Effects of Structural and Stacking Configuration of Containers for Transporting Chicks in Their Microenvironment

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Abstract. *Breeder (layer) chicks in transit are vulnerable to oxygen shortages that stem from the lack of mechanical ventilation in holding areas such as warehouse and cargo compartments of aircraft. Such vulnerable periods tend to occur around departure time of an aircraft when the cargo door is closed but the compartment has not been pressurized, and vice versa upon landing. To maintain the well-being of the chicks, sufficient air exchange through the containers is essential during these periods. This study examined the air flow rates and internal thermal conditions of a commercial chick container as influenced by its structural and stacking configurations. Specifically, a 2×2 factorial arrangement of container structures was examined that consisted of a regular cardboard box (62 × 47 × 15 cm) and a box modified by adding extra vent holes (128 vs 92) on the side walls; each type of box was covered with either the regular cardboard lid or a modified plastic poultry grid lid. The effects on air flow rate of vertical distances (VD) from 2.5 cm (currently used) to 17.8 cm between the boxes were evaluated with one stack of four containers. The effects on air flow rate of horizontal distances (HD) from 5.1 to 15.2 cm between the stacks were evaluated with four stacks of six containers each. NI/CR electrical heating wires evenly located above the excelsior bedding were used to simulate sensible heat production rate (21 W at 30°C) of 88 unfed day-old chicks that are normally held per container.*

The results revealed that the measured ventilation rate under the current box structure and stacking arrangement (averaging 0.013 L/s/chick or 0.028 CFM/chick) seemed sufficient during cold weather but was considerably below values recommended for mild to hot weather. An improved, practical container structure and stacking configuration features the regular container body with the grid lid, 7.6 cm VD between boxes, 5.1 cm HD between stacks linked with the existing cardboard spacers. The improved structure and stacking configurations had an average air flow rate of 0.062 L/s/chick. The corresponding internal temperature rise of the containers relative to the test room temperature was 3.4, 4.7, 4.8, 5.0, 5.5, and 4.8 K for layer 1 (bottom layer), 2, 3, 4, 5 and 6 (top layer), respectively, compared to 5.5, 8.1, 9.1, 9.8, 9.9, 7.8 K for the current box structure and stacking arrangement. Because of the excessive air flow rate and potential cold draft for the top layer, the original cardboard lid was recommended for the top containers.

Keywords. *Air transportation, Air exchange, Breeder chicks, Natural ventilation, Stress, Mortality.*

Unexpected delays and stressful environmental and nutritional conditions have been reported for international shipments of breeder chicks (Xin and Rieger, 1995). Certain nutritional stress-alleviation measures have been investigated by Xin and Lee (1996) and are being adapted by the breeder industry. Another issue that influences the well-being of the chicks is the airflow rate through the containers during the journey. Field observations have indicated that the chicks occasionally show signs of oxygen deficiency when unloaded from the airplanes. Such claims probably bear some truth considering the operational procedure of the shipment. For instance, the time between closure of the cargo door and pressurization of the compartment for take-off may last from 30 to 60 min. Likewise, upon landing, the period between the time the engines are turned off and the opening of the cargo door and unloading of the chicks may also vary considerably. During these time periods, natural ventilation through the chick containers may be quite limited, resulting in a shortage of oxygen. In fact, higher container temperatures, presumably caused by reduced ventilation rate, during these periods had been reported by Xin and Rieger (1995). To improve the situation, a container structure and stacking arrangement that enhances natural ventilation is needed.

The objectives of this study were (1) to quantify the airflow rate and internal thermal conditions of layer chick shipping containers as influenced by container structures and stacking configurations; and (2) to identify a practical, cost-effective container structure and a stacking configuration that will lead to an improved microenvironment for the chicks.

