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Heat and Moisture Production and Minimum Ventilation Requirements of Tom Turkeys During Brooding-growing Period

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HEAT AND MOISTURE PRODUCTION AND MINIMUM VENTILATION REQUIREMENTS OF TOM TURKEYS DURING BROODING-GROWING PERIOD

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ABSTRACT. *Heat and moisture production rates of Nicholas tom turkeys raised under lab-scale commercial production settings were continually measured during a five-week brooding-growing period. Functions were established that relate age and body mass (BM) of the birds to their specific total heat production rate (THP), sensible heat production rate (SHP), moisture production rate (MP), and CO_2 production rate. MP of the current study included both latent heat loss of the birds and evaporation of moisture from the litter and drinkers. Comparison of the HP and MP data from the current study with those in the ASAE Standard (EP 270.5) for BM = 0.1 to 1.1 kg revealed a 4% (for BM = 0.1 kg) to 282% (for BM = 1.0 kg) higher MP and a 2% to 107% lower SHP for the current study. THP from the current study was generally greater (up to 49%) than that in the Standard except for younger birds (< 0.1 kg) whose THP was 36% less than that in the Standard. THP of the experimental tom turkeys peaked near two weeks of age. Compared with the literature data, HP and MP characteristics of the litter-grown young turkeys more closely resemble those of equal BM broilers raised on litter (Reece and Lott, 1982). Minimum ventilation rates (MVR) based on the new MP data for the five-week brooding-growing period were determined and tabulated for selected cold outside conditions and thermoneutral inside conditions. There were substantial discrepancies in MVR between the literature (MWPS, 1990) recommendations and the values derived from this study, with the literature MVR being 20 to 557% of the derived MVR. The age- or BM-dependent MVR obtained from the current study provide a new, convenient reference for ventilation design and operation of turkey brooder houses. Moreover, the equations of CO_2 production rate from this study provide a practical tool for estimating ventilation rates in naturally ventilated brooder facilities. The results further revealed the urgent need to systematically update the literature HP and MP data for ventilation design of animal structures so that modern genetics, nutrition, housing systems, and management schemes can be more realistically reflected.*

Keywords. *Energetics, Indirect calorimeter, Tom turkey, Environmental control, Minimum ventilation.*

Heat and moisture production rates (HP and MP) from animals and their housing components provide fundamental data for the engineering design of a building environmental control system (ASAE, 1997; ASHRAE, 1997; CIGR, 1992). For instance, the design of heating and cooling needs by a confinement building requires the knowledge of sensible HP (SHP) characteristics of the building. Similarly, determination of minimum ventilation rate (MVR) under cold climates generally relies on MP data. This is particularly true with floor-reared poultry facilities such as turkey brooder houses where fresh bedding is used and implementation of the moisture-based MVR generally can sustain an acceptable air quality (e.g., ammonia level) in the building. The need of extra ventilation to maintain acceptable ammonia levels in broiler houses employing reused litter has been previously reported (Xin et al., 1996a).

Most HP and MP data in the literature, however, date back 20 to 40 years, and remarkable changes have since taken place in animal genetics, nutrition, housing equipment, and management schemes. Such changes can significantly alter the HP and MP characteristics of the animals and their housing facilities. For instance, a recent study with early weaned pigs (Harmon et al., 1997) revealed that modern faster-growing nursery pigs have a 30 to 55% higher total HP (THP) than their 40-year-old literature counterparts, and that MP from the current nursery pig housing facility is up to 135% higher than that used by the ASAE Standard. The underlying cause for this large MP discrepancy was presumably that MP data in the ASAE Standard, derived from animal energetics studies, exclude the moisture evaporation from litter/feces or water spillage. To compensate for such shortfalls, certain empirical coefficients have been suggested to adjust the literature MP data before they are used in the design of building ventilation systems (ASHRAE, 1997). But such empirical adjustments are doomed to be hit-or-miss because the partition of THP into SHP and MP can vary

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considerably among production facilities even when the animals share similar THP with their literature counterparts (Reece and Lott, 1982; Gates et al., 1996; Xin et al., 1996b). Such variations stem from the different management practices and/or housing schemes. Thus, a systematic examination and update of the HP and MP data specific to modern animal production situations seems warranted.

The objectives of this particular study were twofold: (1) to determine HP and MP from tom turkey brooding units that emulate commercial production with regard to environmental settings and management schemes; and (2) to develop MVR, based on the measured MP, as a function of bird age or body mass (BM) at selected climatic conditions during the five-week brooding-growing period.

Materials and Methods

Experimental Turkeys and Management Schemes

Three hundred and thirty-two Nicholas tom poults were procured from a commercial hatchery and transported to the Livestock Environment and Animal Physiology (LEAP) Research Lab of the Agricultural and Biosystems Engineering Department at Iowa State University in Ames, Iowa. Before delivery, the experimental poults were processed by debeaking and vaccination, as typically performed with commercial production poults. The poults were exempt from toe-clipping because of the relatively short duration of the experiment (35 days). Upon arrival at the LEAP Lab, the poults were randomly divided into four groups (83 birds/group) by BM similarity. They were then randomly assigned to four environmentally controlled indirect calorimeter chambers (1.8 × 1.5 m floor space per chamber). The chambers used suspended wooden floors covered with approximately 8-cm-thick fresh wood-shaving bedding and had been warmed at 29°C for 24 h before receiving the experimental poults.

Fresh air was introduced to each chamber by an air handling unit (model Climate-Lab-AA, Parameter Generation & Control, Black Mountain, N.C.). Air change per hour (ACH) for the chambers ranged from 6.7 at the beginning of the trial period to 16.7 toward the end of the trial period. Air temperature inside the chambers was maintained at 29.4, 28.3, 26.7, 23.9, and 21.1°C (±0.5°C), respectively, during the first, second, third, fourth, and fifth week of the brooding-growing period. During the initial 10 days, localized heating was provided with a 135W electrical infrared (IR) brooder (28 × 102 cm) (QC Supply, Schuyler, Nebr.) suspended about 46 cm above the center of the chamber floor. The highest floor surface temperature under the brooder was measured with an IR thermal imaging camera (Model PM-250, Inframetrics, N. Billerica, Mass.) to be around 35°C. An interior view of the chamber setup with the IR brooder in place is shown in figure 1. The air temperatures and the localized heating seemed to provide thermoneutral micro-environments for the birds, as evidenced by the nearly contacting postural behaviors of the birds. Relative humidity (RH) of the chambers ranged from 35 to 60% throughout the trial period. Air velocity at the bird level, measured with a hot wire anemometer (model MPM 4100, Solomat Neotronics, Norwalk, Conn.), was less than 0.15 m/s which is commonly considered as "still" air.

