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Variable velocity system for evaluating effects of air velocity on Japanese quail

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Abstract. This study documents the design and performance of a system to apply different magnitudes of air velocity to Japanese quail, to evaluate the combined effects of velocity, temperature and humidity on bird behaviour, performance and welfare. The system was developed to simulate observed field conditions ocurring in regions with high winds where quail are raised in curtain-sided housing. System performance consisted of characterizing air velocity distribution in cages downstream of the air velocity which was directed at the front of the cages. The system consisted of two fans attached to a 25 cm PVC tube, one at each end, with the outlet airflow directed through a continuous slot over the cage front at the feeder. The design and performance of this experimental system was evaluated, with six such systems were built and utilized in research trials. To assess system performance, air velocity was measured at 275 points per cage uniformly arranged along the three dimensions (length, width and height) in eight cages with zero, 1, 2 or 3 m s^{-1} nominal velocity setpoints. Spatial distribution of velocity was analysed by mapping and from descriptive statistics, with attention to the zone closest to the feeder where birds must go to eat. There was no significant difference ($P > 0.05$) found in mean paired difference of air speed data measured for pairs of front portion cages with similar velocities. A significant positive correlation was found ($P < 0.001$) between the measured air velocity at paired points in the cages subjected to the same velocity treatment. A comparison of measured mean air velocity to the nominal setpoint values used for experiments indicated that careful attention to outlet adjustment is important, especially at higher nominal velocity setpoint as 3 (± 0.10) m s^{-1} which was difficult to achieve with the system. An example of the use of the deployment of the variable velocity system in controlled environment chambers with Japanese quail is provided.

Key words: cold stress, effective temperature, engineering design, heat stress, wind chill.

INTRODUCTION

The thermal environment comprises a complex of factors that interact and combine to influence the effective ambient temperature, i.e., perceived by people, poultry and livestock (Curtis, 1983; ASHRAE, 2017; ASHRAE, 2019). Air temperature, relative humidity, air velocity, pollutant concentration and solar radiation are the main variables that characterize the microclimate and influence the behaviour welfare of livestock and poultry. According to Dhari et al. (2019), as these variables can interfere in the birds' comfort, the productive performance can also be strongly affected. The bird's welfare and performance can be severely impaired when climatic conditions and air quality are not within appropriate ranges (Rojano et al., 2018). Therefore, for a better understanding of climatic variables combination, various indices have been developed to quantify their impacts, e.g. effective temperature, THI and wind chill index.

Despite all the technological progress of the Brazilian poultry sector, the thermal environment in which birds are housed remains one of the main factors affecting production performance (Vilela, 2016; Freitas et al., 2017) since the buildings are largely open. Thus the type of management and climatic characteristics of each region are important for animal facilities project planning due to environmental needs of the species (Santos et al., 2012), including wind direction and velocity, so that the air velocity may be controlled according to need. The magnitude of air velocity levels inside a building favours convective heat transfer between birds and air (Baêta & Souza, 2010). Within certain limits, air velocity and fresh air exchange control the temperature and relative humidity, and are critical for mitigating the negative effects caused by heat stress in birds (Abreu et al., 2011; Bianchi et al., 2015; Oloyo & Ojerinde, 2019). In addition to convection, air velocity is fundamental to evaporative cooling (Oloyo & Ojerinde, 2019).

Blakely et al. (2007) state that the thermal variations of environment are strongly influenced by air velocity, significantly affecting bird performance. High air velocity decreases the effective temperature; thus, in cold environments the presence of air currents can be harmful. However, in warm environments, elevated air velocity can alleviate heat stress and is the basis for modern tunnel ventilation, as reported by Ruzal et al. (2011), that stated that high velocity (3 m s^{-1}) positively affects hens egg production in hot environments. According to Dhari et al. (2019), air temperature and velocity are the main factors affecting the physiology and performance of broilers. Vigoderis et al. (2010) evaluated the influence of minimum ventilation on thermal comfort, air quality and broiler performance during winter, using a system consisting of three fans with a flow of 300 m^3 min^{-1}, positioned close to the ceiling, in parallel to the floor and blowing air into the shed. In these conditions, they concluded the minimum ventilation system significantly reduced the temperature inside the broiler house, reflecting on losses at feed conversion, slaughter weight, and animals' productive efficiency.

