of range	8.9
Angle out	21.7	40.0	36.0	Less with increasing visits per day	8.6	More with higher ammonia levels	3.3
Rotation	11.6	40.2	36.7	Increases with nipple drinkers	8.2		
				Less with no misters	11.6		
Total leg deviation	20.9	43.2	32.7	Increases with concrete floors	4.9	Increases with nipple drinkers	10.1
				Trend to increase with more variation in W5 temperature	2.3		
Average corticosteroid	69.4	83.7	46.5	Lower with drop down ventilation	30.7	Higher in winter	33.7
				Lower with increasing W1 temperature	2.2		
				Higher with increasing W5 RH	2.8		
Mortality	37.6	44.4	41.2	Positive relationship with corticosteroid levels	21.8		
				Less with no misters	11.4		
				Increases with increasing variation in W4 RH	3.6		
Growth rate	46.4	65.8	57.5	Less with natural ventilation	10.9	Less with increasing target density	4.8
				Less with 3 or less visits	27.4	Negative relationship with hock 0	1.9
				Positive relationship with pad 0	2.1		

[1]Model 1 with environment and management covariates; model 2 plus company effects. **[AUTH QUERY: Define W1, W2, and W3 used in table]**

angle-in with no misters (pR^2 12.0%), and with temperature out of range in wk 5 (pR^2 8.9%).**[AUTH QUERY: Previous sentence unclear; please adjust]** There was a higher incidence of birds scored as angle-out with increasing ammonia levels (pR^2 3.3%), and fecal corticosteroid was higher in winter (pR^2 33.7%).

DISCUSSION

These results emphasize the importance of temperature and RH to the health and mortality of broiler chickens produced in a northern European climate. In particular, much of the variation in the extent to which a producer company can maintain broiler health at high stocking densities is associated with how much time that company can maintain temperature and RH within the limits recommended for birds of that age (Aviagen, 1999). High temperature and RH and the percentage of time these are out of range adversely affected foot pad dermatitis, impaired gait, and affected angle-in deviation, mortality, and corticosteroid levels.

Partial R^2 values indicated the percentage of variation explained by the predictor in the model, whereas the difference in levels of explanation between the 2 models indicated that explained by company after adjustment for measured predictors. If a predictor disappears when company is added to the model, then the predictor mainly explains between-company variation. Temperature is predominantly explained by week because it is purposefully reduced over the growth cycle. The addition of company adds little to the model, and the other predictors in the model are of low explanatory power. Company explains more variation in the RH variables, although week still explains a high percentage of the variation. Company explained high levels of ammonia (pR^2 72.8%) and litter moisture (pR^2 45.5%) variation.

Management practices that had the greatest impact on the environment included the provision of fans with side inlet ventilation, the numbers of drinkers per unit area, the number of stockpersons and daily stockmen visits, and litter type. Other important factors included drinker type (nipple versus nipple with cup), automatic control over temperature, and a north-south orientation (indicating that consideration should be given to prevailing winds, particularly in the summer months).

The provision of fans (with side inlet ventilation) gave better control over temperature and RH and reduced ammonia levels over naturally ventilated systems or systems with fan assisted drop-down ventilation, indicating a more effective mixing of air and flow of air over the birds. Additionally, more variation in RH was recorded in newer houses, possibly because these were larger more open span buildings, and more than 3 daily inspections by stockpersons led to more frequent readings of RH < 50%, possibly due to additional opening and closing of external doors and increased movement of birds around the house.

Fewer drinkers per unit area led to less litter moisture and less hockburn, and greater levels of leg rotation were associated with nipple drinkers (as opposed to nipple drinkers with cups). This effect may be operating through damp litter; however, birds with poor walking ability were observed (T. A. Jones, anecdotal observations) to lose balance while stretching to drink from a nipple. Further research would be required to ascertain drinking postures and if there is a true effect of nipple drinkers on leg health. Misting systems were associated with more pad dermatitis, rotation, and mortality; again the effects might have been through wet litter.

Higher levels of ammonia were directly implicated in greater levels of angle-out deviation, and manual control over temperature was implicated in lower levels of best gait. This stiff gait may potentially be related to lower than recommended temperatures associated with manually controlled systems. Ammonia affects poultry in a number of different ways, for example by causing irritation to the mucous membranes in the eyes and respiratory system and by affecting food intake and growth rate (Kristensen and Wathes, 2000; Homidan et al., 2003). Chickens are averse to ammonia (Jones et al., 2003) at levels less than 25 ppm (Kristensen et al., 2000), but there is no other evidence currently suggesting a link with poor leg health.

The results support the conclusion that stocking density per se is less important to bird welfare than control of the birds' environment, particularly those factors related to good ventilation and air control (Feddes et al., 2002; Heier et al., 2002; Martrenchar et al., 2002; Dawkins et al., 2004) and litter quality (Hester 1994). It further supports the conclusion of the European Union Scientific Committee on Animal Health and Animal Welfare that "the problems of high stocking rates are less in buildings where good indoor climatic conditions can be sustained and any recommendations on stocking density should take this into account."

Producer companies tended to err on the side of having temperatures that were too low in wk 1 and too high in the later half of the growth cycle. At the same time, they tended to have levels of humidity that were too low in very young chicks and too high in older birds. Low levels of humidity in wk 1 were associated with poorer gaits in wk 6; the mechanism for this is unknown, but low RH in wk 1 can lead to dehydration and uneven growth (Aviagen, 1999). There was also a significant effect of stocking density on RH in wk 6 of the cycle, indicating that environmental control is being lost as birds get older.

Although the companies measured and controlled temperature with varying degrees of success, none of them measured or controlled humidity. It may be that monitoring and controlling RH directly could make a substantial contribution to chicken welfare, particularly at high stocking densities. This has been called for by other researchers (e.g., Weaver and Miejerhof, 1991), who showed that low RH late in the growth cycle results in less foot pad dermatitis. Certainly high RH (beyond wk 1 of the growth cycle) in the current study was implicated in wet litter and a greater incidence of pad dermatitis and hockburn.

Reiter and Bessei (2000) have emphasized the importance of local variation in temperature and humidity on bird welfare. They point out that temperature between birds or in the litter 10 cm below a group of sitting birds may have an even greater effect on local litter and air quality than temperature measured above their heads or on global ventilation rates throughout the house. Future studies to define recommended environments for rearing broilers should, therefore, consider local as well as whole house effects.

We concluded that the control of the environment of broiler chickens is a key factor in improving their welfare, particularly the ability, through good ventilation, to control temperature and humidity. RH in the first week of a chick's life is particularly important as it affects health and welfare in later life. However, direct control or even measurement of humidity levels is not current commercial practice but could in future result in a significant improvement to bird husbandry.

Our results should not be interpreted as demonstrating that stocking density has no effect on broiler welfare. Rather, they show that simply lowering stocking density without regard to the environment that the birds experience is not sufficient. Genuine improvements in bird welfare will come from shifting the emphasis to factors in the birds' environment and genetic make-up.

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