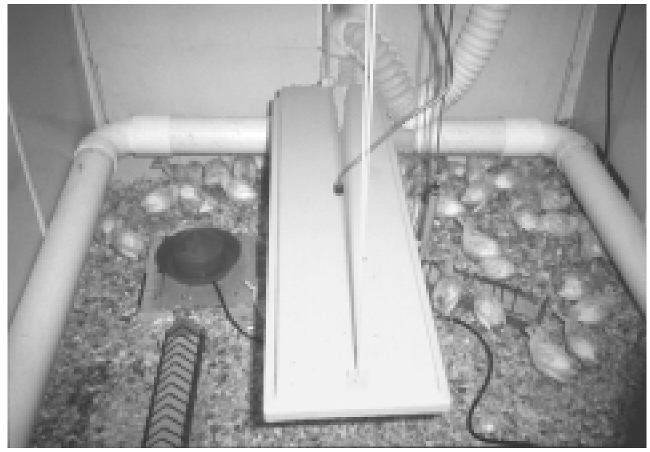

Figure 1–An interior view of the indirect calorimeter chambers. An electric IR brooder was used to provide localized heating during the initial 10 days of the trial period.

Corn-soybean meal diet was provided to the birds *ad libitum* with plastic egg crates placed under the brooder (two per chamber) for the first two days, with trough feeders (two per chamber) from three to seven days of age, and with self feeders (one per chamber) thereafter. Fresh feed was introduced two to three times daily by either adding new feed to the egg crates or trough feeders or shaking the self feeders. The same diet was used throughout the five-week trial period and it contained 2,850 kcal/kg ME, 28.50% protein, 1.08% total sulfur amino acids, 0.55% methionine, 1.65% lysine, 1.20% calcium, and 0.60% nonphytate phosphorus. Fountain type (also known as satellite) drinker (two per chamber) were used to deliver tap water to the birds. They were situated on wooden stands and were cleaned two to three times daily. Continuous lighting of 25 lux intensity at the bird level was provided throughout the trial period.

The number of birds housed in each chamber was 83, 77, 60, 50, and 40, respectively, during the first, second, third, fourth, and fifth week. The corresponding weekly stocking density was 336, 362, 465, 557, and 697 cm^2/bird (0.36, 0.39, 0.50, 0.60, and 0.75 ft^2/bird), respectively.

As normally practiced in commercial brooder buildings, fecal accumulation, particularly around the feeders and drinkers, was removed once or twice a week to maintain acceptable aerial ammonia level (< 25 PPM) in the chambers. Fresh bedding was added after each removal of the caked litters (decaking).

Measurement of Bird Performance, THP, MP, SHP, and Respiratory Quotient (RQ)

Average BM of the birds was measured, on a per-chamber basis, with a digital electronic scale (60 kg capacity and 10 g resolution) at the beginning of the trial and at the end of each growing week. Weekly feed use per chamber was determined by the difference in the amount of feed in the storage container between the beginning and the end of each week and the amount of feed left in the feeder. Weekly average feed conversion was calculated as the ratio of weekly feed use to weekly BM gain. Water consumption was not measured.

THP of the birds was determined by indirect calorimetry, i.e., from measurement of oxygen (O_2)

consumption and carbon dioxide (CO_2) production of the birds. MP from the chambers (birds *and* the surroundings) was measured by the difference in air moisture content between the fresh air and the outgoing air. SHP was calculated as the difference between THP and the MP-based latent HP. RQ was calculated as the ratio of volume of CO_2 produced to volume of O_2 consumed. The HP, MP, and RQ data were collected at 30-min intervals throughout the trial period. When the chamber was opened to access the feeders/waterers or to remove caked litter, the resultant data of altered air composition were excluded from the analysis. This exclusion was carried out by both program filtering and manual screening of the raw data. The HP and MP for each chamber were converted to specific values (i.e., unit body mass) by dividing the daily average total BM of the chamber into the HP or MP. The specific THP, SHP, MP, and RQ were then expressed as the daily means with the respective 95% confidence intervals. Detailed description of the ISU indirect calorimeter system and the mathematical equations used to determine THP, MP, and SHP have been previously presented by Xin and Harmon (1996). Calibration of the gas analyzers with primary standard zero and span gases was performed twice daily throughout the experiment. Error analysis of the measurement instruments revealed a maximum error of ±0.3 W per chamber for the THP determination. Note that the terms HP and heat loss have the same meaning for this study because HP was measured under equilibrium conditions of the birds and the housing system.

Determination of MVR for Moisture Removal Under Selected Climatic and Housing Conditions

The MP data from this study was used to determine the MVR of turkey brooder buildings for selected cold to cool outside conditions. Specifically, the selected outside temperatures ranged from –23 to 10°C at an increment of 2.8°C. The concomitant outside RH ranged from 20 to 90% at increments of 10%. The inside air temperature followed the thermoneutral levels of 29.4°C to 21.1°C depending upon the bird age, as used in the current experiment. Two inside RH levels of 50% and 60% at each air temperature were considered in the MVR determination. The following equation was used:

$$\text{MVR} = \frac{\text{MP}}{\rho \times (W_o - W_i) \times 1000} \quad (1)$$

where

- MVR = minimum ventilation rate [m^3/(kg-h)]
- MP = moisture production rate from the housing system [g/(kg-h)]
- ρ = air density, 1.25 g/L (0°C, 50% RH, and 98 kPa barometric pressure)
- W_i,W_o = humidity ratio of incoming (fresh) and outgoing (exhaust) air, respectively

W_i and W_o were determined with a computer psychrometrics program that uses dry-bulb temperature, RH, and barometric pressure (98 kPa) as the input variables (Hoff, 1996. Personal Communication).

Results and Discussion

BM, THP, MP, SHP, and RQ

THP and RQ of the experimental tom turkeys from 1 to 35 days of age are plotted in figure 2. MP and SHP during the same period are shown in figure 3. Also plotted on the same figures is the daily mean BM of the birds derived from curve fitting of weekly BM data. The inclusion of BM allows for determination of HP and MP for a given BM that may correspond to a different age from that of the birds used in this study. An illustration example is shown for a 500 g bird by the arrow lines in figures 2 and 3. THP, MP, and SHP as a function of BM are more explicitly shown in figure 4. The regression equations, developed using Microsoft Excel for Windows 95, that relate the response variables to bird age (D) or BM are of the following forms.