The annual growth in Brazilian poultry flock had an increase of 2.9% in 2018, highlighting in hens eggs production, with about 4.4 billion dozen produced (IBGE, 2019). Egg production from Japanese quail (*Coturnix conturnix japonica*) is rapidly expanding in Brazil, with annual growth in the number of quails in excess of 3.9% between 2017 and 2018, (IBGE, 2019), with about 297.3 million dozen eggs produced. Therefore, in order to remain competitive, it is extremely important to pay attention to ventilation conditions in Brazilian poultry houses, so as not to harm the birds comfort. Recently, Brazilian producers have expressed concerns regarding the influence of high air velocity in cooler temperatures on the feeding behaviour and egg production in open poultry houses. Hence, one of the most interest regions for analysis of air velocity influence on bird's welfare and performance is the area closest to the feeder. The importance of studying airflow intensity and distribution in this zone is due to its influence on the animals' ingestive behaviour, which is an aspect closely related to their performance. In view of the importance of air velocity influence on bird welfare and performance, and considering the practical difficulties often encountered in implementing this type of experiment under field conditions, it was determined to be helpful to develop an air velocity control prototype for use in poultry experiments in controlled environments. Other systems have been developed, such as the system developed by Yanagi et al. (2002), for the measurement and control of temperature, relative humidity and air velocity to evaluate heat stress in birds.

However, a system that provides high air velocity in a controlled fashion over the entire face of a birdcage, especially in the feeder zone, similar to exterior rows of cages in open-sided housing, is not readily available. No similar device could be found in the literature, prompting the design and fabrication. The objectives of this study were to: (1) evaluate the performance of the system to provide nominal air velocity setpoints, (2) to evaluate the uniformity of air velocity at common lines and heights where birds approach the feeder, and (3) to evaluate the repeatability of system performance between prototypes.

MATERIALS AND METHODS

Velocity Control System

The velocity control system was fabricated from a simple length of 25cm diameter PVC tubing, with axial fans (Micro Motor Elgin 1⁄25 MM – 20B, 60 Hz, 11.93 W) mounted on each end (Figs 1–3), each capable of producing 950 $m^3 h^{-1}$. A 10×100 cm (w×l) long opening was cut along one side of each PVC tube for air to discharge (Fig. 3) toward the cage. Aluminium angles, 2×2×110 cm were fastened to the edges of the opening. This facilitated establishment of an air jet to smooth outflow of air toward the cage. A simple solid-state rheostat was used to adjust the fan motor speeds, hence volumetric flow rate and resultant discharge velocity from the tube. A total of six prototypes were fabricated for use in a series of research trials designed to evaluate the effect of velocity, temperature and humidity on Japanese quail behaviour. A typical setup in one of the climate chambers used is illustrated in Fig. 1.

Four climate chambers were used, one for each nominal velocity level: 0, 1, 2, and 3 m s^{-1}. Individual dimensions are 3.2 m wide × 2.44 m deep × 2.38 m high, and each climate chamber includes equipment for heating, cooling and humidification as highlighted in Fig. 1. The test facilities are located in the Ambiagro group (Research Center of Environment and Agroindustry Systems Engineering) at the Department of Agricultural Engineering at the Federal University of Viçosa (Minas Gerais, Brazil).

Experimental Design

The velocity control system was designed to provide different mean velocities over the feeding zone of cages, simulating situations of strong winds occurrence that affect the batteries of cages located at the ends of opened aviaries, so that velocity effects on bird behaviour could be investigated. Four nominal velocity levels (setpoints) were evaluated: 0 m s^{-1}; 1 m s^{-1}; 2 m s^{-1} and 3 m s^{-1} representing still air, low, medium and high air velocities in the feeder area. This system provided an outflow of air from the tube over the feeder and into the cage. For each nominal velocity level, two cages were used as replicates. Fan speeds were adjusted using the average velocity readings from three points along the length of the tube opening, as depicted in Fig. 2, to obtain the desired nominal velocity setpoint values.

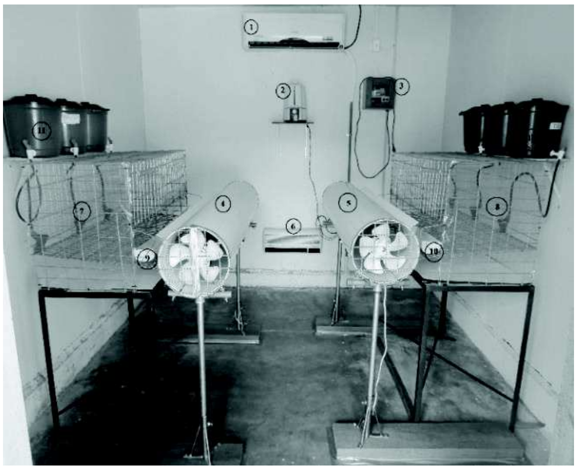

Figure 1. Inside view of the climatic chambers, where 1 – air conditioning; 2 – air humidifier; 3 – electronic temperature and relative humidity controller (MT-531R plus); 4 and 5 – ventilation tubes; 6 – air heater; 7 and 8 – cages; 9 and 10 – feeders; 11 and 12 – water tanks.