Materials and Method

Experimental Chick Containers

Two types of chick shipping containers (boxes for short) were evaluated in this study: the regular box (RB) and the modified box (MB). The RB was a commercial perforated cardboard box (fig. 1) with 92 vent holes (1.6 cm diameter)

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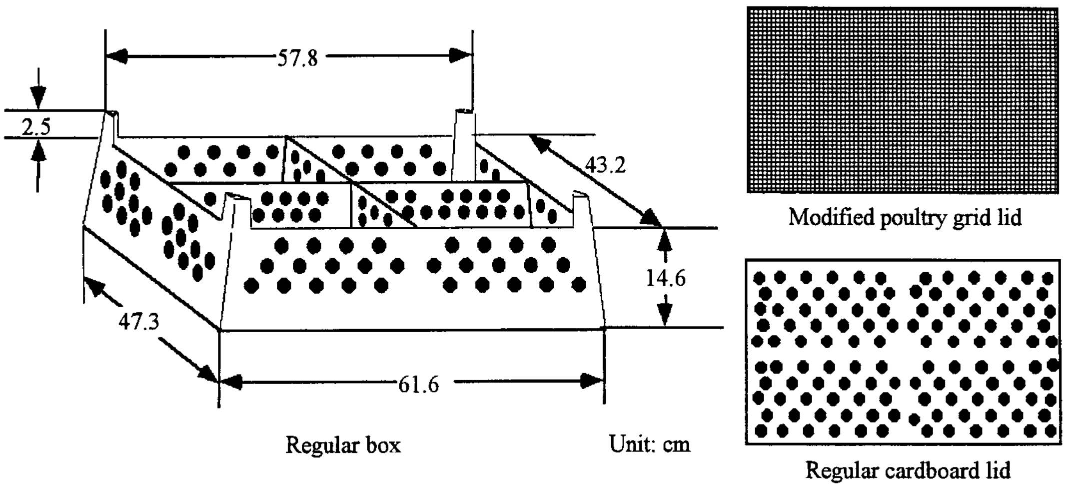

Figure 1–Outline of chick shipping container with regular and modified lids.

on the side walls and 124 vent holes on the lid. The MB was made of the RB with 36 extra vent holes (1.6 cm diameter) on the side walls. Each box was divided into four sections with perforated cardboard dividers and had the capacity of holding 88 chicks per box. Excelsior bedding was used to cover the floor of the box. Two types of lids were used in this study: the regular cardboard lid (RL) and a plastic poultry grid lid (GL) with 1563 square holes (1.1 × 1.1 cm) to enhance air exchange. The two box body types and two lid types thus constituted four box configurations, designated as RBRL, RBGL, MBRL, and MBGL. The area opening ratios (the ratio of opening area to the total surface area) for each surface and the overall container are summarized in table 1.

DETERMINATION OF OVERALL HEAT TRANSFER COEFFICIENT (UA) OF THE CONTAINERS

The overall heat transfer coefficient, UA, of the containers, was determined by the energy balance method, namely,

$$P - UA \times \Delta\theta - C_p \times \rho \times \Delta\theta \times V = 0 \qquad (1)$$

Table 1. Opening ratios of container surface components and as a whole

Variable		Vent Hole No.	Opening Area (cm^2)	Surface Area (cm^2)	Opening Ratio
Surface					
Lid	Regular*	124	249	2497	0.100
	Grid†	1563	1891	2497	0.757
Side wall	Regular	92	185	1532	0.121
	Modified	128	257	1532	0.168
Overall					
Regular	Regular lid*	216	434	6943	0.063
	Grid lid†	1655	2076	6943	0.299
Modified	Regular lid*	252	506	6943	0.073
	Grid lid†	1691	2148	6943	0.309

* Hole diameter = 1.6 cm.
† Square side = 1.1 cm.

where
P = internal heat generation rate of the container (W)
UA = overall heat transfer coefficient (W/K)
$\Delta\theta$ = air temperature gradient between inside and outside of the container (K)
C_p = specific heat of the air [J/(g(K)]
ρ = density of the air (g/L)
V = ventilation rate of the container (L/s)

The internal heat (P, 21 W) was generated with 12 Vdc-powered NI/CR heating wires (Omega Engineering, Stanford, Conn.) that were evenly distributed in the container. The boxes were sealed with thin plastic film (plastic food wrap with negligible thermal resistance) so that no ventilation took place. Substituting V = 0 into equation 1.

$$UA = \frac{P}{\Delta\theta} \qquad (2)$$

Air temperatures inside and outside the containers were measured with special-limit-error type T (copper-constantant) thermocouples (Omega Engineering) at an accuracy of 0.1 K. The sensors were connected to a data acquisition system (CR-10 & AM-416, Campbell Scientific Inc., Logan, Utah). Once internal conditions of the containers reached equilibrium, air temperatures were taken every 2 s and averaged every minute. Eleven-minute averages were then used for calculation of the UA values. Table 2 lists the UA values for the experimental containers.