As a function of bird age:

$$\text{THP [W/kg]} = 7.155 \times 10^{-4}D^3 - 5.4102 \times 10^{-2}D^2 + 1.0605D + 7.70 \qquad (R^2 = 0.958) \quad (2)$$

$$\text{MP [g } H_2O\text{/(kg-h)]} = -0.3027D + 17.26 \qquad (R^2 = 0.974) \quad (3)$$

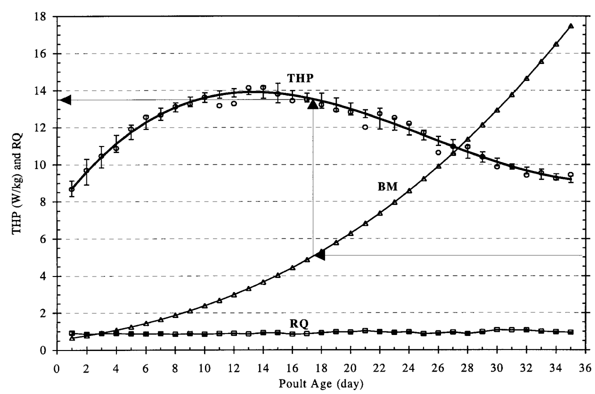

Figure 2–Total heat production rate (THP), respiratory quotient (RQ), and body mass (BM) of tom turkeys as a function of bird age. The vertical bars represent 95% confidence intervals of the daily THP variation.

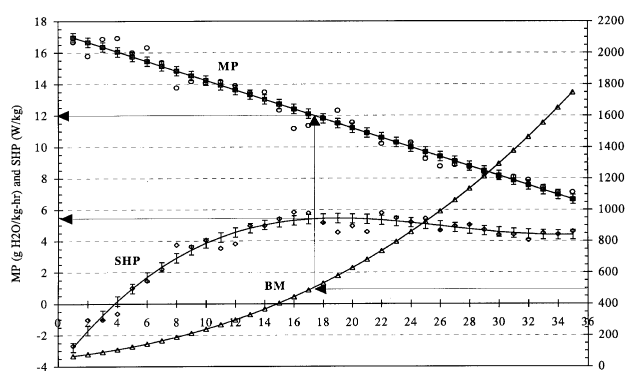

Figure 3–Moisture and sensible heat production rates (MP, SHP) and body mass (BM) of tom turkeys raised on litter as a function bird age. The vertical bars represent 95% confidence intervals of the daily MP or SHP variations. The MP and SHP take into account evaporation of moisture from litter and drinkers.

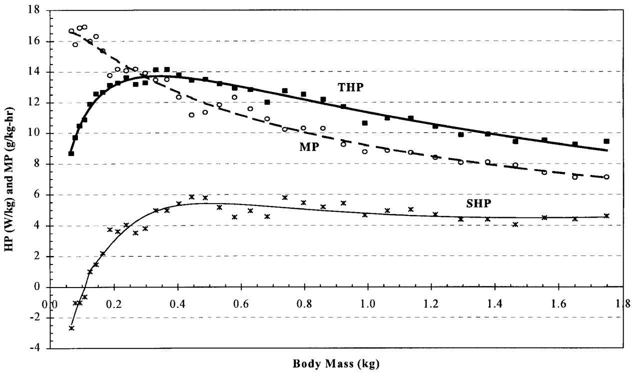

Figure 4–Heat and moisture production rates of tom turkeys raised on litter as a function of body mass.

$$SHP\ [W/kg] = 6.296 \times 10^{-4} D^3 - 4.9979 \times 10^{-2} D^2 + 1.2164D - 3.94 \qquad (R^2 = 0.958) \qquad (4)$$

$$CO_2Prod[mL/(kg\text{-}min)] = 0.0014D^3 - 0.1147D^2 + 2.4424D + 20.527 \qquad (R^2 = 0.918) \qquad (5)$$

$$BM\ [g/bird] = 0.0109D^3 + 0.7124D^2 + 10.057D + 55.6 \qquad (R^2 = 0.999) \qquad (6)$$

As a function of BM:

$$THP = \frac{11.335}{BM^{[0.1624 \ln(BW) + 0.3517]}} \qquad (7)$$

$$(R^2 = 0.966)$$

$$MP = \frac{9.167}{BM^{[0.0742 \ln(BW) + 0.4197]}} \qquad (8)$$

$$(R^2 = 0.980)$$

$$SHP = 4.888 \ln(BM) + 10.80 \qquad (BM < 0.125\ kg) \qquad (R^2 = 0.872) \qquad (9)$$

$$SHP = 4.7655\ BM^{\{0.2731 [\ln(BW)]^2 + 0.1138 \ln(BW) - 0.2392\}} \qquad (BM \geq 0.125\ kg) \quad (R^2 = 0.925) \qquad (10)$$

$$CO_2\ Prod = \frac{31.162}{BM^{[0.1496 \ln(BM) + 0.2935]}} \qquad (11)$$

$$(R^2 = 0.920)$$

As shown in figure 2, the specific THP of the tom turkeys increased with increasing age during the first two weeks and decreased with increasing age thereafter. This pattern is similar to that for litter-grown broiler chickens except that the broiler chicks reached their metabolic peak earlier, around one week of age (Reece and Lott, 1982). However, the peak THP of the tom poults (14.0 W/kg), occurring near 350 g BM, was considerably lower than that of the broiler chicks (19.4 W/kg), occurring near 100 g BM. The lower peak THP of the poult was likely attributed to its smaller surface to volume ratio, as can be explained by the surface law. The phenomenon of metabolic peak for growing animals has been well documented in the literature (Brody, 1945). The occurrence of such a metabolic peak is, as described by Brody (1945), *"the resultant of many factors — to puberty, to weaning, to changes in growth rate, but particularly to stabilization of the neuro-endocrine homeothermic system"*. Hence, it is inherent for different species to reach their metabolic peak at different ages or BM.

Daily mean RQ of the birds ranged from 0.85 to 1.07 during the five-week trial period, averaging 0.93 (fig. 2). A RQ greater than 1.0 would imply fat accretion in the body. Feddes et al. (1992) reported a RQ of 0.93 to 1.07 for hen turkeys from 16 to 36 days of age under commercial production conditions.