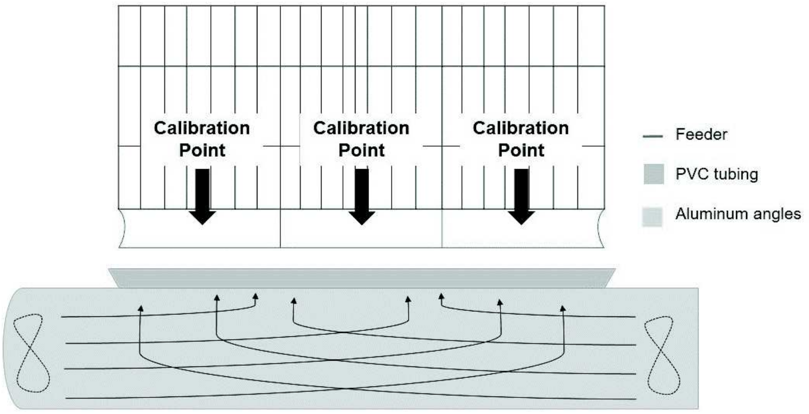

Figure 2. Airflow behaviour within the PVC tubes and location of points used for fan velocity adjustment.

A three-dimensional abstraction of the cage system was created, with the origin located at the right rear side of each cage (Fig. 3) with coordinates (x, y, z) referring to lateral, depth and height, respectively. A grid was established, consisting of 275 points/cage within this grid, spaced equidistantly (Fig. 3). Resolution for locating these points was estimated to be ± 10 mm.

The data collected within the entire cage were useful in order to characterize the distribution of air velocity. However, the main focus was on the velocity in the feeder zone, as is highlighted in Fig. 3. This zone comprises the points located in Lines 3, 4 and 5, measured at 7 points located at the most central portion of the cage (Fig. 3, A). Two heights, denoted Z0 and Z1, were established for the Line measurements. Z0 is located at the feeder top surface, and Z1 is approximately at the height of the birds when at the feeder.

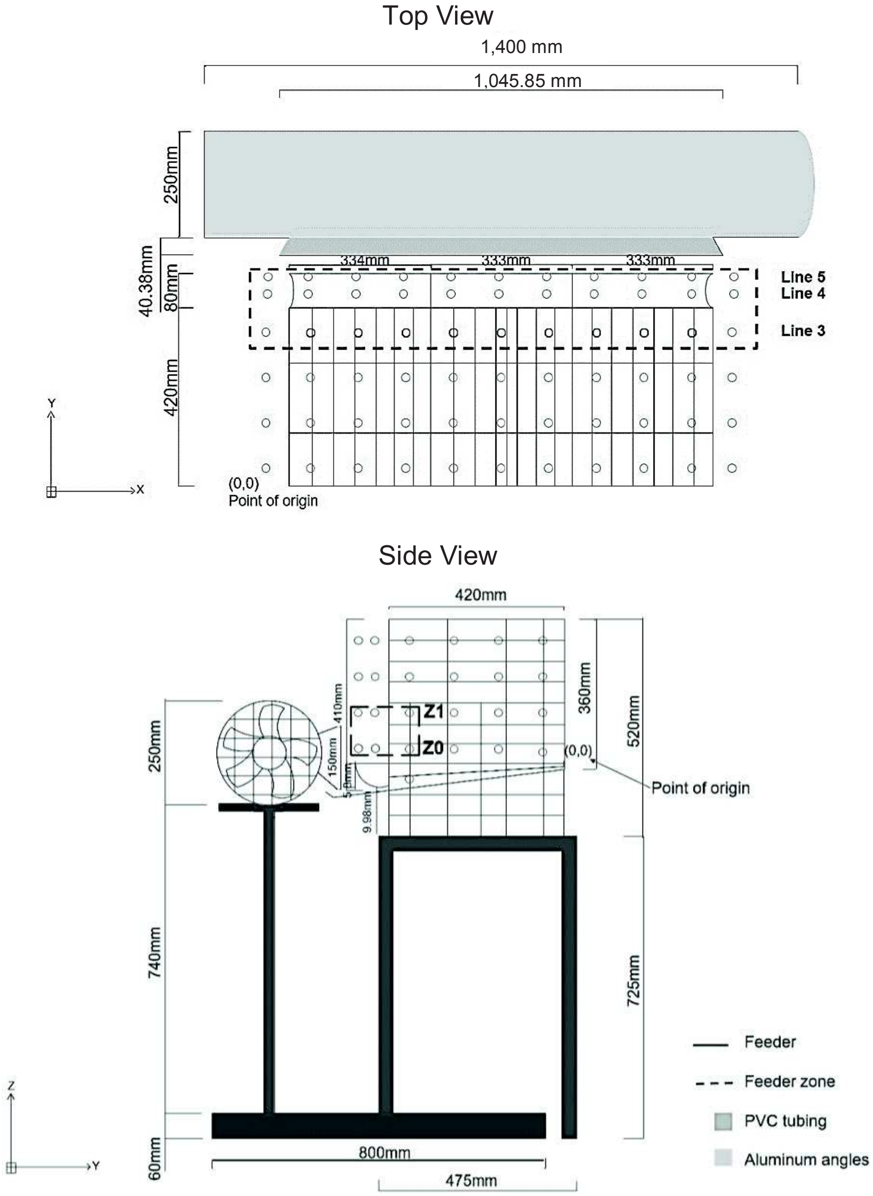

Figure 3. Schematic of cage and ventilation control system, with sampling points (275 per cage), Lines (3, 4 and 5) located at different distances from the feeder zone, and heights (Z0, Z1) of primary interest for assessing actual velocities experienced by birds at the feeder. A) Top view. Note the grid includes points located at the exterior of each side of the cage. Line 5 was at the feeder, Line 4 was spaced 40 mm further into the cage, and Line 3 was spaced 115 mm from Line 4. B) Side view, illustrating the location for heights Z0 and Z1 that are used to quantify system performance.