EVALUATION OF VERTICAL DISTANCE (VD) BETWEEN BOXES ON AIRFLOW

A single stack of four boxes was used to determine the effects of VD on airflow rate and temperature rise (fig. 2). The stack was placed in a small “warehouse” (3.2 m long ×

Table 2. Overall heat transfer coefficients (UA, W/K) of the experimental containers

	RBRL	RBGL	MBRL	MBGL
UA	1.87	2.07	1.88	2.10

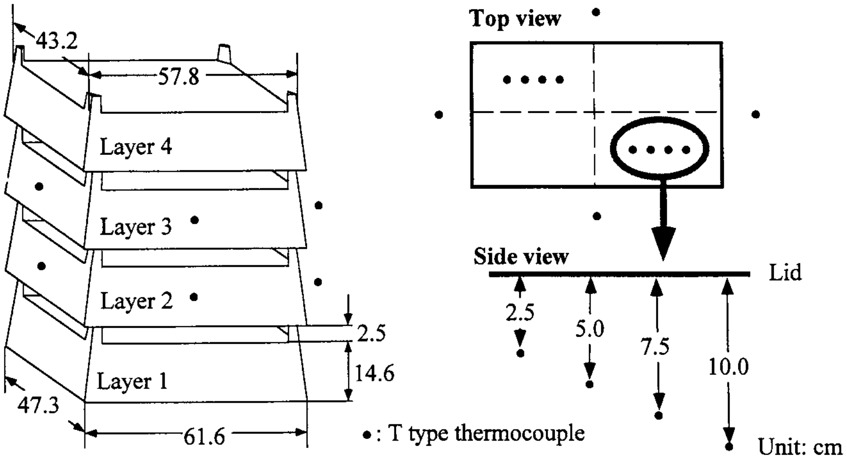

Figure 2–Schematic of 4-layer container stack and locations of temperature sensors.

2.7 m wide × 3.5 m high) without mechanical ventilation. Ambient and container temperatures were measured under a steady-state thermal condition of 30°C. Figure 2 also shows the locations of the measurement thermocouples. The VDs evaluated were 2.5, 6.4, 10.2, 14.0, and 17.8 cm, with 2.5 cm being the VD currently used by the breeder company.

EVALUATION OF HORIZONTAL DISTANCE (HD) ON AIRFLOW

Four stacks of six boxes each were used to evaluate the effects of HD between the stacks on airflow and internal temperature (fig. 3). The evaluation was performed under steady-state conditions in a larger "warehouse" of 12.0 m long × 9.0 m wide × 4.8 m high. The measurement locations are shown in figure 3. The HDs tested were 5.1, 10.2, and 15.2 cm. The HD effects were evaluated for two VH levels of 2.5 cm and 7.6 cm. Furthermore, the effects of stack spacers on airflow were evaluated for the 5.1 cm HD conditions.

All the boxes had an internal heat source, P, of 21 W (as described above) that represented the sensible heat production rate of 88 unfed chicks at 30°C (Xin and Harmon, 1996). Ventilation rate of the container was calculated by rearranging equation 1.

$$V = \frac{P - UA \times \Delta\theta}{C_p \times \rho\, \Delta\theta} \qquad (3)$$

RESULTS AND DISCUSSION

EFFECTS OF BOX STRUCTURE AND VD ON AIRFLOW RATE AND INTERNAL TEMPERATURE RISE

The average airflow rates of the second and third boxes of the four-box stacks as affected by VD are delineated in figure 4. The corresponding internal temperature rises are shown in figure 5. The overall airflow rate averaged 0.040 L/s/chick for the GL boxes (i.e., RBGL and MBGL) and 0.024 L/s/chick for RL boxes (RBRL and MBRL), a difference of 0.016 L/s/chick ($P<0.01$). The corresponding difference in internal temperature rise was 1.1 K ($P<0.01$). The airflow difference between the RL and GL containers increased with VD. Figures 4 and 5 show that replacing the cardboard lid with the grid lid was much more effective than adding extra vent holes on the side walls in enhancing airflow rate and reducing the internal temperature rise of the boxes. The less significant effects of extra vent holes on the side walls are further demonstrated in table 3 for GL boxes. As shown in table 3, the airflow difference between the 144-vent-hole box and 92-vent-hole box (regular box) was 0.007 L/s/chick, an 18.4% increase. The associated air temperature decrease was 0.3K. During flight, airplane cargo is ventilated, and the temperature of the cargo compartment can be as low as 10°C to 15°C (Xin and Rieger, 1995). To avoid cold air draft directly through the sidewall vent holes into the containers, the box with fewer sidewall vents would be more desirable. Therefore, the regular box with grid lid (RBGL) seemed more suitable for use in the international shipment of baby chicks.