Specific SHP of the turkey housing units generally increased with increasing bird age, and became relatively constant (4.5 to 5.5 W/kg) after two weeks (fig. 3). This result agreed with that reported by Reece and Lott (1982) for litter-grown broiler chicks. Moreover, the SHP from the poults was insufficient to evaporate moisture from the bird surroundings—feces and drinkers during the initial four days. Consequently, supplemental heat was used in this process, which resulted in negative SHP values during this period. Reece and Lott (1982) also reported negative SHP during the first day of broiler brooding on litter. This heat sink should be considered when sizing the supplemental heat needs of the building.

Specific MP of the turkey housing units followed a linearly declining function with bird age. This MP profile was different from that of the litter-based broiler brooding unit as measured by Reece and Lott (1982) who showed peak MP occurring near one week into the brooding period.

Comparisons of THP, MP, and SHP between the current study and the *ASAE Standards* (1997) for tom turkeys

Table 1. Comparison of heat and moisture production rates of tom turkeys between this study and the ASAE Standard (turkeys and broilers)

BM (kg)	MP	SHP	THP	MP	SHP	THP	MP	SHP	THP
	Tom Turkeys — This Study			Tom Turkeys — ASAE			% Diff		
0.1	16.3	–0.5	10.8	15.6	6.1	16.8	4	–107	–36
0.2	14.9	3.0	13.1	9.8	6.3	12.9	52	–52	2
0.4	12.7	5.3	13.7	7.2	5.4	10.2	76	–2	34
0.6	11.1	5.3	13.0	4.1	5.9	8.7	172	–9	49
1.0	9.2	4.8	11.3	2.4	6.3	7.9	282	–24	43
1.25	8.3	4.6	10.4	–	–	–	–	–	–
1.5	7.6	4.5	9.6	–	–	–	–	–	–
1.75	7.1	4.5	9.4	–	–	–	–	–	–
	Tom Turkeys — This Study			Broiler Chickens — ASAE			% Diff		
0.1	16.3	–0.5	10.8	22.0	4.5	19.5	–26	–110	–45
0.4	12.7	5.3	13.7	12.5	6.5	15.0	1	–19	–9
0.7	10.5	5.2	12.6	10.5	5.2	12.2	0	0	3
1.0	9.2	4.8	11.3	8.8	4.0	10.0	5	19	13
1.5	7.6	4.5	9.6	8.3	3.8	9.3	–7	20	3

Unit: [SHP, THP] = W/kg, [MP] = g/(kg·h).

weighing 0.1, 0.2, 0.4, 0.6, and 1.0 kg are shown in table 1. Similar comparisons are also made in table 1 between the tom turkeys of this study and broiler chickens of equal BM in the ASAE Standard.

As can be seen from table 1, modern (Nicholas) tom turkeys have considerably higher metabolic rates or THP (up to 49%) than the literature (Large White) counterparts, particularly as the body mass increases; however this was not true for poults of less than 0.2 kg in BM. Poults of 25 years ago, as represented by the ASAE data, evidently reached their metabolic peak at less than 0.2 kg; whereas, poults in the current study did not show peak metabolic rate till approximately 0.4 kg. Comparison with THP of Large White hen turkeys (0.3, 0.7, 1.0, and 1.5 kg BM) in a commercial facility from a more recent study by Feddes et al. (1992) revealed that THP of the Nicholas tom turkeys was up to 55% higher. Further comparison revealed that THP of the tom turkeys was more similar to that of broiler chickens of equal BM, especially for BM = 0.4 to 1.5 kg. The higher metabolic rates for modern animals have also been reported for early weaned pigs by Harmon et al. (1997). Such higher metabolic rates presumably arise from the faster growth and improved nutrition for today's animals.

The most drastic difference between the current study and the ASAE Standard lies in the MP, with MP of the current study ranging from 4% at 0.1 kg BM to 282% at 1.0 kg BM higher (table 1). Such large differences could be attributed to the fact that MP data of the ASAE Standard are based on calorimetric studies of bird energetics, which do not include evaporation of moisture from feces and the litter. Although MP (latent HP) from the birds only is helpful in understanding their thermoregulation, MP including all the moisture sources in the housing system provide much more realistic representation of the moisture load for design of the building ventilation system. As with THP, the MP characteristics of the litter-grown turkeys more closely resembled those of litter-grown broilers of equal BM for BM = 0.4 to 1.5 kg (table 1); however, substantial differences in MP existed between the two species for younger ages or lighter BM (< 0.1 kg).

Differences in SHP between the current study and the ASAE Standard, though not as drastic as for MP, were substantial (table 1). With part of the SHP contributing to evaporation of the moisture from the litter and drinkers, the values were lower than those in the literature even though the THP was higher. The largest difference tended to occur at younger ages, with SHP of the current study averaging 107% lower than that in the literature at BM = 0.1 kg. Compared with SHP for the litter-grown broilers, SHP for the turkeys was lower at younger ages (< 0.7 kg) and higher thereafter.

A comparison of the HP and MP data from the current study with those simulated by Timmons and Gates (1988) revealed an 8 to 30% higher THP, an 87 to 95% higher MP, and a 13 to 29% lower SHP for the current tom turkeys. The urgent need to update the HP and MP characteristics of modern poultry production facilities for design and operation of environmental control systems has been pointed out by Gates et al. (1996). Results from this study provide additional strong evidence for this urgently needed update.

MVR for Selected Climatic and Housing Conditions

Based on the MP data obtained from the current study, MVR for the selected climatic conditions are listed in table 2 (inside RH = 50%) and table 3 (inside RH = 60%), respectively. Comparison of MVR between the current study and the MWPS (1990) recommendation is shown in table 4.

Note that the recommended MVR by MWPS (1990) ranges from 1.65 to 5.57 times the MVR determined from the current MP data for 1 to 7 days of age (table 4). Although additional ventilation would be necessary for houses utilizing old litter to remove excess aerial ammonia (Xin et al., 1996a), the MP-based MVR should suffice for houses using new bedding, as typically practiced in turkey brooding houses. Over ventilation not only wastes energy but likely degrades the indoor air quality that affects bird health by creating dusty environments. For the remaining brooding-growing period (8 through 35 days), the MWPS values range from 20 to 49% of those derived from this study. Comparing MVR of the turkeys with MVR of equal BM broilers (0.1 to 1.4 kg) as determined by Gates et al. (1996) (T_o = 4.4°C, RH_o = 40%, RH_i = 50%), MVR for the turkeys ranged from 143% to 186% higher. The use of open fountain drinkers, hence more water spillage in this study (as is the case in commercial turkey production) compared to nipple drinkers for broilers, was speculated to contribute to the higher MVR for the turkeys.