Air velocity was measured using a hot wire anemometer (Testo 425, TESTO INC., Germany) with a 7.5 mm probe diameter, measurement range of 0–20 m s^{-1}, display resolution of 0.01 m s^{-1}, and 2-s sampling frequency. Velocity measurements at each point were the mean of 30 individual samples taken over a 1-min period to average out fluctuations from turbulence. Care was taken to ensure that the probe tip was oriented perpendicular to the predominant velocity direction, and a single person recorded all measurements to control uncertainty between cages. Air temperature in the climatic chambers during these measurements was 24 °C, considered a comfort average temperature for Japanese quail.

Data Analysis

To evaluate the velocity control system performance and utility for research use, the collected air velocity data were analysed in two different ways.

1) Comparisons between replicate cages subjected to the same velocity set point were made using a paired *t-test* on the mean velocity difference, and a correlations analysis of the collected velocity readings.

2) Spatial distribution of air velocity in the feeder zone was mapped and plotted for assessment of uniformity between replicate cages and between set point velocities.

The velocity difference between identical points in each replicate cage was calculated and subjected to a paired *t-test* to assess if measurements from two replicate cages were different, with the null hypothesis that mean velocity difference was zero. A confidence level of 5% was used. To further assess similarity (or difference) between replicate cages, velocity measurements between cages were subjected to correlation analysis. The Pearson correlation coefficient for velocity measurements between cages was calculated and subjected to a test of significance.

Velocity distribution for each cage was evaluated from boxplots, and maps of spatial distribution were generated using the software SIGMAPLOT® v.12.0. Velocity distribution was analysed at two horizontal plans referring to the area close to the feeder, at high 55 and 142 mm above the floor. These surfaces were named Z0 and Z1, respectively. The velocity distribution maps were generated for each of these plans at each cage, in the zone near the feeder as depicted in Fig. 3.

RESULTS AND DISCUSSION

The two nearest lines to the feeder (Lines 4 and 5 at Z1 height), in combination, best represent the condition in which the birds were exposed due to the fact that they correspond to the zone effectively occupied by the birds during the feeding. Thus, it is possible to observe in Table 1 the actual air velocity to which the animals were submitted when approaching the feeder. The importance of studying the intensity and distribution of airflow near the feeder is associated with its influence on the animals' ingestive behaviour. Thus, Ruzal et al. (2001), studying the air velocity effect on the broilers performance subjected to heat stress (35 °C), concluded that birds exposed to higher air velocities (2.5 and 3 m s^{-1}) obtained better results for weight gain, feed intake and feed conversion when compared to birds subjected to 0.5 m s^{-1} air velocity. Santos et al. (2018) studied effect of different air velocities on behaviour of Japanese quails and concluded that in heat stress the birds showed a higher frequency of feeding behaviour when subjected to high air velocities. In this same sense, Sevegnani et al. (2005), working with broilers of the AgRoss strain in the final creation stage, submitted to different heat stress conditions, found that in general, the hotter the environment, the less time spent by birds in the feeder. Barbosa Filho et al. (2007), evaluating the influence of heat stress in laying hens of the Hy-Line Brown line housed in a cage system, observed a reduction of approximately 50% in the frequency of the eating behavioural pattern. On the other hand, when higher air velocities are used in heat stress situations, it is observed that the thermal environment does not significantly influence the animals' ingestive behaviour, since high air velocity ranges favour the body heat exchange through the convection process (Baêta & Souza, 2010).

As shown in Table 1, for the low and medium velocities, the actual mean air velocity achieved in the feeder zone corresponded with the nominal velocity for the experiment. For the highest velocity, the average actual air velocity reached in the feeder area was 2.3 m s^{-1}, showing that the desired set point of air velocity was not effective. However, Vilela (2016) and Santos et al. (2017) showed that the developed system can be used for such research because provided with the correct adjustments and considering air velocity levels of up to approximately 2.5 m s^{-1}, the mean air velocity was suitable for controlled environments. However, for experimental velocities greater than 2 m s^{-1}, an alternative for setting the nominal setpoint or an alternative design would be required, since the used system configuration provided air velocities approximately 23% lower than that desired when the setpoint (experimental velocity) was 3 m s^{-1}. Which may end up influencing the behavioural and performance evaluations of poultry, associated with the air velocity applied on them. Vilela et al. (2019) developed a computational fluid dynamics (CFD) model to evaluate the performance of air velocity control prototypes designed for animal and, through this tool, they affirm that it is possible to carry out simulations for improvement of air velocity control system for ranges above 2 m s^{-1}, optimizing structural designs to aim animal thermal comfort.

