Evaluating Draft EPA Emissions Models for Laying Hen Facilities

A report of the

Egg
Industry Center

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Executive Summary

Draft emissions models for laying hen facilities and manure storage were made available by the US Environmental Protection Agency (EPA) in August 2021 for public comments and reviews. This report was commissioned by the American Egg Board to evaluate these draft models and provide suggestions on their suitability for use by the US egg industry. As for the assessment, the draft model equations were coded independently and then subjected to a series of 'stress tests', followed by an evaluation of the impact of using these models to estimate annual emission factors at 12 representative locations.

While an effort was made initially by EPA to develop process-based models, the necessary underlying data were not collected, and as such, the EPA draft report explicitly states that these are not process-based models. Rather, the draft models comprise a series of straightforward regressions of log-transformed emissions data to estimate whole-building emissions of ammonia, hydrogen sulfide, and particulate matter ($PM_{2.5}$, PM_{10}, and TSP).

Our analysis suggests that the draft models cannot be used to the degree of precision that is suggested in the 2021 EPA report and equations. When an emitted mass of a pollutant per hen, i.e., as an emission factor, was evaluated, the influence of changing bird inventory on model output is substantially outside that reported in previous literature. The EPA dataset had three different bird inventories (38,000, 95,000, and 218,000 hens per barn) for three different high-rise sites from the National Air Emissions Monitoring Studies (NAEMS) in California, Indiana, and North Carolina. High-rise housing is no longer the *de facto* standard in the US (being replaced by cage-free aviaries and manure belt houses). The EPA dataset had a single manure belt housing site, with about 280,000 hens per barn. The draft model emission factor predictions for ammonia and hydrogen sulfide from manure belt housing deviated substantially for lower and higher inventories. EPA also provided a set of models for emissions from manure storage, based on a single building, using inventory (5-day lag) as an independent variable. These models erroneously predicted increased emission factors with bird inventory, as well as negative emissions for some particulate matter types.

Deploying the draft EPA models to estimate annual effective emission factors and farm emissions from a dozen selected areas of the US demonstrated substantial differences in emission predictions with inventories smaller or greater than that on which they were developed. These predicted emissions were also variable for climate since most EPA draft models include ambient temperature and relative humidity as independent variables to the extent that is not supported in the literature. An assessment of the marginal influence of climate on emissions predictions varied from relatively small amounts that are likely beneath any detection threshold to measure, within the uncertainty of the models' predictions, and in some cases demonstrate surprisingly large marginal changes with temperature and relative humidity that are not supported in the literature. There was little difference in estimated annual emission or emission factor when daily, monthly, or annual climate averages were used at constant bird inventories.

Several recommendations are suggested regarding these draft models; a key problem for the industry is that they do not address cage-free housing, or the advances made in managing both manure belt housing and manure storage since the data underlying these draft models were collected. A much simpler modeling approach is suggested, using NAEMS inventories to determine emission factors and adjusting for climate only within the range possible and appropriate from NAEMS climate data during the field campaign.

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Introduction

The US Environmental Protection Agency (EPA 2021a) produced numerous candidate emissions models, by housing style (high rise, manure belt, and manure storage), for consideration by the US egg industry. Each model was derived from NAEMS (National Air Emissions Monitoring Study) data collected over a decade ago and subsequently adjusted for background concentrations. Models are provided for ammonia, hydrogen sulfide, and particulate matter (PM_{10}, $PM_{2.5}$, and TSP). They are in the following form in general:

$$ln(Y) = \mathrm{Intercept} + C_{\mathrm{Inventory}} \times \mathrm{Inventory} + C_{AmbT} \times \mathrm{AmbT} + \mathrm{C}_{AmbRH} \times \mathrm{AmbRH} \tag{1}$$

$$ER = e^{ln(Y)} \times \mathrm{E}_0 + \mathrm{E}_1 \tag{2}$$

where the quantity $\ln(Y)$ is the natural log transformed mass of pollutant from a house on a daily basis, ER is emission rate, and the various model coefficients include Intercept and values for Inventory ($C_{\mathrm{Inventory}}$), mean daily ambient temperature (C_{AmbT}), and mean daily ambient relative humidity (C_{AmbRH}). The independent variables are bird number in a facility (Inventory, an integer value divided by 1,000), mean daily ambient temperature (AmbT, °C), and mean daily ambient relative humidity (AmbRH, %). E_0 and E_1 are named $\overline{E}_i$ and C in the General Report (EPA 2021b), page 6-5, and in the Layer Report (EPA 2021a), Table 7-1; they are used to adjust the bias and offset. Note that in Eq (2) we add the magnitude of E_1 (which is generally a negative number) rather than subtracting it, as done in the reports (EPA 2021a,b).

EPA put forth substantial efforts in model development, and refined the datasets generated by the NAEMS effort which was conducted over a decade ago. Notably, the dataset does not include cage-free housing, currently about 28% of US egg production. Greater than 70% of US laying hens are housed in cages, mostly in manure belt housing; thus, these models, if adopted, will have a substantial impact on the US egg industry and their lack of applicability to the current US housing systems is a concern.

The objectives of this report were to evaluate model robustness and assess modeled annual emission factors for 12 locations throughout the USA associated with egg production under differing climate scenarios.

The EPA model development and selection for the three facility types are summarized below:

High-rise hen housing: EPA developed and evaluated ten models (G-1 to G-10) for NH_3 and H_2S emissions from high-rise houses. EPA selected model G-8 (including the parameters: intercept, inventory, ambient temperature, and ambient relative humidity) for further analysis of NH_3 and H_2S as it had the best normalized mean bias among the remaining models. All parameters were significant during the regression of model G-8 for NH_3 and H_2S ($P<0.0001$).

A total of 15 models (P-1 to P-15) were developed and evaluated by EPA for PM_{10}, $PM_{2.5}$, and TSP. EPA selected model P-4 (including the parameters: intercept, inventory, ambient relative humidity, and ambient temperature) for further analysis of PM_{10} as it had the lowest mean error and one of the lowest normalized mean biases among the models. All parameters were significant during the regression of model P-4 for PM_{10} ($P<0.0001$). Model P-4 had reasonable performance for $PM_{2.5}$ and TSP and was also consistent with the PM_{10} formulation developed from a much larger dataset. Therefore, EPA selected model P-4 for $PM_{2.5}$ and TSP to conduct further evaluation and analysis as an emission estimation method. For the regression of P-4 for $PM_{2.5}$, the P-value is <0.05 or <0.0001. For the regression of P-4 for TSP, the P-value is <0.05 or <0.0001 for most of the parameters, except for ambient temperature ($P=0.1417$). All relevant parameters for calculating the air pollutant emission in high-rise housing are presented in Table 1.

Table 1. Parameters for high-rise systems.

	NH_3	H_2S	PM_{10}	$PM_{2.5}$	TSP
Intercept	2.6598	2.7231	6.8702	4.6219	7.5995
$C_{Inventory}$	0.0059	0.0098	0.0077	0.008	0.0079
C_{AmbT}	0.0387	0.0210	0.0145	0.051	0.0137
C_{AmbRH}	0.0018	0.0038	-0.0030	-0.0181	-0.0058
E_0	1.58238	1.24359	1.11745	1.51089	1.11429
E_1	0	-15	-494	-37	0

Manure belt hen housing: EPA developed and evaluated 12 models (G-1 to G-12) for NH_3 and H_2S emissions from manure belt houses. Among models G-1, G-3, and G-7 that had terms statistically significant, EPA selected model G-7 (including the parameters: intercept, inventory, ambient temperature, and ambient relative humidity) for further analysis for NH_3. All parameters were statistically significant ($P<0.05$ or <0.0001). Of the remaining models that used ambient parameters, EPA selected model G-7 (including the parameters: intercept, inventory, ambient temperature, and ambient relative humidity) for further analysis of H_2S as it had one of the lowest normalized mean biases of the remaining models and was consistent with the parameters selected for the NH_3 model, limiting the data collection burden. All parameters were statistically significant ($P<0.0001$).

A total of 16 models (P-1 to P-16) were developed and evaluated by EPA for PM_{10}, $PM_{2.5}$, and TSP. The model fit evaluation statistics for PM_{10} indicated models P-1 and P-16 performed similarly. Therefore, EPA selected model P-1 (including the parameters: intercept and inventory) with fewer parameters compared with model P-16 for further analysis of PM_{10}. The parameters were statistically significant ($P<0.005$ or <0.0001). Overall, model P-1 (including the parameters: intercept and inventory) was selected for both $PM_{2.5}$ and TSP, as it would be consistent with the parameters selected for the PM_{10} model. However, in model P-1 for $PM_{2.5}$, the P-values were 0.0681 and 0.0604 for intercept and inventory, respectively (i.e. not significantly different from zero). In model P-1 for TSP, these coefficients had P-values of 0.4404 and 0.7855 (not significant) for intercept and inventory, respectively. All relevant parameters for calculating the air pollutant emission in manure belt housing are presented in Table 2.

Table 2. Parameters for manure belt systems.

	NH_3	H_2S	PM_{10}	$PM_{2.5}$	TSP
Intercept	2.4392	3.7391	6.631005	-127.4489	6.936206
$C_{Inventory}$	0.0047	0.0073	0.007205	0.534577	0.00987
C_{AmbT}	0.0294	0.0222	0	0	0
C_{AmbRH}	0.0019	0.0048	0	0	0
E_0	1.27315	1.09812	1.45218	2.97703	1.34146
E_1	0	-39	-1045	-108	-696

Manure storage: EPA developed and evaluated 20 models (G-1 to G-20) for NH_3 and H_2S for manure storage shed emissions. Models G-16 and G-17 had statistically significant parameters. Model G-16 contained airflow (building ventilation rate), which is not an easy parameter for a producer to calculate, as it requires hourly wind measurements in several openings of the structure. Model G-17 required an estimate of the volume of manure produced and manure accumulation time. EPA selected the model G-2 with easily accessible parameters (including intercept, inventory (5-day lag), and ambient temperature) for NH_3 and H_2S. However, in model G-2 for NH_3, the P-value for the intercept was not significant (0.7116) but was <0.001 for the rest of the parameters. All the parameters in model G-2 for H_2S were statistically significant ($P<0.05$ or <0.0001).

A total of 13 models (P-1 to P-13) were developed for PM_{10}, $PM_{2.5}$, and TSP emissions from a manure storage shed by EPA. Again, of the models that included bird inventory or live weight, but did not have airflow, EPA selected model P-11 (with parameters: intercept and inventory (5-day lag)) for further consideration. However, in model P-11 for PM_{10}, the *P*-value was 0.0007 for the intercept and 0.7853 (i.e., not significant) for 5-day lag inventory coefficient. This simply indicates that bird inventory was not a significant factor, and only the intercept (4.5366) became the dominant log-transformed emission estimate for that building across the entire dataset. Including bird inventory is not justified. In model P-11 for $PM_{2.5}$, the *P*-value was 0.0505 for intercept and 0.0334 for inventory (5-day lag). In model P-11 for TSP, neither coefficient was significantly different from zero, with *P*-values of 0.8022 and 0.945 for intercept and inventory (5-day lag), respectively. This model is inappropriate to use. All relevant coefficients for calculating the air pollutant emission in manure storage are presented in Table 3.