The effects of inside RH (RH_i) on MVR can be observed from tables 2 and 3. A 10% rise in RH_i from 50 to 60% can reduce MVR by as much as 50% to 60%, depending on the outside RH (RH_o) and temperature (T_o). Hence on cold and humid days, a short-term increase in RH_i would be an effective means to conserve both heating fuel and fan electricity energy. The efficacy of such a practice had also been illustrated by Timmons and Gates (1987) in their algorithm of dynamic RH control to conserve energy and maintain litter quality for broiler housing. Caution, however, should be taken in exercising such a practice so that NH_3 build-up, excessive litter moisture, and hence disease problems would not result. By comparison, RH_o has little effect on MVR at cold T_o. Specifically, for a given bird age of the 5-week brooding period, MVR values are within 10% of one another for T_o < –15°C as RH_o varies from 20 to 90%. This result is consistent with the thermodynamic properties of air in that as the air becomes colder its moisture content approaches similarity regardless of RH level. This property can be seen from a psychrometric chart.

For naturally ventilated brooding buildings, as may be the case in warm climatic regions, estimate of the building ventilation rate (BVR) via mechanical means would be rather difficult. The CO_2 production rate (eq. 11) for the tom turkeys could be used for such purpose. With a readily obtainable measurement of the CO_2 concentration (PPM) inside and outside the building (by either time-weighed or instantaneous sampling), BVR in m^3/(h·house) as a function of BM, bird number (N), and CO_2 concentration differential between inside and outside of the building (ΔCO_2[ppm]) can be estimated as:

Table 2. Minimum ventilation rates (MVR) of tom turkeys during brooding-growing at selected outside temperatures (T_o) and RH (RH_o) and thermoneutral inside temperatures (T_i) and constant inside RH of 50%

T_i [°C] =		29.4			28.3		26.7		23.9		21.1		
Age [d] =		1	4	7	10	13	16	19	22	25	28	31	34
BM [kg] =		0.068	0.109	0.163	0.236	0.331	0.445	0.576	0.735	0.921	1.134	1.374	1.647
T_o [°C]	RH_o	$m^3/(h\cdot 1000\ hd)$											
–23.3	20%	73	111	157	228	300	413	496	691	792	1053	1144	1212
–20.6		74	112	158	229	300	414	497	694	795	1056	1148	1217
–17.8		74	112	158	229	301	415	499	696	798	1062	1154	1223
–15.0		74	112	159	230	303	417	501	700	802	1068	1161	1230
–12.2		74	113	160	231	304	420	504	705	807	1076	1170	1240
–9.4		75	113	161	233	306	422	507	710	814	1087	1182	1252
–6.7		75	114	162	235	308	426	512	718	822	1101	1196	1268
–3.9		76	115	163	237	312	431	517	727	833	1118	1215	1288
–1.1		77	117	165	240	315	437	525	739	847	1141	1240	1314
1.7		78	118	167	244	320	444	533	754	864	1168	1269	1345
4.4		79	120	170	247	325	452	543	770	883	1199	1303	1381
7.2		81	122	173	253	332	462	555	792	907	1239	1347	1427
10.0		83	125	177	259	340	475	571	818	938	1291	1403	1487
–23.3	30%	74	112	158	229	301	415	498	695	796	1059	1151	1220
–20.6		74	112	159	230	302	416	500	698	800	1065	1157	1226
–17.8		74	113	159	231	303	418	503	702	805	1073	1166	1235
–15.0		75	113	160	232	305	421	506	708	811	1083	1176	1247
–12.2		75	114	161	234	308	425	510	715	819	1096	1191	1262
–9.4		76	115	163	236	311	429	516	724	830	1112	1209	1281
–6.7		77	116	165	239	314	435	522	736	843	1133	1232	1306
–3.9		78	118	167	243	319	442	531	751	860	1162	1262	1338
–1.1		79	120	170	248	325	452	543	770	883	1199	1303	1381
1.7		81	123	174	253	333	463	557	794	910	1244	1352	1433
4.4		83	126	178	260	341	477	573	822	942	1298	1410	1495
7.2		85	129	183	268	352	494	594	859	984	1371	1490	1579
10.0		89	134	190	279	367	517	620	907	1040	1469	1596	1692
–23.3	40%	74	112	159	230	302	416	500	698	800	1065	1158	1227
–20.6		74	113	159	231	304	419	503	703	805	1073	1166	1236
–17.8		75	113	160	232	305	422	506	709	812	1084	1178	1248
–15.0		75	114	161	234	308	425	511	716	820	1098	1193	1264
–12.2		76	115	163	237	311	430	517	726	832	1115	1212	1285
–9.4		77	117	165	240	315	436	524	738	846	1139	1238	1312
–6.7		78	118	167	244	320	444	533	754	864	1168	1270	1346
–3.9		80	121	171	249	327	455	546	776	889	1209	1314	1392
–1.1		82	124	175	255	336	468	562	804	921	1263	1373	1455
1.7		84	127	180	264	346	485	582	839	961	1331	1447	1533
4.4		87	132	186	273	359	504	606	881	1009	1415	1538	1630
7.2		91	137	194	286	376	531	638	939	1076	1534	1667	1767
10.0		95	145	205	302	397	566	680	1018	1167	1704	1852	1963
23.3	50%	74	112	159	231	303	418	502	702	804	1072	1165	1235
–20.6		75	113	160	232	305	421	506	707	811	1082	1176	1246
–17.8		75	114	161	234	307	425	510	715	819	1095	1190	1262
–15.0		76	115	163	236	311	429	516	724	830	1113	1209	1282
–12.2		77	116	165	239	315	436	523	737	844	1136	1235	1308
–9.4		78	118	167	243	320	444	533	753	863	1167	1268	1344
–6.7		80	120	170	248	326	454	545	774	887	1206	1310	1389
–3.9		82	124	175	255	335	467	561	802	919	1260	1369	1451
–1.1		84	128	180	264	347	486	583	841	963	1335	1451	1538
1.7		87	132	187	275	361	508	611	889	1019	1432	1556	1649
4.4		91	138	196	288	379	536	643	949	1088	1556	1691	1792
7.2		96	146	207	306	402	574	689	1036	1187	1742	1893	2006
10.0		103	157	222	330	434	626	753	1161	1330	2030	2206	2338