Table 1. Relationship between air velocity set point and mean observed data (± standard deviation) for the combination of values obtained in lines 4 and 5

Air velocity set point (m s^{-1})	Mean observed in lines 4 and 5 (in combination) (m s^{-1})
1. (Low)	1.1 ± 0.09
2. (Medium)	2.0 ± 0.22
3. (High)	2.3 ± 0.10

Boxplots of the velocity distribution of all 275-measurement points for each cage by velocity combination are presented in Fig. 4. They demonstrate very consistent velocity distributions between replicate cages at the same set point velocity. Also noteworthy is a positive bias with a long tail at higher velocities, indicative of turbulent conditions. There is a relatively small increase in median velocities with increasing set point values, although upper quartile (Q3) thresholds increased with set point increase. The velocity distributions at each set point in Fig. 4 further indicate that the replicate cages behaved similarly.

Maps of velocity distribution in the cages further illustrate the velocity distribution within a single cage. For brevity, only a one example of the velocity maps for the two cages subjected to 3 m s^{-1} velocity set point are provided in Figs 5–6. Clearly delineated in these graphs is the distribution of higher velocities towards the cage front, and over the feeder area in the lower levels (Z1 and Z2), with relatively calm conditions toward the cage backs and at higher levels (Z2 and Z3). The linear distribution across the cage front is somewhat variable, with lower velocities towards the cage edges and a relatively broad section along the front with highest velocities.

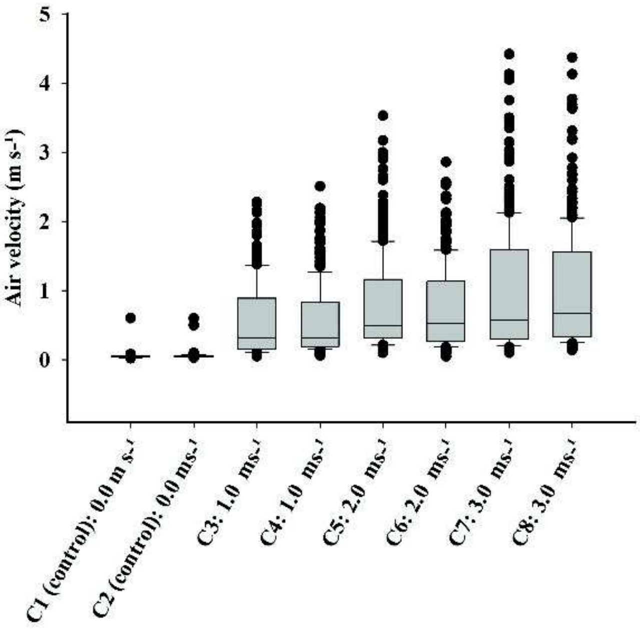

Figure 4. Boxplot of air velocity measurements at 275 locations in two replicate cages in still air and 3 controlled velocities. C1 and C2) Control (cages 1 and 2, still air), 0 m s^{-1}; C3 and C4) Cages 3 and 4, set point 1 m s^{-1}; C5 and C6) Cages 5 and 6, set point 2 m s^{-1}; C7 and C8) Cages 7 and 8, set point 3 m s^{-1}.

The highest air velocity values were concentrated in the front part of the cages, corresponding to the feeder zone (close to the prototype air outlet), as desired. The tendency was for a decrease in the intensity downstream from this region. Since the cages were relatively open to air circulation, part of the flow was dispersed through lateral and upper openings. As the air velocity influences directly the animal feeding behaviour, it was necessary to highlight the characteristics of the air flow and intensity in the region closest to the feeder, located at the air outlet of the tube. The spatial distribution of air velocity maps in this region are shown in Figs 5–6, for setpoint of 3 m s^{-1}, which represents a 'worst-case' scenario for the design.

The velocity distribution in both cases tended to be more uniform at bird head level (Z1), whereas, at the lower level, it was seen to diminish more rapidly with depth into the cage. There was a tendency to have a reduced speed on the sides of the cage. This was a consequence of the system design, with two opposing axial fans creating a substantial amount of turbulence within the tube and pushing a larger percentage of air out the centre 80–90% of the opening. The tendency of velocities to diminish rapidly with depth into the cage was also noted by Rocha et al. (2010), in which they verified high velocities along cage fronts in curtain sided buildings exposed to strong wind. Once more, the configuration of the air flow distribution and intensity can be explained by the system design, as it consists of a fan at each tube end, and thus, there is a tendency for more intense air flow in the central outlet region. In addition, the tube length can be a potential factor for uniformity of air flow distribution.