Table 3. Parameters for manure storage shed.

	NH_3	H_2S	PM_{10}	$PM_{2.5}$	TSP
Intercept	-0.194945	1.295775	4.5366	-30.57734	4.041666
$C_{Inventory}$	0.003927	0.004976	0.000732	0.067599	0.002286
C_{AmbT}	-0.013752	-0.024164	0	0	0
C_{AmbRH}	0	0	0	0	0
E_0	1.28615	1.36619	1.68902	1.68697	2.01361
E_1	-1.3	-6.0	-54.0	0	-30

Methods and Results

Coding the Draft Models

Each draft emission model identified by EPA was coded with the open-access Pandas and Numpy libraries in Python (Version 3.9.7). The program was designed so that model input values (i.e., housing type, bird inventory, ambient temperature, and ambient relative humidity) can be provided via command lines for simple point checks, and from a comma separated variable (CSV) text file when multiple combinations of inputs were evaluated. Model coefficients (those listed in Tables 1-3) were stored in a separate input file. Model output was written to a CSV text file for post-processing in Microsoft Excel and Origin-Pro.

The basic framework of this model can be used as a calculator for other parties to assess the draft models. It requires a (free) Python package to operate. The developed codes can also be run for multiple locations with the same input file format as this report.

Stress Tests of Models

Model stress testing was accomplished by the following steps:

1. Checking EPA examples for high-rise, manure belt, and manure storage that were provided in the draft report.
2. Checking each EPA recommended model prediction, first for physically realistic values (for example, matched with literature, no negative values) at common midpoints in the input data factors.
3. Testing the influence of a single input factor (e.g., temperature, humidity, bird inventory) while holding others at different constants.
4. Assessing model predictions from step 2 on a per hen-day basis, per the common emission factor methodology typically applied.

Inconsistencies and trends were noted and documented.

Checking EPA Example Calculations

Example calculations were repeated using our developed codes. Inputs and outputs are summarized in Table 4. Key findings include:

- For the high-rise example (page 86/455), the results of $ln(NH_3)$ was 3.37517 rather than 3.3707, resulting in a total daily emission of 46.09 kg/day, but should be 46.25 kg/day.
- For the manure belt example (page 87/455), the inventory should be divided by 1,000 rather than 100, and the result of $e^{3.05184} \times 1.27315$ should be 26.93 rather than 26.95.
- For the manure storage calculation, the results were the same between these calculations and the EPA draft report.

Table 4. Inputs and outputs for calculating the daily NH_3 emission rate (kg/day) based on the EPA draft emission models.

Inputs				**Outputs by developed codes**	**Outputs in EPA draft**
Housing system	Ambient temperature (°C)	Ambient RH (%)	Inventory (birds)		
High-rise	-0.9	89	100,000	46.25	46.09
Manure belt	-0.9	89	100,000	26.93	26.95
Manure storage	-0.9	89	200,000	1.05	1.05

Testing the Influence of a Single Input Factor

A combination of constant environmental single input variables was determined based on typical ambient conditions for major egg production systems. These variables are outlined in Table 5 and were used to stress-test the emission models. House inventory numbers for the three housing systems are listed in Table 6. For each housing system, the bird inventory numbers that matched the previously reported NAEMS sites were included along with additional values representative of different size egg producing operations.

Table 5. Combinations of ambient average daily temperature and relative humidity used in EPA draft emission model stress-test evaluations.

Temperature (°C)	**Relative Humidity (%)** 10	50	90
-40		X	
-20		X	
0	X	X	X
20	X	X	X
40	X	X	

Table 6. Hen inventory values used in EPA draft emission model stress-test evaluations.

Housing system	**Laying hen inventory tested** *(* NAEMS reported inventory)*							
High-rise	38,000*	95,000*	125,000	218,050*	400,000	600,000	-	-
Manure belt	10,000	40,000	250,000	280,000*	400,000	600,000	-	-
Manure storage	10,000	40,000	100,000	250,000	280,000	400,000	580,000	600,000

Predicted building emissions, in mass of pollutant per day, are provided by the draft EPA models. These emissions were recalculated with our developed codes, and the results were divided by bird inventory for each specific case, to develop daily emission factors. This approach is consistent with EPA practices and can be helpful for evaluating the effects of inputs (inventory, ambient temperature, and ambient relative humidity). Figures 1-3 plot daily emission factors versus bird inventory, for ten combinations of ambient temperature and relative humidity that span very cold to very hot and humid to dry environments.

A key finding was the unanticipated sensitivity of the draft model outputs to bird inventory. To a reasonable first approximation, the building emissions were expected to be proportional to inventory yet in Figures 1-3 there is a strong tendency to increase per bird emissions at the lower or upper ranges of bird inventory simulated. Most models exhibited an increase of emission factors at lower bird inventories. All but two particulate matter models for manure storage exhibited substantial increases at higher bird inventories. At least one model, PM$_{2.5}$ from manure belt housing, was unstable and extremely sensitive at higher inventories. These sensitivities to bird inventory may in part be explained by the stress test results using values for inventory that represented extrapolations from which the models were developed (see Table 2 for values). For example, high-rise housing models were developed from inventories of 38,000 to 218,050 hens from only three sites; bird inventories outside this range represented extrapolation, but the effect of increased bird inventory with all other factors held constant was not expected to be an increase in per bird emissions. The per hen emissions of PM$_{2.5}$, and in some cases the sum of PM$_{10}$ and PM$_{2.5}$ exceeded TSP, which is physically impossible because TSP encompasses ALL particulate matter in a sample. The PM2.5 model for storage facilities is invalid at higher NAEMS inventories.

For high-rise housing, the ammonia emission model predicted higher per bird emissions at the lowest bird inventory of 38,000 hens, with a subsequent drop of over 100% at the higher bird inventories used to develop the models. The particulate matter models also showed substantially greater per bird emissions at the lower flock size for this housing.

For manure belt housing, EPA draft models were calibrated against bird house inventory of about 280,000 hens. Any other bird inventory presented to these models represented an extrapolation; the plots in Figure 2 demonstrate that ammonia and hydrogen sulfide models were reasonably stable between 250,000 to 280,000 birds but increased substantially at lower or greater inventories. The plot for PM$_{10}$ in manure belt housing (Figure 2) is an example of poor model performance outside its fitted range. PM$_{10}$ emissions, per bird, were predicted to increase exponentially with bird inventory, contrary to expectations. For better data visualization, a log$_{10}$ scale was used for the PM$_{2.5}$ plot in Figure 2. The plot for PM$_{2.5}$ clearly showed that model to be unstable above the inventory of 280,000 birds.

The draft models for emissions from manure storage were developed from a facility accepting manure from two manure belt houses in the previous NAEMS sites (Ni et al., 2010). The bird inventory to use for manure storage is approximately the same as the manure belt housing (280,000); thus, we used a range of bird numbers 10,000 to 580,000, representing small to large manure storage facilities for the stress test (Figure 3). The predicted ammonia and hydrogen sulfide emission factors increased linearly with bird inventory above 100,000; this is unexpected since the emission from stacked manure is mostly proportional to emitting surface (which does not change appreciably as a manure pile grows only in height) and manure moisture content, which were not measured in the study. Negative emission factors were observed for ammonia and hydrogen sulfide. These emission factors increased many-fold at lower or higher inventories and were clearly not appropriate for use.

Figures 1-3 also demonstrate the impact of different combinations of average daily temperature and relative humidity. These had no impact on predicted particulate matter emissions (PM_{10}, $PM_{2.5}$, and TSP) for manure belt and manure storage because those terms were not included in the models. For high-rise housing, the predicted ammonia emission factor ranged over an order of magnitude between the coldest and hottest combinations, which may not be substantiated by the underlying data, i.e., because of extrapolation. By contrast, hydrogen sulfide emission factors were relatively stable with an inventory up to 218,050 birds, varying by about 50% across the range of conditions tested. All three particulate matter models behaved like the ammonia model, but with a less clear distinction between different temperature and relative humidity combinations.

The ammonia and hydrogen sulfide emission factors for manure belt housing (Figure 2) were similar in trend to that for high-rise housing (Figure 1); however, the ammonia emission factor was much less sensitive to the range in temperature and humidity that it was for the high-rise housing, whereas the hydrogen sulfide emission factor was more sensitive. Particulate matter emissions were insensitive to environmental conditions.

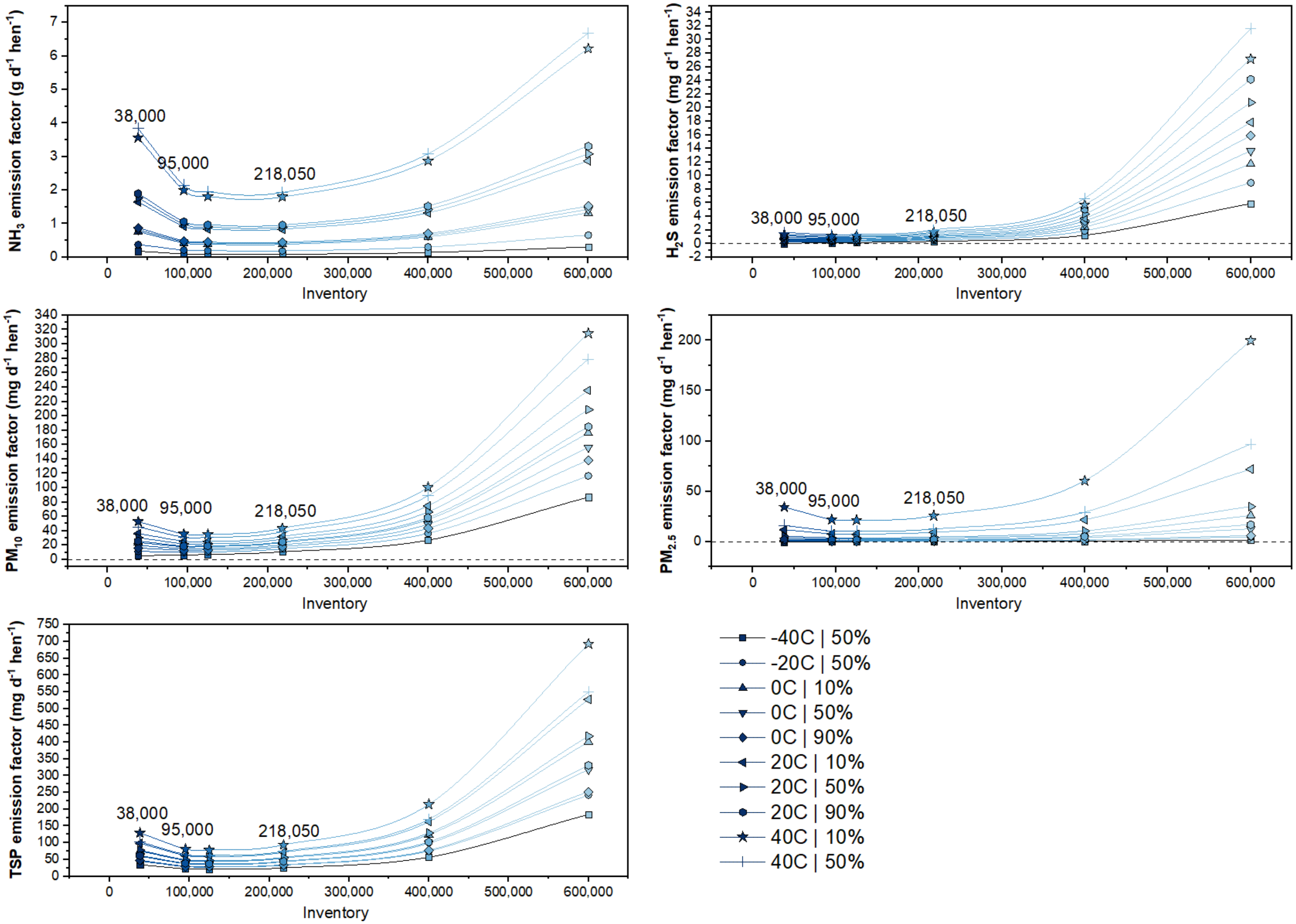

Figure 1. Single input variable stress-test results – daily emission factor of each pollutant (mass per day per hen): High-Rise Housing. EPA models were established from the capacities of 38,000, 95,000, and 218,000 hens per house.