A minimum ventilation rate of 0.019 L/s/chick during cold weather was recommended by MWPS (1990). From figure 4, note that at least 5.1 cm (2 in.) VD is needed for the RBGL structure to achieve this minimum airflow rate. Because stressful container temperatures of 38 to 40°C can be and have been encountered during transportation (Xin and Rieger, 1995), a higher ventilation rate is desired. The higher flow rate is also expected to help alleviate oxygen stress caused by lack of air circulation in the holding compartment around take-off and landing periods. Meanwhile, because the breeder companies are charged by the volume of space occupied in the aircraft cargo compartment (Lohr, 1996, Personal Communication, Hy-Line International, Dallas Center, Iowa), it is desirable to keep the VD and thus stack volume as small as practical. Balancing the ventilation needs and economic feasibility, a 7.6 cm (3 in.) VD was chosen to further test the effects of stacking arrangements.

EFFECT OF HD BETWEEN STACKS ON AIRFLOW RATE AND INTERNAL TEMPERATURE RISE

Average airflow and temperature differences between the container and the test room are summarized in table 4. Duncan's multiple mean comparison test was performed using each container airflow rate and temperature to evaluate the effects of HD on airflow rate and temperature rise for both RB and MB, and the results are presented in tables 5 and 6.

The RBGL box with 7.6 cm VD, 5.1 cm HD, and cardboard spacers had the highest airflow rate and the