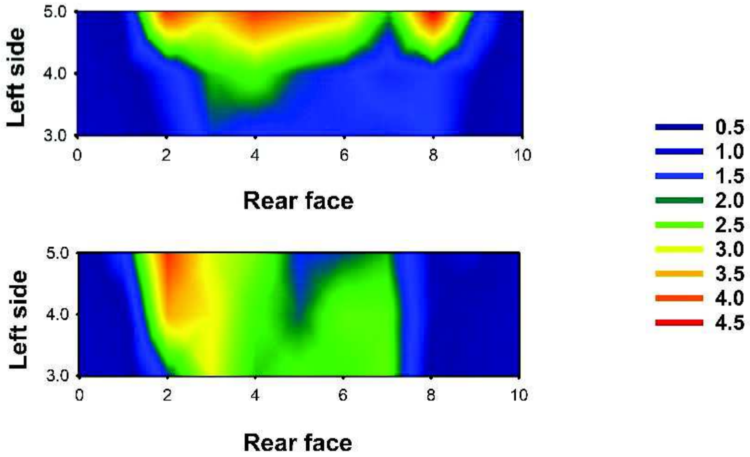

Figure 5. Velocity distribution map for the front feeding zone at the two bottom levels in Cage 7 with velocity set point 3 m s^{-1}; A) lowest level, Z0; B) bird head level, Z1.

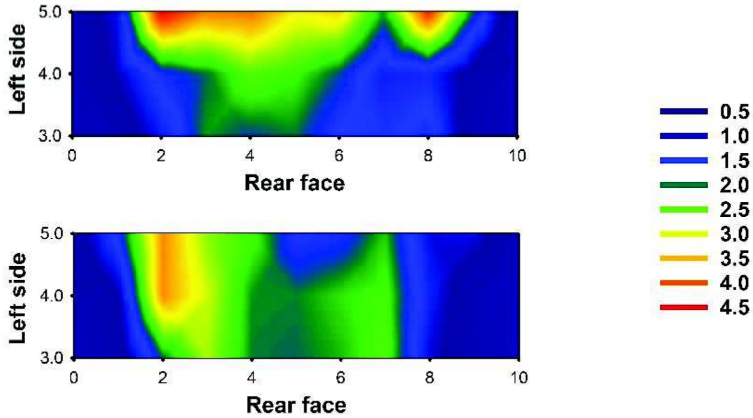

Figure 6. Velocity distribution map for the front feeding zone at the two bottom levels in Cage 8 with velocity set point 3 m s^{-1}; A) lowest level, Z0; B) bird head level, Z1.

An assessment of the relative similarity between replicate cages at four different velocity controller settings is provided in Table 2, in which mean differences, standard deviations and probability of significant difference in mean values are tabulated. Mean velocities between the two replicate cages were similar (P values ranging from 0.053 to 0.820). The magnitude of mean differences ranged from 0.0 to 0.09 m s^{-1} with standard deviations ranging from 0.02 to 0.39 m s^{-1}. Thus, it is concluded that the replicate cages provided suitably similar velocity distributions for each velocity set point tested. However, the mean velocity for the medium and high air velocity setpoint did not achieve the desired values of 2 and 3 m s^{-1}, instead averaging 1.1 and 1.6 m s^{-1}, respectively.

Table 2. Mean (± standard deviation) of velocity measurements in replicate cages, mean $(\bar{d})$ and standard deviation $(S\bar{d})$ of velocity differences between replicate prototypes, and results of a paired t-test for significant difference from zero. Values are for the feeding zone

Nominal Air Velocity Setpoint	Mean Velocity (m s^{-1}) *Prototype 1**	*Prototype 2**	$\bar{d}$	$S\bar{d}$	t_{calc}	*P*
still air (off)	0.05 ± 0.01	0.05 ± 0.01	-0.00	0.02	-0.58	$0.56^{n.s}$
low	0.95 ± 0.69	0.93 ± 0.71	0.02	0.32	0.52	$0.60^{n.s}$
medium	1.14 ± 0.89	1.04 ± 0.75	0.09	0.39	1.97	$0.05^{n.s}$
high	1.62 ± 1.19	1.61± 1.12	0.01	0.23	0.23	$0.82^{n.s}$

* – Prototypes 1 and 2 are replicate systems; *ns* – not significantly different at 5% confidence; $\bar{d}$ – mean of paired differences; $S\bar{d}$ – standard deviation of paired difference.

Strong positive correlations were found in velocity at similar points in these replicate cages, as illustrated in Table 3. The overall correlation results for all points in the replicate cages (n = 275), by velocity setpoint, demonstrate excellent correlation with the Pearson correlation coefficients exceeding 0.9 for all three velocity set points. Similarly, restricting the analysis to the feeding zone produced similarly high correlation coefficients (0.9 to 0.98). Consequently, it was concluded that replicate cages are adequately similar for experimental purposes, if adjusted carefully at the outset.