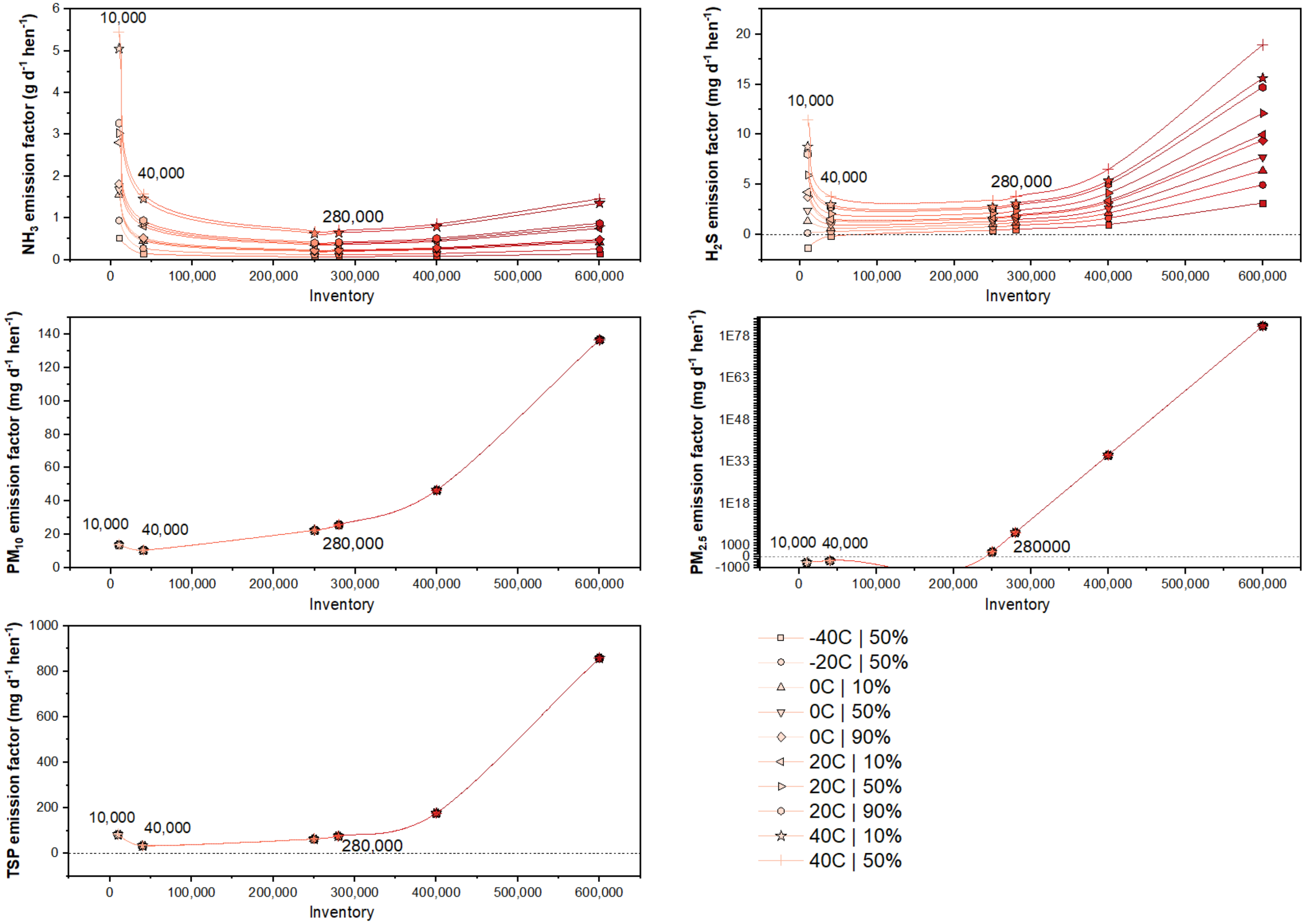

Figure 2. Single input variable stress-test results – daily emission factor of each pollutant (mass per day per hen): Manure Belt House. EPA model was established from a flock size of 280,000 hens.

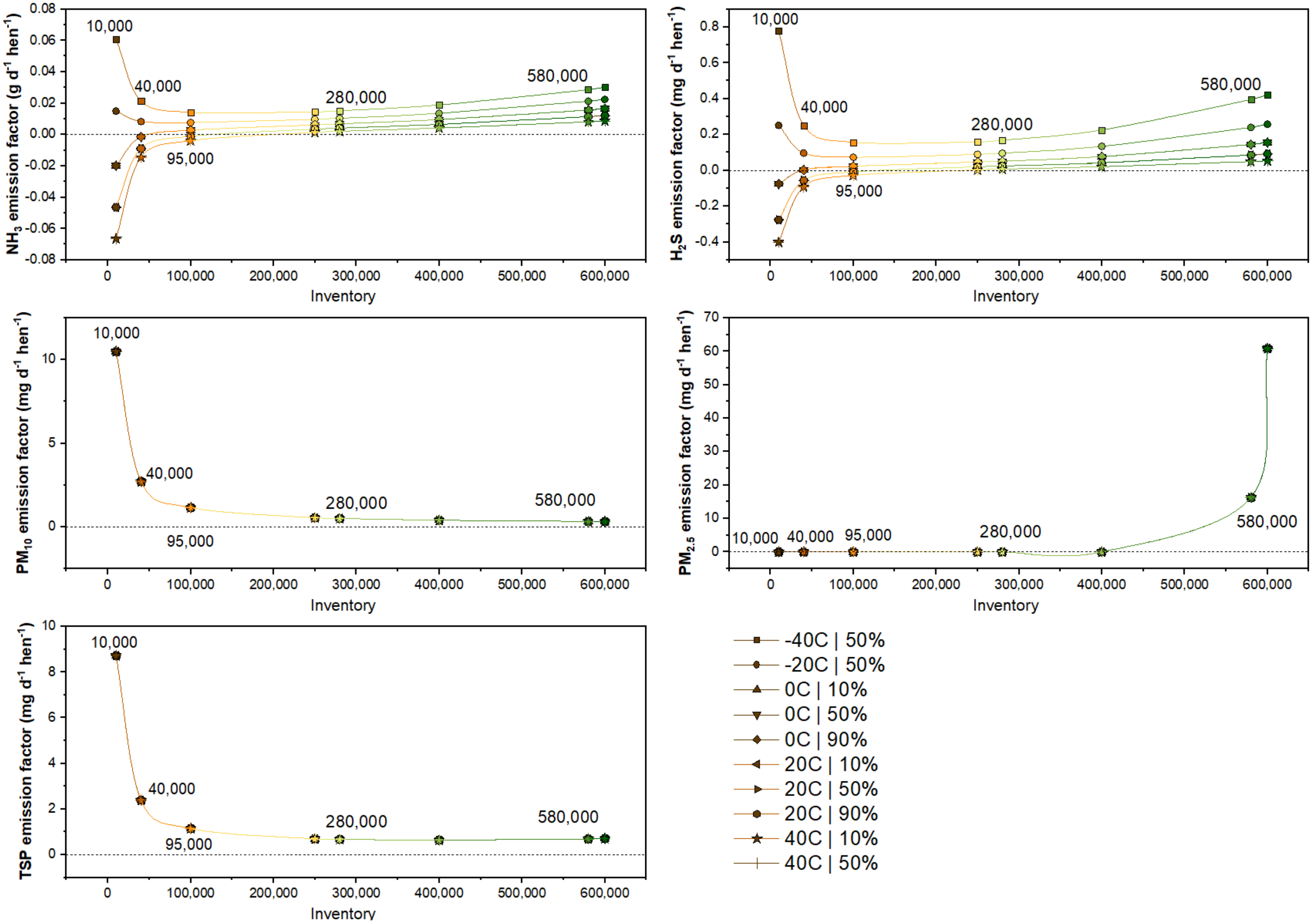

Figure 3. Single input variable stress-test results – daily emission factor of each pollutant (mass per day per hen): Manure Storage. EPA model was established with manure storage from up to two manure belt houses, total estimated at 580,000 hens.

Testing Effects of Temperature and RH Individually at Constant Inventory

For each model, bird inventory was held at a level corresponding to the NAEMS inventory as reported by EPA (2021a) and as shown in Table 6, and the effects of a range in temperature (at 50% RH) and a range in relative humidity (at 20 °C) were evaluated.

Holding inventory at the same levels and ambient relative humidity at 50%, while altering ambient temperature from -40 °C to 40 °C with 10 °C intervals, the results are presented in Table 7. The models for particulate matter did not depend on temperature or humidity for either manure belt housing or manure storage.

For high-rise houses, the percentage marginal increase in daily emission was 4.7% per °C for ammonia; 2.5 to 7.5% per °C for hydrogen sulfide; -30.5 to +29.2 % per °C for $PM_{2.5}$; 1.7 to 3.3 % per °C for PM_{10}; and 1.5 % per °C for TSP.

The percentage marginal changes of daily emissions for manure belt houses and manure storage shed were 3.4% per °C and -1.5% per °C for ammonia; and 2.6 to 2.9% per °C and -2.5 to -2.2 % per °C for hydrogen sulfide, respectively.

Table 7. Marginal change in daily emissions per 1 °C temperature increment at a constant 50% RH.

Housing system (Site location)	Bird inventory	NH_3 (%)	H_2S (%)	PM_{10} (%)	$PM_{2.5}$ (%)	TSP (%)
High-rise (CA)	38,000	+4.7	+3.3 to +7.5	+2.2 to +3.3	-30.5 to +24.8	+1.5
High-rise (NC)	95,000	+4.7	+2.8 to +3.8	+1.9 to +2.4	+7.4 to +29.2	+1.5
High-rise (IN)	218,050	+4.7	+2.5 to +2.6	+1.7 to +1.8	+6.9 to +9.4	+1.5
Manure belt (IN)	280,000 (1 house)	+3.4	+2.6 to +2.9	-	-	-
Manure storage (IN)	580,000 (2 houses)	-1.6 to -1.4	-2.5 to -2.2	-	-	-

By contrast, holding inventory at the same levels and ambient temperature at 20°C, while altering ambient RH from 0% to 100% with 10% intervals (see Table 8) resulted in percentage marginal increases in ammonia emissions of slightly less than 0.2% per %RH for high rise and manure belt housing, respectively. There was no effect of changing RH on emissions from storage. For hydrogen sulfide emissions, the percentage marginal increase varied from 0.4 to 0.6% per %RH for high-rise housing, increasing as inventory was reduced; it was about 0.5% per %RH for manure belt housing. With respect to particulate matter emissions, high rise housing emissions decreased with each percentage point increase in RH, ranging from -0.4 to -0.3%, -2.5 to -1.7%, and -0.6% for PM_{10}, $PM_{2.5}$, and TSP, respectively. Particulate emissions in manure belt housing and manure storage were insensitive to changes in RH.