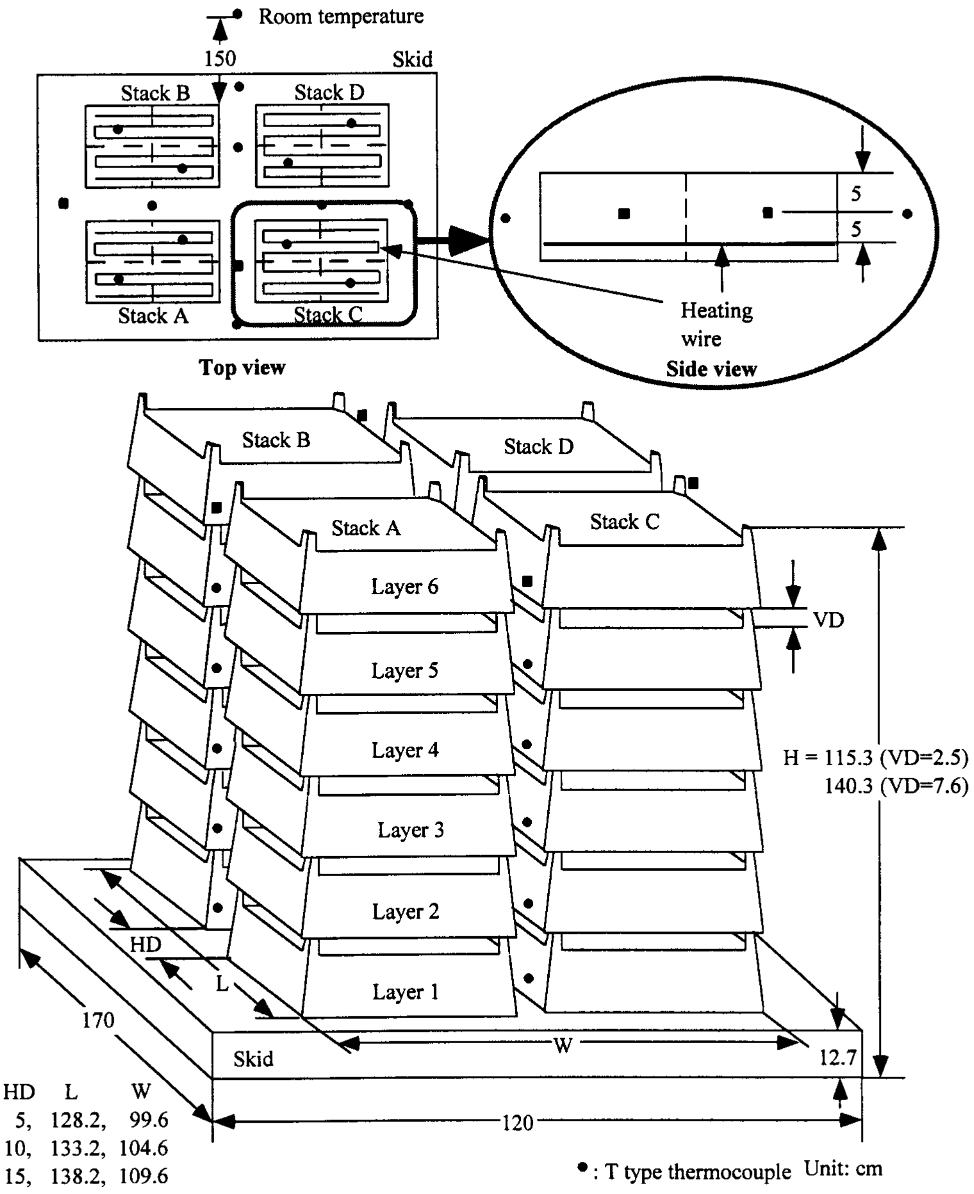

Figure 3–Four stacks of 6-layer chick containers used to evaluate the effects of horizontal distances on airflow rate.

lowest internal temperature rise. Interestingly, as HD increased, airflow rate decreased. Table 7 shows the average open space air velocity at the top (sixth) layer level and the average temperature difference between the open space and the room.

Although no statistical significance was detected (P>0.05), air velocity in the open space of the stack was greatest for HD = 5.1 cm. Also, air velocity in the open space increased with height. This outcome was believed to result from the thermal buoyancy and air entrainment effects

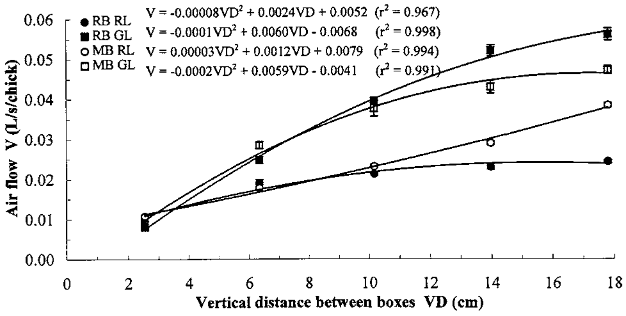

Figure 4–Average airflow for each container of 88 chicks.

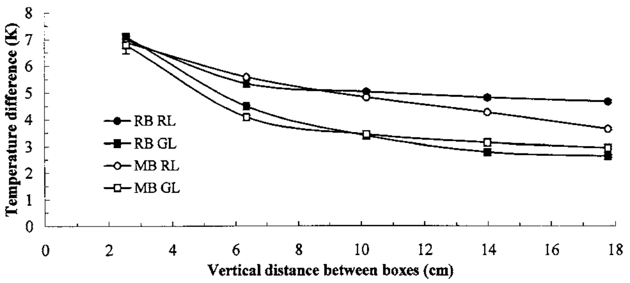

Figure 5–Temperature difference (container — ambient) vs vertical distance between boxes.

Table 3. Effect of side holes on airflow rate and temperature difference when the grid lid is used

Total number of vent holes on side walls	92	112	128	144
Opening ratio	0.299	0.305	0.309	0.314
airflow (L/s/chick)	0.038	0.041	0.043	0.045
Temperature difference* (K)	3.4	3.3	3.2	3.1

* (Inside container — ambient).

of airflowing through the open space, which pulled air from the containers into the open space. Air velocity caused by thermal buoyancy is expressed as (Albright, 1990):

$$V = \sqrt{\frac{2gh}{\gamma_1}\left(\gamma_2 - \gamma_1\right)} \cong \sqrt{\frac{2gh}{T_m}\left(t_1 - t_2\right)}$$

$$T_m = 273.15 + \left(\frac{t_1 + t_2}{2}\right) \qquad (4)$$

where

g	acceleration of gravity (m/s^2)
h	vertical distance between lower and upper points (m)
t_1	air temperature at upper point (°C)
t_2	air temperature at lower point (°C)
T_m	absolute mean temperature (K)
γ_1	air density at upper point (kg/m^3)
γ_2	air density at lower point (kg/m^3)