Notes:
Divide the table values (SI unit) by 1.699 to obtain MVR in cfm (IP unit) per 1,000 heads.
Temperatures under the electric brooders ranged from 35 to 29°C during the initial 10 days.
Where unvented gas heaters are used, provide at least 4.25 m^3/h (2.5 cfm) additional ventilating capacity per 293W (1,000 BTU/h) heater capacity.
The tabulated ventilation rates are based on moisture removal. If excessive aerial ammonia (> 25 PPM) is encountered in the building, additional ventilation should be applied (refer to Xin et al., 1996a).

$$BVR = \frac{1870 \times N}{\Delta CO_2\ [ppm]\ BM^{[\,0.1496\ \ln\ (BM) - 0.7065\,]}} \qquad (12)$$

When using equation 12, note that CO_2 production from the supplemental heaters in the building is not included. Hence, it is advisable to measure the inside CO_2 concentration while the heaters are inactive and after the residual CO_2 from the previous cycle of gas combustion

Table 2. (continued) Minimum ventilation rates (MVR) of tom turkeys during brooding-growing at selected outside temperatures (T_o) and RH (RH_o) and thermoneutral inside temperatures (T_i) and constant inside RH of 50%

T_i [°C] =		29.4			28.3		26.7		23.9		21.1		
Age [d] =		1	4	7	10	13	16	19	22	25	28	31	34
BM [kg] =		0.068	0.109	0.163	0.236	0.331	0.445	0.576	0.735	0.921	1.134	1.374	1.647
T_o [°C]	RH_o	m^3/(h·1000 hd)											
–23.3	60%	75	113	160	232	304	420	505	706	808	1078	1172	1242
–20.6		75	114	161	233	307	423	509	712	816	1091	1185	1256
–17.8		76	115	162	236	310	428	514	721	826	1107	1203	1275
–15.0		77	116	164	238	313	434	521	733	840	1129	1227	1300
–12.2		78	118	167	242	318	441	530	748	857	1157	1258	1333
–9.4		79	120	170	247	325	451	542	769	881	1196	1299	1377
–6.7		81	123	174	253	333	464	557	795	911	1245	1353	1434
–3.9		84	127	179	262	344	481	578	831	952	1316	1430	1516
–1.1		87	132	186	273	359	505	606	881	1010	1416	1538	1631
1.7		91	138	195	287	378	534	642	946	1084	1549	1684	1784
4.4		96	146	206	305	400	571	686	1030	1180	1728	1878	1991
7.2		103	156	221	329	433	624	750	1155	1323	2016	2190	2322
10.0		113	171	242	364	478	701	842	1350	1547	2511	2729	2892
–23.3	70%	75	113	160	233	306	422	507	709	813	1085	1179	1250
–20.6		75	114	162	235	308	426	511	717	822	1099	1195	1266
–17.8		76	115	163	237	312	431	518	728	834	1119	1216	1289
–15.0		77	117	165	241	316	438	526	742	850	1145	1244	1319
–12.2		79	119	168	245	322	447	537	760	871	1180	1282	1359
–9.4		80	122	172	251	330	459	551	785	899	1226	1333	1413
–6.7		83	125	177	258	340	474	570	817	936	1288	1400	1484
–3.9		86	130	184	269	353	496	595	862	988	1377	1497	1586
–1.1		90	136	192	283	372	525	631	926	1061	1507	1637	1735
1.7		95	144	204	301	395	563	676	1011	1158	1687	1834	1944
4.4		102	154	218	323	425	612	735	1125	1289	1944	2113	2239
7.2		111	168	238	356	468	684	822	1306	1496	2392	2600	2756
10.0		125	189	267	406	533	797	957	1614	1849	3295	3580	3795
–23.3	80%	75	114	161	233	307	424	509	713	817	1092	1187	1258
–20.6		76	115	162	236	310	428	514	722	827	1109	1205	1277
–17.8		77	116	164	239	314	434	522	734	841	1131	1229	1303
–15.0		78	118	167	243	319	442	531	751	860	1162	1262	1338
–12.2		79	120	170	248	326	453	544	772	885	1203	1307	1385
–9.4		82	123	175	255	335	467	561	802	918	1259	1368	1450
–6.7		84	127	180	264	347	485	583	840	962	1333	1449	1536
–3.9		88	133	188	276	363	511	614	895	1026	1444	1569	1663
–1.1		93	141	199	293	386	547	657	975	1117	1610	1750	1855
1.7		99	150	213	316	415	595	715	1085	1243	1853	2014	2135
4.4		108	163	231	345	453	658	791	1239	1420	2222	2414	2559
7.2		120	182	257	389	511	757	910	1502	1721	2944	3199	3390
10.0		139	210	297	458	602	923	1109	2008	2300	4794	5210	5522
–23.3	90%	75	114	162	234	308	426	511	717	821	1099	1194	1266
–20.6		76	115	163	237	311	431	517	727	833	1118	1215	1287
–17.8		77	117	165	240	316	438	526	741	849	1144	1243	1317
–15.0		79	119	168	245	322	447	537	760	871	1179	1281	1358
–12.2		80	122	172	251	330	459	551	785	899	1227	1333	1413
–9.4		83	125	177	259	340	475	571	819	939	1293	1405	1489
–6.7		86	130	184	269	354	497	597	865	991	1382	1502	1592
–3.9		90	136	193	284	373	527	634	931	1067	1518	1650	1749
–1.1		96	146	206	305	401	571	686	1030	1180	1730	1879	1992
1.7		104	158	223	332	437	631	758	1171	1342	2055	2233	2367
4.4		114	173	245	369	485	713	856	1380	1581	2593	2818	2986
7.2		130	198	280	427	561	848	1019	1768	2026	3826	4158	4407
10.0		157	237	335	526	691	1097	1317	2656	3043	8809	9573	10146

Notes:

Divide the table values (SI unit) by 1.699 to obtain MVR in cfm (IP unit) per 1,000 heads.

Temperatures under the electric brooders ranged from 35 to 29°C during the initial 10 days.

Where unvented gas heaters are used, provide at least 4.25 m^3/h (2.5 cfm) additional ventilating capacity per 293W (1,000 BTU/h) heater capacity.

The tabulated ventilation rates are based on moisture removal. If excessive aerial ammonia (> 25 PPM) is encountered in the building, additional ventilation should be applied (refer to Xin et al., 1996a).

has been reasonably purged. It is also desirable to use an average of several such inside CO_2 concentration readings throughout the day to integrate the dynamic profile of the CO_2 concentration and its effect on BVR estimation. Use of CO_2 concentration to estimate building ventilation rate has also proven feasible for broiler and swine houses (Feddes et al., 1984.)