Table 8. Marginal change in emissions per 1% RH increment at 20 °C temperature.

Housing system (Site location)	Bird inventory	NH_3 (%)	H_2S (%)	PM_{10} (%)	$PM_{2.5}$ (%)	TSP (%)
High-rise (CA)	38,000	+0.18	+0.52 to +0.60	-0.44 to -0.40	-2.46 to -1.77	-0.56
High-rise (NC)	95,000	+0.18	+0.45 to +0.49	-0.38 to -0.35	-2.09 to -1.73	-0.56
High-rise (IN)	218,050	+0.18	+0.40 to +0.41	-0.32 to -0.31	-1.79 to -1.68	-0.56
Manure belt (IN)	280,000 (1 house)	+0.19	+0.51 to +0.52	-	-	-
Manure storage (IN)	580,000 (2 houses)	-	-	-	-	-

Selection of Representative Weather Locations

Regions of the USA with significant egg production were identified from our experience, USDA data, and conversations with egg industry leaders. Approximately 30 locations were selected and reviewed for similarities and differences in weather patterns, and the availability of a representative weather dataset (see Appendix 1, Tables A1.1 and A1.2). Climate was characterized using Typical Meteorological Year 3 (TMY3) data from the Department of Energy's National Renewable Energy Lab (Wilcox and Marion, 2008). Each TMY file contains hourly values of various independent variables (including ambient dry bulb temperature and relative humidity), and the TMY data represents the statistically selected months having the most typical weather data from the last 30 years or so for a location. Each month in the TMY can be from a different year.

Locations with TMY files available within the selected regions of interest were then reviewed for similarities in either temperature or relative humidity ranges, and consistency with the International Energy Conservation Code (IECC) Climate Zone classification (Figure 4) and the US Department of Energy Building America classification scheme (Figure 5). TMY files were categorized according to IECC Climate Zones (2 to 6) and Building American categories simplified to Dry, Moist, and Marine (A to C). Candidate stations for selecting TMY files were color coded as shown in Figures 6 (boxplots of annual ambient temperature) and 7 (boxplots of annual ambient relative humidity).

Candidate weather stations (listed in Table A1.2 of Appendix 1) were sorted and grouped based on the following criteria:

1. Representative of egg production
2. Representative of the range in annual ambient temperature across the country
3. Representative humidity zones, as denoted by Building America classification (Figure 5)
4. Multiple sites with similar Zone classifications sorted by extremity of temperature and relative humidity, as denoted in boxplots of Figures 6 and 7.
5. Multiple sites with similar characteristics were reduced to a single or pair of sites.

Table 9 lists the 12 selected stations. Note that Table A1.2 and Figures 4-7 provide a means of identifying other candidate stations that are like those stations selected for use in the subsequent analysis.

Table 9. Selected Stations for TMY Data

Station	TMY/WMO ID	IECC Climate Zone*	Building America Climate Zone	Annual Average ±SD	
				Ambient temperature (°C)	Ambient RH (%)
San Antonio, TX	722530	2A	Hot-humid	20.4 ± 8.5	67.4 ± 21.4
Orlando, FL	722057	2A	Hot-humid	21.6 ± 6.6	71.4 ± 17.3
Phoenix, AZ	722780	2B	Hot-dry	23.8 ± 9.8	34.2 ± 19.6
Jackson, MS	722350	3A	Hot-humid	17.7 ± 9.4	73.7 ± 20.9
Charlotte, NC	723140	3A	Mixed-humid	16.0 ± 9.1	66.4 ± 21.7
Modesto, CA	724926	3B	Hot-dry	16.9 ± 7.9	60.8 ± 23.7
Columbia, MO	724450	4A	Mixed-humid	12.1 ± 11.6	70.2 ± 17.6
Portland, OR	726986	4C	Marine	11.4 ± 7.1	76.8 ± 19.3
Grand Rapids, MI	726350	5A	Cold	8.8 ± 11.3	72.9 ± 17.6
Spokane, WA	727850	5B	Cold	8.7 ± 9.6	64.6 ± 24.0
Fort Dodge, IA	725490	6A	Cold	8.8 ± 12.7	70.7 ± 16.5
Minneapolis, MN	726580	6A	Cold	7.7 ± 12.9	65.7 ± 17.4

*Note: Temperature and moisture zones as depicted in Figure 4. A=Moist, B=Dry, C=Marine

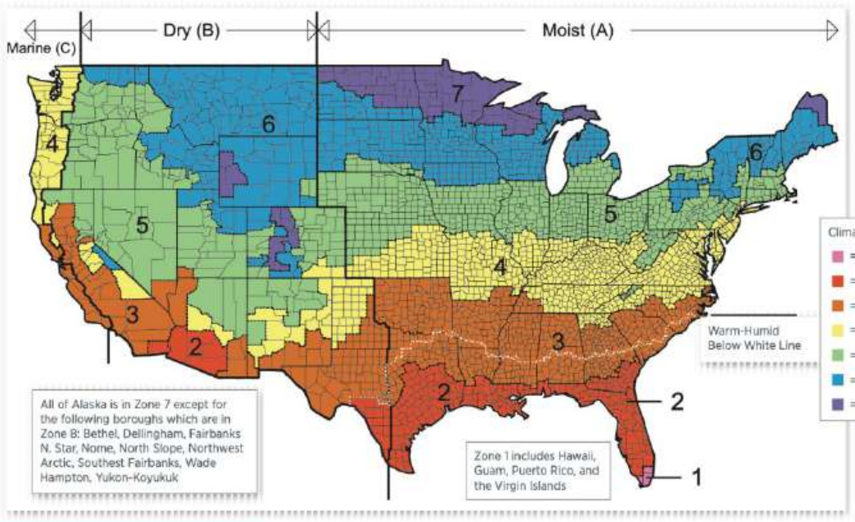

Figure 4. IECC Climate Zone Characterizations (numbers) and ASHRAE humidity categories (source: Baechler et al., 2015).

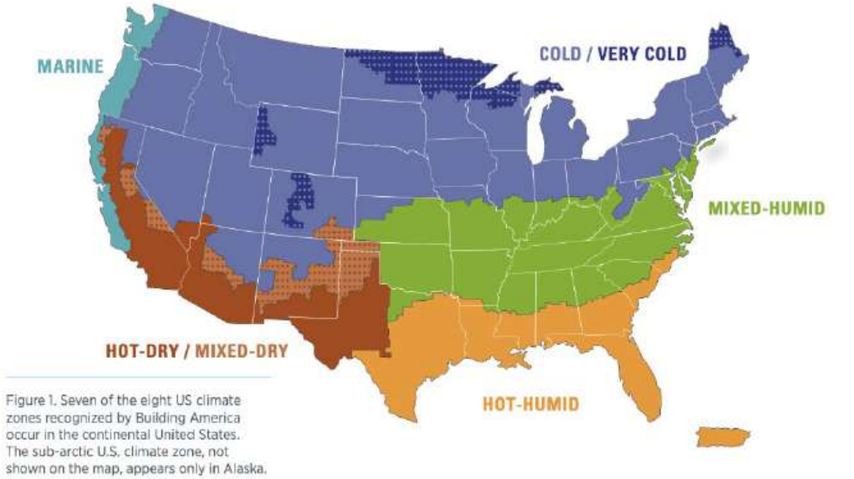

Figure 1. Seven of the eight US climate zones recognized by Building America occur in the continental United States. The sub-arctic U.S. climate zone, not shown on the map, appears only in Alaska.

Figure 5. Building America Climate Designations (source: Baechler et al., 2015)

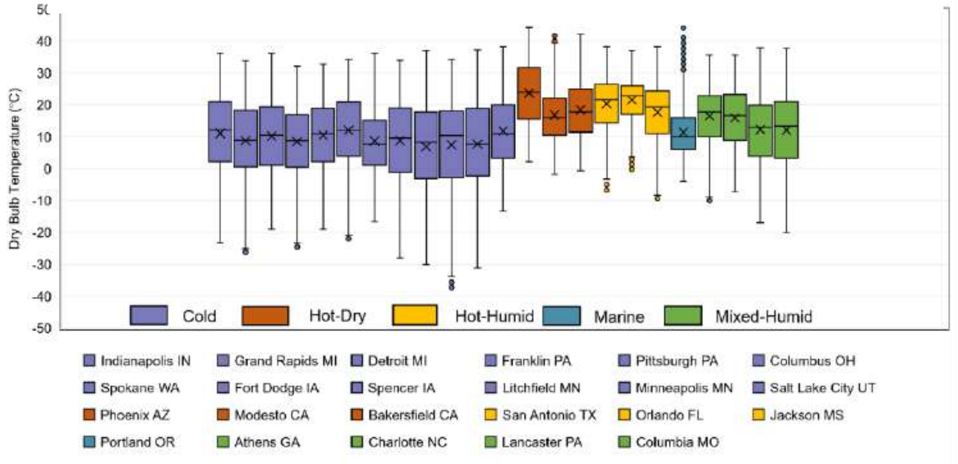

Figure 6. Boxplot demonstrating the dry bulb temperatures of the candidate locations during a typical metrological year. Each location is color coded according to the Building America Climate Designations.

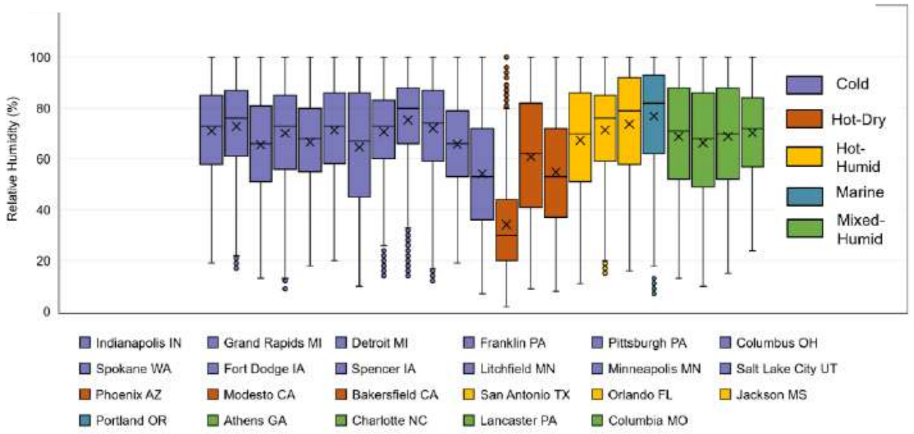

Figure 7. Boxplot demonstrating the relative humidity of the candidate locations during a typical metrological year. Each location is color coded according to the Building America Climate Designations.