Table 4. Summary of air flow rate and temperature difference between the container and room

Lid Type	Vert. Dist. (cm)		H.D.* = 5.1 cm With Spacer		H.D.* = 5.1 cm Without Spacer		H.D.* = 10.2 cm Without Spacer		H.D.* = 15.2 cm Without Spacer	
			Air Flow (L/s/chick)	Δθ† (K)	Air Flow (L/s/chick)	Δθ† (K)	Air Flow (L/s/chick)	Δθ† (K)	Air Flow (L/s/chick)	Δθ† (K)
Reg.	2.5	Mean	0.013	8.4	0.012	8.2	0.012	8.0	0.011	7.8
		S.D.	0.009	0.07	0.008	0.05	0.010	0.05	0.010	0.03
	7.6	Mean	0.027	6.3	0.023	6.2	0.020	6.1	0.019	6.0
		S.D.	0.008	0.04	0.005	0.04	0.004	0.04	0.004	0.05
Grid	2.5	Mean	0.022	8.2	0.021	8.1	0.016	7.6	0.016	7.0
		S.D.	0.026	0.06	0.028	0.02	0.016	0.04	0.014	0.03
	7.6	Mean	0.062	4.7	0.053	5.3	0.035	5.0	0.033	4.8
		S.D.	0.041	0.05	0.065	0.07	0.013	0.03	0.011	0.05

* Horizontal distance between stacks.
† (Container — Room) temperature.
Each mean value is based on 264 data points (i.e., 24 data points/min × 11 min).

Table 7. Open space air velocity and temperature difference between the open space and room

Lid Type	Vert. Dist. (cm)		H.D.* = 5.1 cm With Spacer		H.D.* = 5.1 cm Without Spacer		H.D.* = 10.2 cm Without Spacer		H.D.* = 15.2 cm Without Spacer	
			Velocity* (m*/s)	Δθ‡ (K)	Velocity* (m*/s)	Δθ‡ (K)	Velocity* (m*/s)	Δθ‡ (K)	Velocity* (m*/s)	Δθ‡ (K)
Reg.	2.5	Mean	0.25	3.6	0.15	2.9	0.15	2.1	0.13	1.3
		S.D.	0.06	1.7	0.04	1.3	0.04	1.0	0.06	0.8
	7.6	Mean	0.23	2.8	0.21	2.5	0.20	1.7	0.15	1.2
		S.D.	0.04	1.5	0.07	1.2	0.08	0.9	0.06	0.8
Grid	2.5	Mean	0.19	4.2	0.19	3.4	0.16	2.2	0.14	1.3
		S.D.	0.02	2.1	0.05	1.7	0.09	1.1	0.06	0.8
	7.6	Mean	0.30	3.0	0.26	3.1	0.25	2.0	0.22	1.5
		S.D.	0.03	1.8	0.03	1.7	0.01	1.2	0.06	1.0

* Horizontal distance between containers.
† Average air velocity at the top layer level (sixth layer).
‡ (Open space — room) temperature.

Thus, as the open space temperature increased with narrower HD, air velocity increased. The average open space temperature using the spacer was 0.4 K higher than that without the spacer, and the air velocity was slightly greater (0.04 m/s). The combination of RBGL, 7.6 cm VH, 5.1 cm HD, and spacer produced the greatest open space air velocity (0.30 m/s), lowest internal temperature rise of the container (4.7 K relative to the room), and the highest airflow rate (0.062 L/s/chick). Use of this combination would be the easiest way to achieve the desired microenvironment without a major overhaul of the manufacturing equipment for the chick containers.

Figure 6 compares the airflow rate and temperature rise at each layer as influenced by lid type and VD for 5.1 cm HD. Clearly, the currently used VD (2.5 cm) severely restricts airflow by natural ventilation (averaging 0.013 L/s/chick), especially for the middle layers. By comparison, airflow (average 0.062 L/s/chick) was 1.5 to 7.0 times (average 4.8 times) greater with the grid lid and VD of 7.6 cm. The modified container structure and stacking arrangement also had a favorable characteristic of increasing airflow rate from the bottom to top layer. This feature allows for maintenance of a relatively uniform temperature rise inside the boxes. One drawback of the GL boxes was the excessive airflow rate (0.14 L/s/chick) at the top layer which may introduce cold drafts for the chicks. This can be corrected by using RL for the top boxes.