Table 3. Mean and standard deviation of difference in velocity measurements between replicate prototypes, Pearson's correlation coefficient, and significance of correlation test

Nominal Air Velocity Setpoint (m s^{-1})	Mean Difference (m s^{-1})	Standard Deviation (m s^{-1})	Correlation Coefficient, r	*P*
Results for all sample points (n = 275)				
low	0.01	0.24	0.893	< 0.001
medium	0.05	0.28	0.905	< 0.001
high	0.02	0.19	0.976	< 0.001
Results for all feeding zone sample points (n = 66)				
low	0.02	0.32	0.899	< 0.001
medium	0.10	0.39	0.900	< 0.001
high	0.01	0.23	0.982	< 0.001

For purposes of analysing bird behaviour in the feeding zone, it is more practical to restrict the system assessment to the velocity distribution near the feeder. The feeding zone, as depicted previously with Lines in Fig. 3, represents velocity measured at 66 points for the front 3 rows of measurement points and the lower two levels (Z0 and Z1).

For the nominal velocities of 0, 1, 2 and 3 m s^{-1} established for each treatment, measured mean values by cage (Table 2) were within measurement error except for the 3 m s^{-1} value which were about 1.6 m s^{-1}. The higher air velocity was difficult to achieve since airflow became unstable due to turbulence generated by the design. Replicate cages performed very similarly (Table 2) with mean differences of 0.01 to 0.10 m s^{-1}. However, the system showed to be capable of providing a reasonable range from still air to 1.6 m s^{-1}.

A further examination of the behaviour of air velocity distribution between replicate prototypes is of interest. Since the feeding zone is one of the most important for birds' behavioural study and the points closest to the side walls did not receive the same flow intensity found in the centre, a velocity analysis was performed from the three parallel lines closest to the cage centre (Lines 3, 4 and 5), including the seven points distributed within this area. The average air velocity of each Line and their respective range are listed in Table 4.

Table 4. Mean (± standard deviation), minimum, and maximum values of air velocity for Lines 5 (closest to air outlet), 4 and 3 (approximately where birds are located to eat) for two cages (Fig. 3, A). Measurements were made at two different heights Z0 (at feeder level) and Z1 (approximately bird height) as shown in Fig. 3, B. Reported velocities are from those observed in each Line for two replicate cages, for three nominal air velocity setpoints representing low, medium and high air velocity at the feeder. Note that velocities for the combination of Z1 and Lines 4 and 5 are most representative of a feeding bird's location

Nominal Air Velocity Setpoint ($m\ s^{-1}$)	Matching cages	Lines	Z0	Velocity range (min-max) ($m\ s^{-1}$)	Z1	Velocity range (min-max) ($m\ s^{-1}$)
Low (1 $m\ s^{-1}$)	Prototype 1	3	1.02 ± 0.4	0.25–1.44	1.24 ± 0.4	0.20–1.55
		4	1.47 ± 0.3	0.92–1.97	1.17 ± 0.5	0.45–1.80
		5	1.99 ± 0.3	1.25–2.30	1.23 ± 0.6	0.4–1.95
	Prototype 2	3	1.07 ± 0.4	0.31–1.57	1.12 ± 0.5	0.24–1.76
		4	1.73 ± 0.3	1.16–2.00	1.06 ± 0.5	0.41–2.01
		5	1.96 ± 0.3	1.37–2.51	1.04 ± 0.6	0.31–2.13
Medium (2 $m\ s^{-1}$)	Prototype 1	3	0.96 ± 0.4	0.53–1.61	2.00 ± 0.7	0.51–2.66
		4	0.93 ± 0.3	0.43–1.52	2.18 ± 1.0	0.44–3.53
		5	0.91 ± 0.5	0.35–1.76	2.18 ± 0.9	0.47–3.17
	Prototype 2	3	1.09 ± 0.5	0.62–1.93	1.63 ± 0.5	0.65–2.13
		4	1.17 ± 0.4	0.59–1.98	1.71 ± 0.7	0.66–2.57
		5	1.05 ± 0.5	0.52–1.88	1.91 ± 0.8	0.61–2.86
High (3 $m\ s^{-1}$)	Prototype 1	3	1.56 ± 0.3	0.93–1.80	2.10 ± 0.7	0.62–3.03
		4	1.71 ± 0.4	1.22–2.38	2.38 ± 0.8	0.86–3.50
		5	3.62 ± 0.7	2.13–4.42	2.31 ± 1.0	0.82–4.05
	Prototype 2	3	1.66 ± 0.3	1.14–2.04	2.02 ± 0.5	0.95–2.78
		4	1.81 ± 0.5	1.15–2.50	2.33 ± 0.7	1.20–3.63
		5	3.51 ± 0.7	2.09–4.37	2.14 ± 0.8	1.01–3.65

As observed in Tables 3and 4, the means for the nominal 3 $m\ s^{-1}$ setpoint were substantially lower. This was true regardless of the Line and height (Z0 or Z1) evaluated, except Line 5. This can be attributed to the greater heterogeneity of data induced by turbulence as noted previously. It is found that, in this velocity, there are very low values, generally smaller than 1 $m\ s^{-1}$, and the highest values are very close to 3 $m\ s^{-1}$, which means averages always below the expected nominal velocity for treatment. Such unevenness can also be explained by the effect of turbulence. For the nominal velocities of 1 and 2 $m\ s^{-1}$, the same does not occur in the Z1 height, since there was a higher frequency of valuesclose to and/or above the nominal expectation. This made the average air velocity found in these treatments consistent with the expected.