Evaluation of Draft Models for Estimating Annual Emission

Twelve TMY3 datasets were used with each EPA model computing annual emissions. For these calculations, bird inventory values are indicated in Table 10. The inventory of two manure storage facilities was estimated as 519,580 according to the EPA draft report and previous NAEMS study (Ni et al., 2010), in which the initial inventory was 262,610 for house 8 and 256,970 for house 9.

Table 10. Bird inventory values used in annual emission estimate calculations.

Housing system (site location)	Bird inventory
High-rise (CA)	38,000
High-rise (NC)	95,000
High-rise (IN)	218,050
Manure belt	280,000 (1 house)
Manure storage shed	280,000 (1 MB house)
Manure storage shed	519,580 (NAEMS IN site*)

*Note: the combined bird inventory for manure storage shed (IN) was from houses 8 (262,610) and 9 (256,970) reported in the EPA draft and Ni et al. (2010).

Daily Averages

The default approach suggested by EPA (2021a) is to utilize daily ambient average values for ambient temperature and relative humidity. Daily averages were calculated from the hourly values provided in the TMY3 weather datasets and used as input to the draft models. The draft models predicted mass of pollutants per day. These are summed up over a year and expressed as annual total emission factors.

Monthly Averages

To assess the sensitivity of EPA draft models, monthly average temperature and relative humidity were computed from the TMY3 weather datasets and used for calculating average emissions in each month from January to December. The monthly values were then multiplied by specific numbers of days in a month, and then summed over a year as annual total emission factor.

Annual Average

To further assess the impact of temperature and relative humidity on the EPA draft models, annual average temperature and relative humidity were computed from the TMY3 weather datasets and used as input. The average emission predictions were then multiplied by 365 days/year and expressed as annual total emission factors.

Results from Annual Emission Estimates

Results of these simulations were tabulated of all 12 locations. An example for ammonia is given in Table 11. The three columns of annual emission factors for each site were computed from daily, monthly, and average ambient temperature and relative humidity. For all emission factors computed there was a negligible or small reduction in emission factor as the averages went from daily to monthly to annual, suggesting that a simple, single value for the annual average would suffice. These emission factors can also be compared with published values in the literature, summarized in Tables 13-1 to 13-3. Some of these are also based on NAEMS sites.

Graphical Perspective of Emission Factors across the US

Figure 8 is a density map depicting relative magnitude of annual ammonia emission factors (units: g hen^{-1} yr^{-1}) for the 12 selected TMY sites, computed from yearly average ambient temperature and relative humidity (annual T/RH average column in Table 11). The annual average ammonia emission factors were illustrated by circles of different sizes, representing values from the smallest emission factor (101 g hen^{-1} yr^{-1} at Minneapolis, MN) to the largest (154 g hen^{-1} yr^{-1} at Orlando, FL). These emission factors were overlaid on another density map that depicted the number of total poultry (chickens only, excluding turkeys) operations (including egg production farms) in each county across the continental US, provided by the USDA NASS 2012 Census (USDA NASS, 2015). This inventory data highly correlated with the layer farm and production inventory map once provided by the USDA that is the best resource available until the USDA publishes its 2017 Census statistics for egg-laying farms. This information was then overlaid on another map – the Building America Climate Zone (Figure 5). Figure 8 thus demonstrates the ranges in annual emission factors within the framework of poultry production density and national climate categories. Colder locations had substantially lower emission factors, while hotter locations showed higher factors, with humidity further increasing the magnitude of emission factors.

Table 11. Example of annual emission factor by region and by different temperature and RH averaging method (daily, monthly, or annual values input to models).

TMY Station	**Annual Ammonia Emission Factors (g hen^{-1} yr^{-1}) Manure Belt House with 280,000 hens:(NAEMS IN Site)**		
	Daily T/RH Average	Monthly T/RH Average	Annual T/RH Average
San Antonio, TX	150	150	147
Orlando, FL	156	155	154
Phoenix, AZ	157	156	152
Jackson, MS	141	140	137
Charlotte, NC	133	132	129
Modesto, CA	133	132	131
Columbia, MO	121	120	116
Portland, OR	116	116	115
Grand Rapids, MI	111	110	106
Spokane, WA	106	106	104
Fort Dodge, IA	112	111	105
Minneapolis, MN	107	106	101

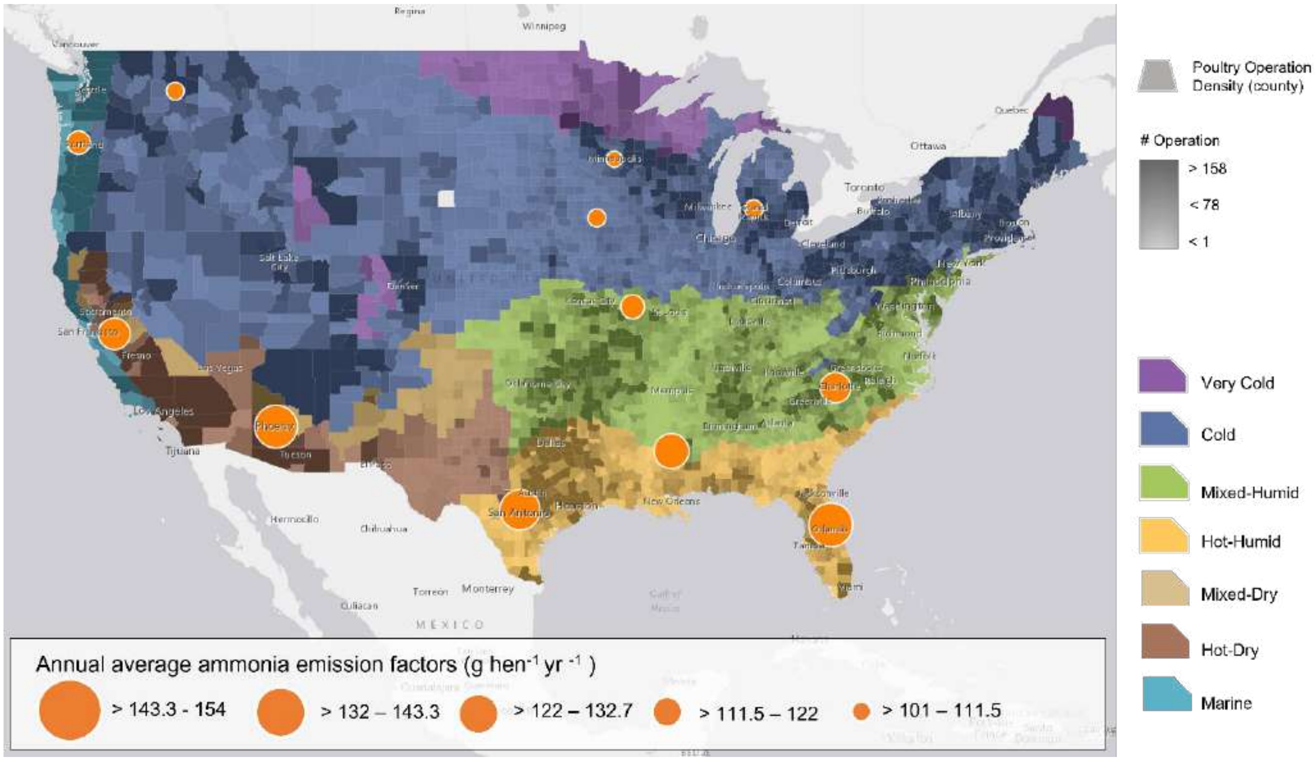

Figure 8. Density map showing the annual ammonia emission factor (g hen^{-1} yr^{-1}) for the 12 US locations selected (Table 9), for a manure belt layer house with 280,000 hens. The map shows county level poultry operation numbers and the Building America climate zones. County level poultry (chicken only) operation numbers are from the 2012 Census (USDA NASS, 2015).

Annual Totals

Three of the 12 locations were selected for representatives of major US climate zones with significant egg production, namely Minneapolis MN (Cold), Modesto CA (Hot-Dry), and Orlando FL (Hot-Humid), were plotted by housing type and pollutant prediction, using the daily average temperature and relative humidity values computed from the corresponding hourly TMY3 weather datasets (Figure 9, Table 10). For better data visualization, a $\log_{10}$ scale was used for the annual $PM_{2.5}$ emission factor plot. Most draft model predictions for high-rise and manure belt housing show a strong effect of bird inventory when extrapolated to smaller or larger values (e.g., 10,000 and 519,580 birds) than found in the NAEMS dataset.

Gaseous emissions (ammonia, hydrogen sulfide) for both bird housing types, and particulate emissions (PM_{10} and TSP) for high-rise housing, were predicted to be greatest for the Orlando site and least for the Minneapolis site. They also demonstrated a strong positive relation to increased daily average temperature and, to a lesser extent, relative humidity. As Table 11 and Figure 8 demonstrate, the temperature and relative humidity likely had greater effects on the magnitude of the NH_3 emission factors, computed on a per hen basis, than that of the inventory sizes. In this analysis, the three leading egg production states [IA (USDA NASS, 2020)] had substantially lower annual ammonia emission factor values than those producing fewer eggs but with higher temperature and more humid (e.g., FL, TX, AZ).

Results for manure storage emissions were virtually constant for all variations in bird inventory or location, except for PM_{10} at 10,000 birds which was greater than other inventory values simulated.