CONCLUSIONS

Airflow rates and internal thermal conditions of chick shipping containers as influenced by structural and

Table 5. Effects of HD on airflow rate for two VD levels of both RL and GL boxes (all boxes are RB)

Lid	GL	GL	GL	GL	RL	RL	GL	GL	RL	RL	GL	GL	RL	RL	RL	RL
VD (cm)	7.6	7.6	7.6	7.6	7.6	7.6	2.5	2.5	7.6	7.6	2.5	2.5	2.5	2.5	2.5	2.5
HD (cm)	5.1	5.1	10.2	15.2	5.1	5.1	5.1	5.1	10.2	15.2	15.2	10.2	5.1	5.1	10.2	15.2
Spacer	Y	N	N	N	Y	N	Y	N	N	N	N	N	Y	N	N	N
Mean*	62_a	53_b	35_c	33_c	27_d	23_{de}	22_e	21_e	20_{ef}	19_{ef}	16_{fg}	16_{fg}	13_{gh}	12_h	12_h	11_h

* Unit, mL/s/chick.
Means with different subscript letters are significantly different ($P < 0.05$).

Table 6. Effects of HD on internal temperature rise for two VD levels of both RL and GL boxes (all boxes are RB)

Lid	GL	GL	GL	GL	RL	RL	RL	RL	GL	GL	RL	RL	GL	GL	RL	RL
VD (cm)	7.6	7.6	7.6	7.6	7.6	7.6	7.6	7.6	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5
HD (cm)	5.1	15.2	10.2	5.1	15.2	10.2	2.5	2.5	15.2	10.2	15.2	10.2	5.1	5.1	5.1	5.1
Spacer	Y	N	N	N	N	N	N	Y	N	N	N	N	N	Y	N	Y
Mean	4.7_a	4.8_a	5.0_{ab}	5.3_b	6.0_c	6.1_c	6.2_c	6.3_c	7.0_d	7.6_e	7.8_{ef}	8.0_{fg}	8.1_{fg}	8.2_{fg}	8.2_g	8.4_g

Means with different subscript letters are significantly different ($P < 0.05$).

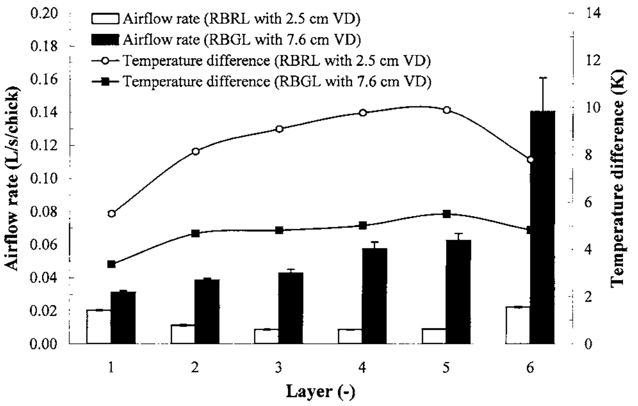

Figure 6–Average airflow rate and temperature difference between containers and room using 5.1 cm horizontal distance with spacers.

stacking configurations were examined. The following conclusions were drawn from this study:

1. Container structure and stacking arrangement currently used in shipping chicks provides an average natural ventilation rate of 0.013 L/s/chick with an internal temperature rise of 8.4 K. Such ventilation rate, though sufficient for cold climate, falls considerably short of the requirement for warm to hot weather conditions.
2. A container structure and stacking configuration that enhance air exchange and thus improve the microenvironment feature the regular box with a poultry grid lid, a 7.6 cm (3 in.) vertical distance between containers, and a 5.1 cm (2 in.) horizontal distance between the stacks linked with the existing cardboard spacers. The modified structure and stacking configuration provide an average ventilation rate of 0.062 L/s/chicks with a 4.7 K temperature rise.
3. The modified container structure and stacking arrangement have a favorable characteristic of increasing airflow rate with stack height, therefore maintaining a relatively uniform internal temperature rise throughout the containers.

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