Table 3. Minimum ventilation rates (MVR) of tom turkeys during brooding-growing at selected outside temperatures (T_o) and RH (RH_o) and thermoneutral inside temperatures (T_i) and constant inside RH of 60%

T_i [°C] =		29.4			28.3		26.7		23.9		21.1		
Bird Age [d] =		1	4	7	10	13	16	19	22	25	28	31	34
BM [kg] =		0.068	0.109	0.163	0.236	0.331	0.445	0.576	0.735	0.921	1.134	1.374	1.647
T_o [°C]	RH_o	$m^3/(h\cdot 1000\ hd)$											
–23.3	20%	61	92	130	189	248	342	411	576	660	873	949	1006
–20.6		61	92	130	189	248	343	412	577	661	876	952	1009
–17.8		61	92	131	189	249	344	413	579	663	879	956	1013
–15.0		61	93	131	190	250	345	414	582	666	884	960	1018
–12.2		61	93	132	191	251	346	416	585	670	890	967	1025
–9.4		62	93	132	192	252	348	419	589	675	897	975	1033
–6.7		62	94	133	193	254	351	421	594	680	906	984	1043
–3.9		63	95	134	195	256	354	425	600	688	918	997	1057
–1.1		63	96	135	197	258	358	430	609	697	933	1014	1075
1.7		64	97	137	199	262	363	436	618	708	951	1033	1095
4.4		65	98	139	202	265	368	442	629	721	971	1056	1119
7.2		66	99	141	205	269	375	450	643	737	998	1084	1149
10.0		67	101	143	209	275	383	461	661	757	1031	1120	1188
–23.3	30%	61	92	131	189	249	343	412	578	662	878	954	1011
–20.6		61	93	131	190	249	344	413	580	665	882	958	1015
–17.8		61	93	131	190	250	346	415	583	668	887	964	1021
–15.0		62	93	132	191	252	348	417	587	673	894	971	1029
–12.2		62	94	133	193	253	350	420	592	678	903	981	1040
–9.4		62	95	134	194	255	353	424	598	685	914	993	1053
–6.7		63	95	135	196	258	357	429	606	694	928	1009	1069
–3.9		64	97	137	198	261	362	435	616	706	947	1029	1091
–1.1		65	98	139	202	265	368	442	629	721	972	1056	1119
1.7		66	100	141	205	270	376	451	645	739	1001	1088	1153
4.4		67	102	144	210	276	385	462	663	760	1036	1125	1193
7.2		69	104	147	215	283	396	475	687	787	1081	1175	1246
10.0		71	107	152	222	292	410	492	718	822	1141	1240	1315
–23.3	40%	61	93	131	190	249	344	414	581	665	882	958	1016
–20.6		61	93	131	191	250	346	415	583	669	887	964	1022
–17.8		62	93	132	191	252	348	418	587	673	895	972	1030
–15.0		62	94	133	193	253	350	421	593	679	904	982	1041
–12.2		63	95	134	194	255	354	425	599	687	916	995	1055
–9.4		63	96	135	196	258	358	430	608	696	932	1013	1073
–6.7		64	97	137	199	262	363	436	619	709	951	1034	1096
–3.9		65	98	139	202	266	370	444	633	725	978	1063	1127
–1.1		66	100	142	207	272	379	455	652	747	1013	1101	1167
1.7		68	103	145	212	279	390	468	674	773	1057	1148	1217
4.4		70	105	149	218	287	402	483	701	803	1109	1205	1277
7.2		72	109	154	226	297	419	503	737	845	1180	1283	1360
10.0		75	114	161	237	311	441	529	786	900	1279	1389	1473
–23.3	50%	61	93	131	190	250	346	415	583	668	886	963	1021
–20.6		62	93	132	191	251	347	417	587	672	893	971	1029
–17.8		62	94	133	193	253	350	420	592	678	902	981	1039
–15.0		62	95	134	194	255	353	424	598	685	914	994	1053
–12.2		63	95	135	196	258	357	429	607	695	930	1010	1071
–9.4		64	97	137	199	261	363	436	618	708	950	1033	1094
–6.7		65	98	139	202	266	369	444	632	724	976	1061	1124
–3.9		66	100	142	207	272	378	455	651	745	1011	1099	1165
–1.1		68	103	146	212	279	390	469	676	774	1059	1151	1220
1.7		70	106	150	219	288	405	486	707	809	1119	1216	1289
4.4		72	110	155	228	299	422	507	744	852	1194	1297	1375
7.2		76	115	162	239	314	445	535	796	912	1300	1412	1497
10.0		80	121	171	253	333	476	572	868	994	1454	1580	1674

Notes:

Divide the table values (SI unit) by 1.699 to obtain MVR in cfm (IP unit) per 1,000 heads.

Temperatures under the electric brooders ranged from 35 to 29°C during the initial 10 days.

Where unvented gas heaters are used, provide at least 4.25 m^3/h (2.5 cfm) additional ventilating capacity per 293W (1,000 BTU/h) heater capacity.

The tabulated ventilation rates are based on moisture removal. If excessive aerial ammonia (> 25 PPM) is encountered in the building, additional ventilation should be applied (refer to Xin et al., 1996a).

CONCLUSIONS

Heat and moisture production characteristics of modern Nicholas tom turkeys brooded on litter are substantially different from data commonly used for design of building ventilation systems. Specifically, in comparison with the ASAE Standard (for BM = 0.1 to 1.0 kg), the current study revealed a 2 to 49% higher THP, a 4 to 282% higher MP, and a 2 to 107% lower SHP.

Large differences in MP-based minimum ventilation rates (MVR) for brooding facilities exist between the

Table 3. (continued) Minimum ventilation rates (MVR) of tom turkeys during brooding-growing at selected outside temperatures (To) and RH (RH_o) and thermoneutral inside temperatures (T_i) and constant inside RH of 60%