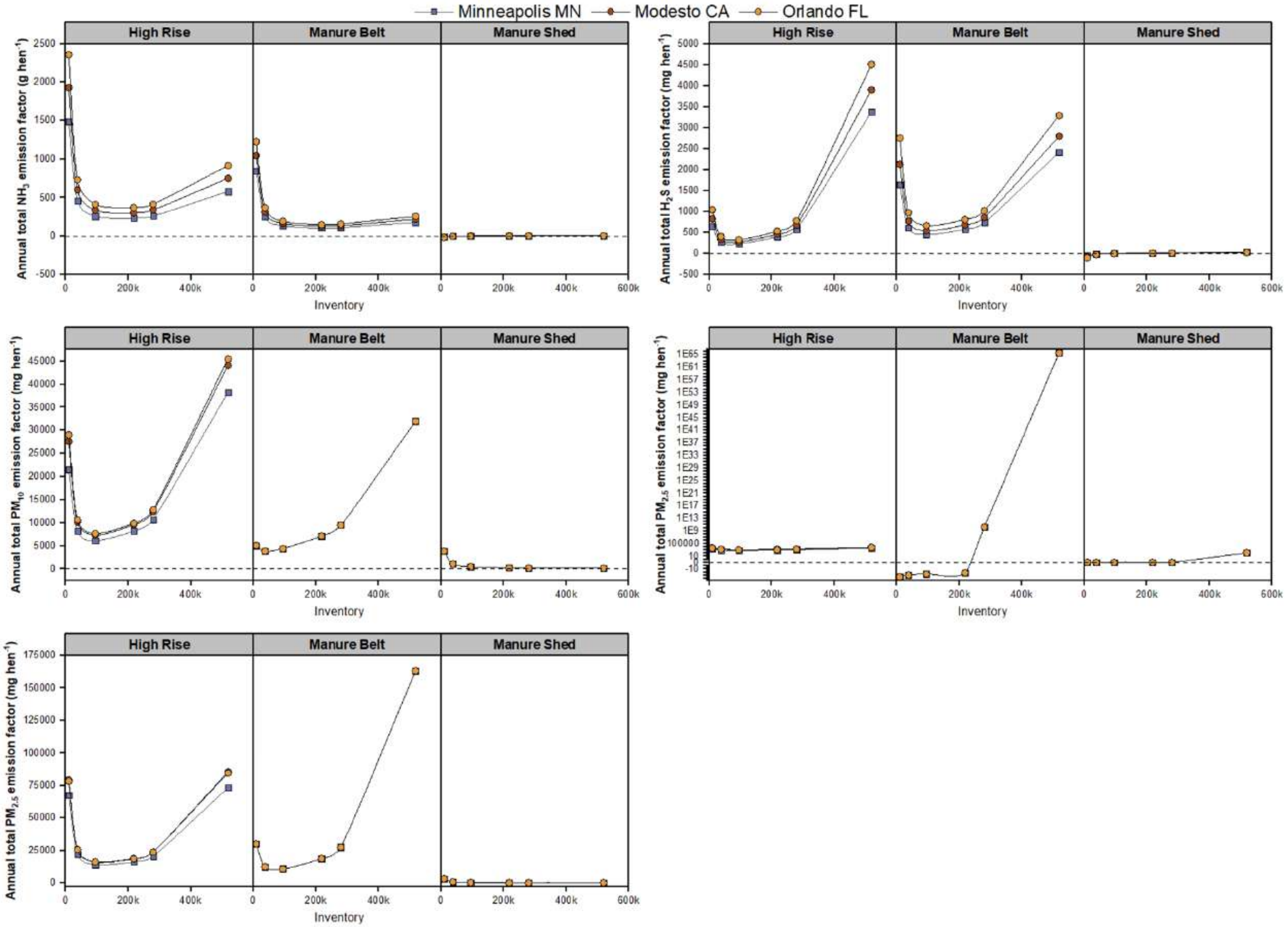

Figure 9. Annual emission factors simulated for three housing systems using TMY3 data of three selected locations: Minneapolis MN, Modesto CA, and Orlando FL. The inventory numbers plotted were 10,000, 38,000, 95,000, 218,000, 280,000, and 519,580.

Observations and Points for Discussion

This section simply consists of a set of points raised as the analyses were conducted, and in some cases include some follow-on recommendations. They are not prioritized.

1. All draft models to predict building emissions include bird inventory. Models were built on log-transformed data regressions and the coefficients in these regressions were effectively "trained" against the range of values available in the dataset for each input variable. In this case the bird inventory range was limited to a small extent of the range normally encountered in the industry (one value for manure belt housing or manure storage, and 3 values for high rise housing).

   An adjustment to this approach is advisable. We suggest that the draft models be modified for other bird inventories in this fashion:

   a. Use the given bird inventory from the modified NAEMS datasets (e.g., 280,000 for manure belt)
   b. Compute the emission factor by dividing the estimated building emission from Step a. Publish these factors for general use.
   c. For a building with other bird inventory, multiply that inventory by the emission factor in Step b.

2. Where other factors such as climate are to be included, the weather data ranges in the NAEMS dataset must match the broad range found in the US climate categories where egg production is significant. In fact, this cannot be assured, so an alternative with a simple marginal change in emission factor per °C change or per % RH change (using simple mean annual ambient conditions) is advised. These marginal changes should be derived from the NAEMS dataset and not for extrapolated climate values.

3. Different numbers of reported digits for the factor C_{AmbT} in the manure storage shed's ammonia model were noted, being -0.013752 in Table 5-9 (page 64/455) and Table G-27 (page 421/455), but -0.01375 (page 87/455). Similarly, E_0 is 1.28615 in Table 7-1 (page 82/455) but listed as 1.2862 in the manure storage shed example (page 88/455). A consistent number of digits in all places is recommended, simply to ensure all users get similar results.

4. The mathematical form of the general emissions models is documented incorrectly in the draft emissions report. EPA developed these models utilizing a natural log transformation of the underlying modified NAEMS data. The EPA Laying Hen report (2021a) incorrectly describes the general process for computing a value of daily emission from a facility by confusing the log-transformed quantity with the actual value. While the General Report, page 6-5 Equation 7, uses mathematically consistent nomenclature, that is not the case in the Layer Report itself. The equations should be updated to something along this line:

   $$ln(Y) = \text{Intercept} + C_{\text{Inventory}} \times \text{Inventory} + C_{AmbT} \times \text{AmbT} + \text{C}_{AmbRH} \times \text{AmbRH} \qquad (3)$$

   In this equation, the quantity *ln(Y)* is the natural log transformed mass of pollutant emitted from a building per day (and not the mass itself), and the various model coefficients include and *Intercept* and values for *Inventory* ($C_{Inventory}$), mean daily ambient temperature (C_{AmbT}), mean daily ambient relative humidity (C_{AmbRH}), and the independent values for bird number in a facility (Inventory, an integer value), mean daily temperature (*AmbT*, °C), and mean daily relative humidity (*AmbRH*, %).

   The EPA report incorrectly uses the value of the pollutant, e.g., NH_3, $PM_{2.5}$, etc. instead of the (back-transformed) variable Y in Equation 1; see for example in Table 5-3 for high-rise housing, Table 5-6 for manure belt housing, and Table 5-9 for manure storage sheds. These should be corrected.

5. To compute daily emission rate, ER, this form is provided by EPA, with one significant concern noted regarding the algebraic sign of coefficient E_1. EPA's version of the following equation subtracts the E_1 term. That requires the user to use an incorrectly signed (positive-valued) E_1 rather than adding the documented (negative) coefficient which is conventional:

$$ER = e^{ln(Y)} \times \mathrm{E}_0 + \mathrm{E}_1 \tag{4}$$

6. The issue of the coefficient E_1 sign and its subtraction vs addition must be addressed for accurate reporting and use is that we also noted inconsistent algebraic sign usage especially for coefficient E_1 (E_0 and E_1 are named $\overline{E_i}$ and C in the General Report (EPA 2021b), page 6-5, and in the Layer Report (EPA 2021a) in Table 7-1). The concern is that, however, the sign of the coefficient C appears as a positive number, and the equation in which it was implemented (Equation 7, General Report) subtracts this value. This is easy for a user to miss, and the coefficients for *all* regressions should keep their signs, using additive terms in the related equations. We recommend all tabulated values of C be rewritten as their actual (negative) values, and the form of Equation 2 be adopted, rather than that of Equation 7 on page 6-5 of the General Report.

7. The two coefficients in the back-transform (E_0 and E_1) in Equation 2 have the effect of adjusting bias and offset for improving (reducing) model variance. There is no evidence of why this is needed, especially for application to the manure belt housing (a single building) and the manure storage shed (two barns with the similar inventory of birds). Further, in all cases the value of the coefficient $E_0 > 1$, meaning that the back-transformed quantity Y is then further increased prior to having the offset coefficient E_1 added. The rationale for this methodology is unclear, especially for sites with a single sized building used to develop the model to represent a national situation.

8. Notes on marginal changes in emissions per °C or %RH increase:
   a. Manure belt 280k birds, NH_3 3.4% per °C increment
   b. Manure belt 280k birds, H_2S 2.7% per °C increment
   c. Manure belt 280k birds, NH_3 0.19% per 1% RH increment
   d. Manure belt 280k birds, H_2S approximately 0.5% per 1% RH increment

9. An extremely large number (17,556,566,943 mg hen^{-1} yr^{-1} or 17.6 metric ton hen^{-1} yr^{-1}) was observed for annual $PM_{2.5}$ emissions for a manure belt house with 280,000 hens (NAEMS IN2B Site). In manure storage with 280k birds, PM_{10} was 181.9 mg per hen annually while PM2.5 is 1.92×10^{-5} mg per hen annually. The big difference between these two may be caused by the intercept in Equations 13 and 14 of the General Report (4.5366 for PM10 and −30.57734).

10. A list of tables (Tables 13-1 to 13-3) that summarize emission factors for different pollutants from studies conducted between 2003 and 2021 are provided. The emission factors are organized per pollutant and per housing type. Values for other facilities, such as houses with pits, composting facilities, tunnel and cross ventilation, are also included for reference.

11. Summary statistics for manure belt NH_3 emission factors from the first three references (2 in IA and 1 in IN; >200,000 birds) in Table 13-1 were calculated and compared to the daily average value in Table 11 for Fort Dodge, IA (112 g hen^{-1} d^{-1}) for 280,000 hens for an EPA estimated NH_3 emission factor of 0.31 g hen^{-1} d^{-1}. Then, summary statistics for manure belt NH_3 emission factors from the next two references (IA and PA; 100,000 to 150,000 birds) in

Table 13-1 were calculated and compared to the daily average value for Fort Dodge, IA for 100,000 hens for an EPA estimated NH_3 emission factor of 0.036 g d^{-1} hen^{-1}.

Results are depicted in Figure 10 and show that EPA models have no variability (other than climate) because of the lack of incorporation of different management practices, housing styles, diet, etc. These practices are better represented in the literature values but there are few studies on this. For 280,000 hens, EPA models overestimate all literature valueswith some reasonable agreement at the maximum value. For 100,000 hens, EPA models overestimate all literature values with 132% difference at the average literature value.

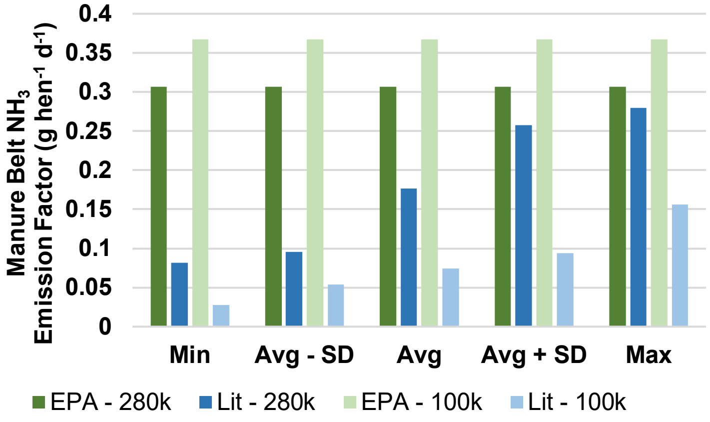

Figure 10. Comparison of ammonia emission factors derived from EPA models and literature (Table 13-1) for Manure Belt Housing with 280,000 and 100,00 hens for Fort Dodge, IA.

12. Another comparison for the NH_3 estimates using EPA models is demonstrated in Table 12, for Minneapolis, MN and Orlando, FL. These values were calculated for high-rise and manure belt operations with a 1 million laying hen total inventory. Compared to the literature values outlined in Tables 13-1 to 13-3, results in Table 12 showed the high-rise numbers are similar with the range of values reported by other projects used the same dataset; however, the manure-belt numbers are considerably higher than those reported from other reference.

Table 12. Annual ammonia emission and emission factor in a farm with 1 million laying hens.