Examples of research for which these systems were deployed are given in Vilela (2016), and Santos et al. (2017, 2018). To demonstrate the system's utility, Fig. 7 illustrates the results of a two-velocity test to determine production performance response to air velocity and thermal environment. The two velocities were low and high

(0 and 2.3 m s^{-1}) and there were three thermal environments: thermal comfort (TC), dry heat stress (DHS), and humid heat stress (HHS). The following production performance parameters were evaluated: feed intake, water consumption, body weight variation, egg mass and feed conversion.

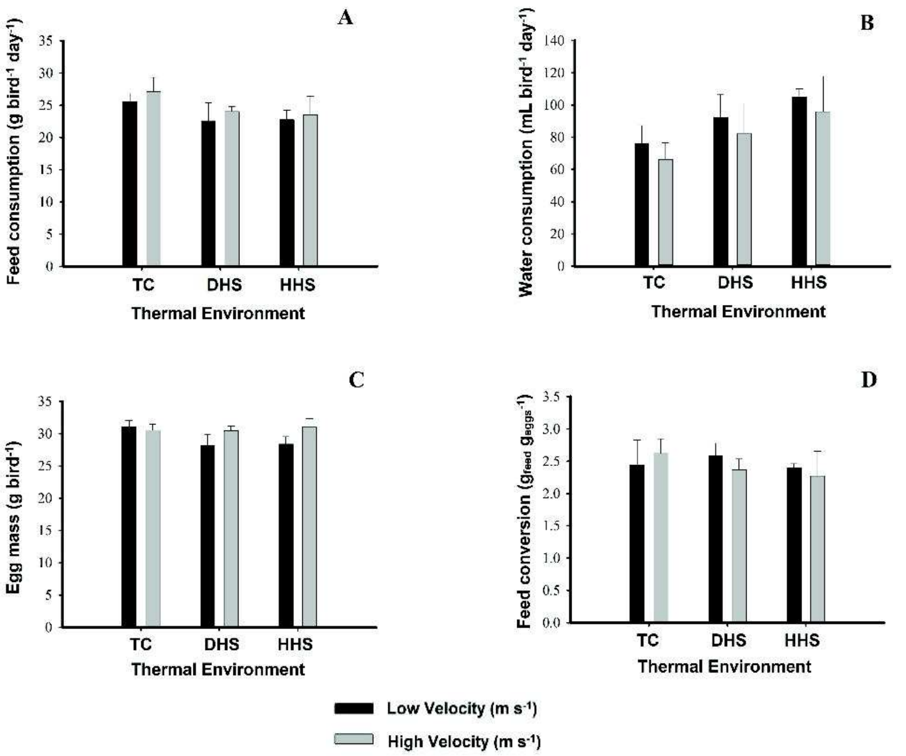

Figure 7. Birds' productive performance (mean ±standard deviation) during the experimental period, under thermal comfort (TC), dry heat stress (DHS) and humid heat stress (HHS) environmental conditions, combined with low and high air velocities. A – Feed consumption (g bird^{-1} day^{-1}); B – Water consumption (mL bird^{-1} day^{-1}); C – Egg mass (g bird^{-1}); Feed conversion (g_{feed} $g_{eggs}$$^{-1}$).

There was no significant statistical influence of the different environment thermal conditions, of the different air velocity levels and of the interaction of these two factors ($P > 0.05$) on feed intake, egg mass and feed conversion. This result may be related to the imposition of discontinuous stress, where the birds returned to the thermoneutrality conditions at night, which may have favoured the stress recovery process. On the other hand, it was found that these different thermal environments significantly influenced water consumption ($P = 0.003$), representing an increase of 29% and 48% in the birds' consumption exposed to DHS and HHS, respectively.

CONCLUSIONS

The system provided mean air velocity that was greatest in the zone where birds are housed (Z0 and Z1), as designed.

Replicate cages, using different air velocity control systems, demonstrated similar velocity magnitude and distribution. This was further confirmed with analysis of paired differences in velocity between replicates and with a correlation analysis.

Measured air velocity variation within a cage was substantial, because of the open nature of the cages; however, desired velocity at the feeder zone was achieved, except for the mean air velocity measured in the feeder zone for the 3 m s^{-1}, where velocity nominal set point was 2.3 (± 0.10) m s^{-1}.

Comparing the mean value of the measured and predetermined air velocity for each treatment, there is a need for greater attention for adjusting the air outlets at higher velocities (e.g. at or above 3 m s^{-1}).

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