T_i [°C] =		29.4			28.3		26.7		23.9		21.1		
Bird Age [d] =		1	4	7	10	13	16	19	22	25	28	31	34
BM [kg] =		0.068	0.109	0.163	0.236	0.331	0.445	0.576	0.735	0.921	1.134	1.374	1.647
T_o [°C]	RH_o	$m^3/(h \cdot 1000\ hd)$											
–23.3	60%	61	93	132	191	251	347	417	585	671	891	968	1026
–20.6		62	94	132	192	252	349	419	590	676	899	977	1036
–17.8		62	94	133	194	254	352	423	596	683	910	989	1048
–15.0		63	95	135	196	257	356	428	604	692	925	1005	1065
–12.2		64	96	136	198	260	361	434	615	704	944	1026	1087
–9.4		65	98	138	201	265	368	442	628	720	969	1053	1117
–6.7		66	100	141	205	270	376	452	646	740	1002	1089	1154
–3.9		67	102	145	211	277	387	465	669	767	1047	1138	1206
–1.1		70	105	149	218	287	402	483	701	804	1109	1205	1278
1.7		72	109	155	227	299	421	506	742	850	1189	1293	1370
4.4		75	114	162	238	313	444	533	792	908	1292	1404	1489
7.2		80	121	171	253	332	475	570	864	990	1446	1572	1666
10.0		86	129	183	273	359	518	623	969	1111	1685	1831	1941
–23.3	70%	62	93	132	192	252	348	418	588	674	895	973	1031
–20.6		62	94	133	193	254	351	421	593	680	905	984	1043
–17.8		63	95	134	195	256	354	426	601	688	918	998	1058
–15.0		63	96	136	197	259	359	431	610	699	936	1017	1078
–12.2		64	97	138	200	263	365	438	622	713	959	1042	1104
–9.4		65	99	140	204	268	373	448	639	732	990	1075	1140
–6.7		67	101	143	209	274	383	460	660	756	1029	1118	1185
–3.9		69	104	148	216	283	397	477	689	790	1085	1179	1250
–1.1		71	108	153	225	295	415	499	729	836	1164	1265	1341
1.7		75	113	160	236	310	439	527	781	895	1269	1379	1462
4.4		79	119	169	249	328	468	562	847	971	1409	1531	1623
7.2		84	128	181	268	353	509	611	946	1084	1631	1772	1878
10.0		92	139	197	295	388	569	683	1098	1258	2005	2179	2309
–23.3	80%	62	94	133	192	253	349	420	590	676	900	978	1037
–20.6		62	94	134	194	255	352	423	597	684	911	991	1050
–17.8		63	95	135	196	257	356	428	605	693	927	1007	1067
–15.0		64	97	137	198	261	362	435	616	706	947	1029	1091
–12.2		65	98	139	202	265	369	443	631	722	974	1058	1122
–9.4		66	100	142	206	271	378	454	650	744	1010	1097	1163
–6.7		68	103	146	212	279	390	469	675	774	1059	1150	1219
–3.9		70	106	151	220	290	407	488	710	814	1127	1225	1298
–1.1		73	111	157	231	304	429	515	759	870	1225	1331	1411
1.7		77	117	166	245	321	458	550	824	944	1359	1477	1565
4.4		82	125	177	262	344	495	595	912	1045	1553	1688	1789
7.2		89	135	192	287	377	549	659	1046	1199	1872	2035	2156
10.0		99	151	213	322	424	630	757	1267	1452	2476	2691	2852
–23.3	90%	62	94	133	193	253	351	421	593	679	905	983	1042
–20.6		63	95	134	195	256	354	425	600	688	918	997	1057
–17.8		63	96	136	197	259	359	431	610	699	935	1016	1077
–15.0		64	97	138	200	263	365	438	622	713	958	1041	1104
–12.2		65	99	140	204	268	373	448	639	732	989	1075	1140
–9.4		67	101	143	209	275	384	461	661	758	1031	1121	1188
–6.7		69	104	148	216	284	398	478	691	792	1089	1184	1255
–3.9		72	109	154	225	296	417	501	733	840	1171	1273	1349
–1.1		75	114	162	238	313	444	533	792	908	1293	1405	1489
1.7		80	121	172	254	334	478	575	873	1000	1465	1592	1687
4.4		86	131	185	276	363	525	631	987	1131	1726	1876	1988
7.2		95	144	204	307	404	595	715	1169	1340	2195	2385	2528
10.0		108	164	232	354	466	707	849	1498	1716	3239	3520	3731

Notes:

Divide the table values (SI unit) by 1.699 to obtain MVR in cfm (IP unit) per 1,000 heads.

Temperatures under the electric brooders ranged from 35 to 29°C during the initial 10 days.

Where unvented gas heaters are used, provide at least 4.25 m^3/h (2.5 cfm) additional ventilating capacity per 293W (1,000 BTU/h) heater capacity.

The tabulated ventilation rates are based on moisture removal. If excessive aerial ammonia (> 25 PPM) is encountered in the building, additional ventilation should be applied (refer to Xin et al., 1996a).

current study and the literature (MWPS, 1990) recommendations. Specifically, the literature MVR values were estimated to be 165 to 557% of those derived from the current study for the first week of brooding, but 20 to 49% of the derived MVR values for the remaining 4-week brooding-growing period.

Regression equations relating THP, MP, SHP, and CO_2 production rate to age and BM of Nicholas tom turkeys during the five-week brooding period have been

Table 4. Comparison of MVR between current study and the MWPS (1990) recommendations

Age (d)	BM (kg)	TNZ (°C)	$m^3/(h \cdot 1{,}000$ heads) MWPS*	Current Study†	X/Y‡ (%)
1	0.068	29.4	340	61 – 96	557 – 354
4	0.109	29.4	340	92 – 146	370 – 233
7	0.163	29.4	340	130 – 206	262 – 165
10	0.236	28.3	71	189 – 305	38 – 23
13	0.331	28.3	99	248 – 401	40 – 25
16	0.445	26.7	133	342 – 571	39 – 23
19	0.576	26.7	173	411 – 686	42 – 25
22	0.735	23.9	220	576 – 1030	38 – 21
25	0.921	23.9	276	660 – 1180	42 – 23
28	1.134	21.1	340	873 – 1730	39 – 20
31	1.374	21.1	412	949 – 1879	43 – 22
34	1.647	21.1	494	1006 – 1992	49 – 25

* MVR based on 0.34 $m^3/(h \cdot hd)$ (0.2 cfm/hd) for the first week, and 0.30 $m^3/(h \cdot kg)$ (0.08 cfm/lb) beyond.

† MVR based on outside temperature of –23 to 0°C and outside RH of 20 to 90%, and TNZ inside temperatures and a RH of 50 to 60%.

‡ X = MVR from MWPS; Y = MVR from current study.

Unit conversion: 1 cfm = 1.699 m^3/h.

established. A series of MVR based on the current MP data have been determined for selected climatic and building conditions. These equations and MVR look-up tables provide a new database, guidance, and a tool for design and operation of building ventilation systems, which would better reflect and meet the environmental needs of modern commercial production of young turkeys.

Further research is urgently needed to update the literature HP and MP data for ventilation design of animal structures to reflect the modern genetics, nutrition, housing systems, and management.

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