Housing type	**Inventory**	**Annual emission** (US Tons farm^{-1} yr^{-1})		**Effective Annual Emission factor** (g hen^{-1} yr^{-1})		**Effective Daily Emission factor** (g hen^{-1} d^{-1})	
		Minneapolis MN	Orlando FL	Minneapolis MN	Orlando FL	Minneapolis MN	Orlando FL
High-rise	83,333 birds/house, 12 houses	302	479	274	435	0.75	1.19
	125,000 birds/house, 8 houses	258	409	234	371	0.64	1.02
	200,000 birds/house, 5 houses	251	398	228	361	0.62	0.99
Manure belt	125,000 birds/house, 8 houses	128	186	116	168	0.32	0.46
	166,667 birds/house, 6 houses	117	169	106	153	0.29	0.42
	250,000 birds/house, 4 houses	115	167	105	151	0.29	0.41

Table 13-1. Reference summary of NH_3 emission factors.

Housing Type	Site Location of Study	Bird inventory	Ambient Temperature (°C)	Ambient RH (%)	NH_3 Emission Factor (g d^{-1} hen^{-1})	Source of Reference
High rise	Central CA	32,500	5 – 35	NA	0.95 ± 0.67	Lin et al. (2012)
	Eastern IN	218,000	12.4 ± 11.3	68.2 ± 13.3	1.08 ± 0.42	Ni et al. (2017b)
	North-central IA	NA	NA	NA	1.03	Liang et al. (2003)
	North Carolina	95,000	16.5	N/A	0.599 ± 0.620	Wang-Li et al. (2013)
	Iowa	73,938 - 82,219	NA	NA	0.90 ± 0.027 0.81 ± 0.044	Liang et al. (2005a)
	Pennsylvania	93,974 - 95,984	NA	NA	0.83 ± 0.099	
	Iowa	73,938- 82,219	NA	NA	0.87 ± 0.29	Liang et al. (2005b)
	North-central IA	73,938 - 82,219	NA	NA	0.69 - 1.48	Liang et al. (2006)
	California	NA	NA	NA	0.94 - 0.95	Liang et al. (2013)
	Indiana	NA	NA	NA	1.03 - 1.13	
	North Carolina	NA	NA	NA	0.59	
High rise deep pit	Forlı´, Italy	60,000	6.6 - 34.5	NA	0.03 – 1.61*	Fabbri et al. (2007)
High rise manure pit	North Carolina	103,000	12 - 22	NA	0.52-0.66	Li et al. (2013a)
Manure belt	North-central IA	NA	NA	NA	0.168	Liang et al. (2003)
	West Lafayette, IN	250,000	12.0 ± 10.9	N/A	0.28	Ni et al. (2017a)
	Iowa	200,000	NA	NA	0.082	Shepherd et al. (2015)
	Iowa	104,860	NA	NA	0.054 ± 0.0035	Liang et al. (2005a)
	Pennsylvania	157,822-158,117	NA	NA	0.094 ± 0.019	
	Iowa	104,860	NA	NA	0.094 ± 0.062, 0.054 ± 0.026	Liang et al. (2005b)
	North-central IA	104,860	NA	NA	0.044 - 0.172	Liang et al. (2006)
	Ohio	180,000	-17.2 - 32.8	17 - 100	0.07 - 0.37	Wang et al. (2009)
	Ontario, Canada	70,600	-4.1 - 19.4	N/A	0.06 ± 0.05	Morgan et al. (2014)
	Forlı´, Italy	60,000	3.6 - 33.2	NA	0 – 0.3*	Fabbri et al. (2007)
	European Union	12,500	NA	NA	0.1 ± 0.003	Hayes et al. (2006)
	Ireland	42,000	3.67-15.46	NA	0.25	Kelleghan et al. (2021)
Manure belt (enriched colony)	Spain	52,000	15.7 ± 4.8	77.3 ± 11.8	0.11 ± 0.08	Alberdi et al. (2016)
Manure belt (enriched colony)	Spain	38,000	15.9 ± 4.7	74 ± 5	0.05 ± 0.15	Rosa et al. (2020)
Manure belt (Mixed tunnel and cross ventilation)	Ohio	170,000	23.0 ± 2.9 summer -0.1 ± 5.6 winter	72.7±11.7	0.081 ± 0.004 0.099 ± 0.004	Tong et al. (2021)
Manure belt storage	Iowa	200,000	NA	NA	0.21	Shepherd et al. (2015)
Manure belt (Composting facility)	Ohio	830,000	14.6 ± 9.5	74.7 ± 18.6	0.72 ± 0.13	Zhao et al. (2016)
Composting facility	Ohio	1,000,000	-20 to 35	64-78	0.32 ± 0.14	Zhao et al. (2008)
Deep litter (deep pit)	European Union	5,000	NA	NA	0.5 ± 0.006	Hayes et al. (2006)

* unit is g d^{-1} hen $space^{-1}$

Table 13-2. Reference summary of H_2S emission factors.

Housing Type	Site Location of Study	Bird inventory	Ambient Temperature (°C)	Ambient RH (%)	H_2S Emission Factor (mg d^{-1} hen^{-1})	Source of Reference
High rise	Central California	32,500	5-35	NA	1.27 ± 0.78	Lin et al. (2012)
	Eastern Indiana	218,000	12.4 ± 11.3	68.2 ± 13.3	1.37 ± 0.83	Ni et al. (2017b)
	North Carolina	95,000	NA	NA	0.618 ± 0.517 0.698 ± 0.620	Wang et al. (2016)
Manure belt	West Lafayette, IN	250,000	12.0 ± 10.9	NA	1.952	Ni et al. (2017a)

Table 13-3. Reference summary of particulate matter emission factors.

Housing Type	Site Location of Study	Bird inventory	Ambient Temperature (°C)	Ambient RH (%)	Emission Factor (mg d^{-1} hen^{-1})	Source of Reference
			PM$_{2.5}$			
High rise	Central California	32,500	5 - 35	NA	5.9 ± 12.6	Lin et al. (2012)
High rise	North Carolina	103,000	NA	NA	0.37 ± 3.06	Li et al. (2013b)
High rise	North Carolina	100,000	19.3 ± 7.07	65.6 ± 14.4	7.86 - 11.4	Li et al. (2011a)
High rise manure pit	North Carolina	103,000	12 - 22	N/A	0.27 - 2.4	Li et al. (2013a)
High rise in-house manure storage	Central Iowa	248,814	NA	N/A	3.6 ± 3.7	Li et al. (2011b)
High rise deep pit	Forlı´, Italy	60,000	6.6 - 34.5	NA	0.72 – 115.92*	Fabbri et al. (2007)
Manure belt	Iowa	200,000	NA	NA	0.9	Shepherd et al. (2015)
Manure belt	Ontario, Canada	70,600	-4.1 - 19.4	NA	1.3 ± 1.0	Morgan et al. (2014)
Manure belt	Forlı´, Italy	60,000	3.6 - 33.2	NA	0.24 – 53.28*	Fabbri et al. (2007)
Manure belt (Mixed tunnel and cross ventilation)	Ohio	170,000	-13.3 to 29.1	29.9 - 99.1	1.41 ± 1.53	Knight et al. (2021)
			PM$_{10}$			
High rise	Central California	32,500	5 - 35	NA	33.4 ± 27.4	Lin et al. (2012)
High rise	Eastern Indiana	218,000	12.4 ± 11.3	68.2 ± 13.3	20.6 ± 22.5	Ni et al. (2017b)
High rise	North Carolina	103,000	NA	NA	17.8 ± 14.9	Li et al. (2013b)
High rise	Ohio	169,000	9.2 ± 9.9	NA	34.8 ± 33.3	T. Lim et al. (2007)
High rise manure pit	North Carolina	103,000	12 - 22	NA	4.41 - 31.5	Li et al. (2013a)
High rise in-house manure storage	Central Iowa	248,814	NA	NA	26.1 ± 15.8	Li et al. (2011b)
High rise deep pit	Forlı´, Italy	60,000	6.6 - 34.5	NA	5.52 - 414.48 *	Fabbri et al. (2007)
Manure belt	West Lafayette, IN	250,000	12.0 ± 10.9	NA	25.2	Ni et al. (2017a)
Manure belt	Iowa	200,000	NA	NA	15.7	Shepherd et al. (2015)
Manure belt	Ontario, Canada	70,600	-4.1 - 19.4	NA	4.5 ± 3.7	Morgan et al. (2014)
Manure belt	Forlı´, Italy	60,000	3.6-33.2	NA	1.92 – 117.12*	Fabbri et al. (2007)
Manure belt (tunnel and cross ventilation)	Ohio	NA	-13.3 to 29.1	29.9 - 99.1	17.9 ± 9.6	Knight et al. (2021)
Belt battery	Central Ohio	168,000	-13.7 - 26.2	48 - 98	20	Zhao et al. (2005)
			TSP			
High rise	Central California	32,500	5 - 35	NA	78.0 ± 42.7	Lin et al. (2012)
High rise	Central Ohio	168,000	-13.7 - 26.2	48 - 98	146	Zhao et al. (2005)
High rise	Ohio	169,000	9.2 ± 9.9	NA	81.2 ± 65.4	T. Lim et al. (2007)
High rise	North Carolina	103,000	NA	NA	43.1 ± 35.5	Li et al. (2013b)
High rise manure pit	North Carolina	103,000	12 - 22	NA	9.55 - 64.7	Li et al. (2013a)
Belt battery	Central Ohio	168,000	-13.7 - 26.2	48 - 98	168	Zhao et al. (2005)

* unit is mg d^{-1} hen space^{-1}

Conclusions

The underlying NAEMS dataset was derived from measurements made on systems nearly 15 years ago. But the industry has changed and will continue to change. High-rise housing has been phasing out for a decade, and manure belt housing for conventional (caged) layers took its place and in turn is now also being supplemented with cage-free aviary housing. The NAEMS dataset has no estimates for cage-free housing, and the trend is for this sector to expand from current levels of about 28% of production upwards 75% to meet state regulations and customer pledges by the end of 2025. If adopted, these draft models based on dated facilities in a rapidly changing industry are of questionable value.

The draft models themselves have substantial implementation challenges. First, they are complicated mathematically for an average person to implement. Second, they erroneously offer impossibly large changes in emission factors for most pollutant/facility combinations as bird inventory (an independent input) is varied over reasonable values. Thirdly, the resultant regional variation in predicted emissions exceeds that seen in the published scientific literature and is fundamentally unvalidated. The selection of emission models for the US egg industry should be made based on the intended use of the models. The draft models presented would be challenging for the industry to adopt, and as currently written are open for misapplication, for example, for siting of new facilities or for checking an existing facility's compliance with the US Clean Air Act. A much simpler modeling approach is suggested, in which emissions for a site are estimated from traditional emission factors developed from the same NAEMS dataset. These emission factors may be selected to have reasonable sensitivity to known forcing variables.

The use of an emission model that includes bird inventory as an independent variable is not warranted unless the range of allowable bird inventories is also specified. Based on the analyses in this report, there is no appropriate inventory range for manure belt housing or manure storage; this is because the underlying EPA draft models were developed from a single site in Indiana, with no substantive range in bird inventory. Thus, any inventory input other than that used to develop the models is an extrapolation. For high-rise housing, three sites with three different bird inventories were used to develop the draft models by EPA. While this does provide a range of reasonable bird inventories for application, the draft models' behavior when extrapolating to lower or higher bird inventories is not reasonable, and a simple emission factor approach is thus advised for high-rise and manure belt housing.

The model for manure storage was from (up to) two manure belt houses and uses 5-day lag bird inventory as an estimate of manure loading rate; yet, emissions from manure piles depend substantially on the emitting surface area, the ventilation rate of the structure, and the moisture content of the manure. Since none of these key factors are available for that site, a much simpler emission factor approach is recommended that might be adjusted for manure moisture content.

Broad ranges in emissions estimates from the draft models for different regions in the US that are relevant to the egg industry were noted. These occur because of model sensitivity to average temperature and relative humidity; the ranges in estimates exceed those found in recent literature and suggest either a revision in this approach, or removal of temperature and relative humidity from emissions predictions.

While a substantial database was created as part of the underlying NAEMS project, it is not credible to justify a national emissions model based on three (high-rise), one (manure belt) and one (manure storage) site for the entire country. Using the emissions estimates for manure belt housing for different climates, such as Minneapolis, Modesto, or Orlando, suggest a need for an alternative approach and an assessment and validation of climate effects.

These draft EPA emissions models do not address cage-free housing, because this housing was not used when the underlying data were collected. Cage-free housing is currently about 28% of US egg production, and some estimates suggest it could exceed 70% of US total by the end of 2026 if state laws and customer pledges are retained at current numbers.

Further, these draft EPA models do not have any means of accounting for the advances made in managing both manure belt housing and manure storage since the data underlying these draft models was collected.

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Appendix

Appendix 1: Candidate Locations for TMY Dataset Selection

The frequencies of candidate stations fitting into these two classification schemes are summarized in Table A1.1. To reduce the number of locations evaluated, groups of stations with similar temperature zones or moisture classifications were represented by a single representative TMY record.

Table A1.1: Number of weather stations used for analysis in each classification zone.

IECC Climate Zone					Building America Zone					
2	3	4	5	6	Marine	Hot-Humid	Mixed-Humid	Hot-Dry	Mixed-Dry	Cold
3	6	2	8	4	1	3	4	3	0	12

The candidate locations pertinent to the US egg industry that were selected are given in Table A1.2.

Table A1.2: Candidate Weather Stations IECC and Building America Climate Classifications

Station	IECC Climate Zone (Temperature/Moisture[a])	Building America Climate Zone
Indianapolis IN	5A	Cold
Grand Rapids MI	5A	Cold
Detroit MI	5A	Cold
Franklin PA	5A	Cold
Pittsburgh PA	5A	Cold
Columbus OH	5A	Cold
Spokane WA	5B	Cold
Fort Dodge IA	6A	Cold
Spencer IA	6A	Cold
Litchfield MN	6A	Cold
Minneapolis MN	6A	Cold
Salt Lake City UT	5B	Cold
Phoenix AZ	2B	Hot-Dry
Modesto CA	3B	Hot-Dry
Bakersfield CA	3B	Hot-Dry
San Antonio TX	2A	Hot-Humid
Orlando FL	2A	Hot-Humid
Jackson MS	3A	Hot-Humid
Portland OR	4C	Marine
Athens GA	3A	Mixed-Humid
Charlotte NC	3A	Mixed-Humid
Lancaster PA	3A	Mixed-Humid
Columbia MO	4A	Mixed-Humid

[a] A=Moist, B=Dry, C=Marine

Appendix 2: Tables of annual emission factors for the 12 selected sites by daily, monthly, and annual average ambient temperature and relative humidity.

30 tables were made for the 12 selected sites by daily, monthly, and annual average ambient temperature and relative humidity.

Table A2.1. Annual Emissions: Ammonia, High-Rise Housing, CA2H Inventory

TMY Station	Annual Ammonia Emissions (g hen^{-1} yr^{-1}) High-Rise House with 38,000 hens: (NAEMS CA2H Site)		
	Daily T/RH Average	Monthly T/RH Average	Annual T/RH Average
San Antonio TX	704	698	676
Orlando FL	731	726	714
Phoenix AZ	765	760	726
Jackson MS	647	640	616
Charlotte NC	599	594	569
Modesto CA	598	596	584
Columbia MO	535	528	492
Portland OR	496	493	485
Grand Rapids MI	473	467	436
Spokane WA	449	445	428
Fort Dodge IA	481	474	434
Minneapolis MN	460	453	413

Table A2.2. Annual Emissions: Ammonia, High-Rise Housing, NC2H Inventory

TMY Station	Annual Ammonia Emissions (g hen^{-1} yr^{-1}) High-Rise House with 95,000 hens:(NAEMS NC2H Site)		
	Daily T/RH Average	Monthly T/RH Average	Annual T/RH Average
San Antonio TX	394	391	378
Orlando FL	409	407	400
Phoenix AZ	428	426	407
Jackson MS	362	359	345
Charlotte NC	335	333	318
Modesto CA	335	333	327
Columbia MO	300	296	276
Portland OR	278	276	272
Grand Rapids MI	265	262	244
Spokane WA	251	249	239
Fort Dodge IA	269	265	243
Minneapolis MN	258	254	231

Table A2.3. Annual Emissions: Ammonia, High-Rise Housing, IN2H Inventory

TMY Station	Annual Ammonia Emissions (g hen^{-1} yr^{-1}) High-Rise House with 218,000 hens:(NAEMS NC2H Site)		
	Daily T/RH Average	Monthly T/RH Average	Annual T/RH Average
San Antonio TX	355	352	341
Orlando FL	369	366	360
Phoenix AZ	386	383	366
Jackson MS	326	323	311
Charlotte NC	302	300	287
Modesto CA	302	300	294
Columbia MO	269	266	248
Portland OR	250	249	245
Grand Rapids MI	239	236	220
Spokane WA	226	224	216
Fort Dodge IA	242	239	219
Minneapolis MN	232	228	208

Table A2.4. Annual Emissions: Ammonia, Manure Belt Housing, IN2B Inventory

TMY Station	Annual Ammonia Emissions (g hen^{-1} yr^{-1}) Manure Belt House with 280,000 hens:(NAEMS IN2B Site)		
	Daily T/RH Average	Monthly T/RH Average	Annual T/RH Average
San Antonio TX	150	150	147
Orlando FL	156	155	154
Phoenix AZ	157	156	152
Jackson MS	141	140	137
Charlotte NC	133	132	129
Modesto CA	133	132	131
Columbia MO	121	120	116
Portland OR	116	116	115
Grand Rapids MI	111	110	106
Spokane WA	106	106	104
Fort Dodge IA	112	111	105
Minneapolis MN	107	106	101

Table A2.5. Annual Emissions: Ammonia, Manure Storage for 1 Manure Belt House (IN)

TMY Station	Annual Ammonia Emissions (g hen^{-1} yr^{-1}) Manure Storage with 280,000 hens:(NAEMS IN Site)		
	Daily T/RH Average	Monthly T/RH Average	Annual T/RH Average
San Antonio TX	1.5	1.4	1.4
Orlando FL	1.4	1.4	1.4
Phoenix AZ	1.3	1.3	1.3
Jackson MS	1.6	1.6	1.6
Charlotte NC	1.7	1.6	1.6
Modesto CA	1.6	1.6	1.6
Columbia MO	1.9	1.8	1.8
Portland OR	1.9	1.9	1.8
Grand Rapids MI	2.0	2.0	2.0
Spokane WA	2.0	2.0	2.0
Fort Dodge IA	2.0	2.0	2.0
Minneapolis MN	2.1	2.1	2.0

Table A2.6. Annual Emissions: Ammonia, Manure Storage for 2 Manure Belt Houses (IN)

TMY Station	Annual Ammonia Emissions (g hen^{-1} yr^{-1}) Manure Storage with 519,580 hens:(NAEMS IN Site)		
	Daily T/RH Average	Monthly T/RH Average	Annual T/RH Average
San Antonio TX	3.4	3.4	3.4
Orlando FL	3.3	3.3	3.3
Phoenix AZ	3.2	3.2	3.2
Jackson MS	3.6	3.6	3.6
Charlotte NC	3.7	3.7	3.7
Modesto CA	3.6	3.6	3.6
Columbia MO	4.0	4.0	3.9
Portland OR	4.0	4.0	4.0
Grand Rapids MI	4.2	4.2	4.1
Spokane WA	4.2	4.2	4.1
Fort Dodge IA	4.2	4.2	4.1
Minneapolis MN	4.3	4.3	4.2

Table A2.7. Annual Emissions: Hydrogen Sulfide, High-Rise Housing, CA2H Inventory

TMY Station	Annual Hydrogen Sulfide Emissions (mg hen^{-1} yr^{-1}) High-Rise House with 38,000 hens: (NAEMS CA2H Site)		
	Daily T/RH Average	Monthly T/RH Average	Annual T/RH Average
San Antonio TX	387	384	379
Orlando FL	406	404	401
Phoenix AZ	358	357	352
Jackson MS	371	368	363
Charlotte NC	340	338	331
Modesto CA	332	332	330
Columbia MO	312	309	300
Portland OR	307	306	305
Grand Rapids MI	285	283	275
Spokane WA	265	264	261
Fort Dodge IA	284	282	271
Minneapolis MN	269	266	254

Table A2.8. Annual Emissions: Hydrogen Sulfide, High-Rise Housing, NC2H Inventory

TMY Station	Annual Hydrogen Sulfide Emissions (mg hen^{-1} yr^{-1}) High-Rise House with 95,000 hens:(NAEMS NC2H Site)		
	Daily T/RH Average	Monthly T/RH Average	Annual T/RH Average
San Antonio TX	313	312	308
Orlando FL	327	326	324
Phoenix AZ	293	293	289
Jackson MS	303	301	297
Charlotte NC	281	280	275
Modesto CA	275	275	274
Columbia MO	261	259	253
Portland OR	258	257	256
Grand Rapids MI	243	241	235
Spokane WA	228	228	226
Fort Dodge IA	242	240	233
Minneapolis MN	231	229	221

Table A2.9. Annual Emissions: Hydrogen Sulfide, High-Rise Housing, IN2H Inventory

TMY Station	Annual Hydrogen Sulfide Emissions (mg hen^{-1} yr^{-1}) High-Rise House with 218,000 hens:(NAEMS NC2H Site)		
	Daily T/RH Average	Monthly T/RH Average	Annual T/RH Average
San Antonio TX	515	512	507
Orlando FL	535	533	530
Phoenix AZ	485	484	479
Jackson MS	499	496	490
Charlotte NC	467	466	458
Modesto CA	459	459	457
Columbia MO	439	436	427
Portland OR	434	433	432
Grand Rapids MI	412	410	401
Spokane WA	391	390	387
Fort Dodge IA	411	408	397
Minneapolis MN	395	392	380

Table A2.10. Annual Emissions: Hydrogen Sulfide, Manure Belt Housing, IN2B Inventory

TMY Station	Annual Hydrogen Sulfide Emissions (mg hen^{-1} yr^{-1}) Manure Belt House with 280,000 hens:(NAEMS IN2B Site)		
	Daily T/RH Average	Monthly T/RH Average	Annual T/RH Average
San Antonio TX	976	970	959
Orlando FL	1,019	1,015	1,008
Phoenix AZ	891	889	879
Jackson MS	949	943	931
Charlotte NC	881	877	861
Modesto CA	859	857	855
Columbia MO	827	820	801
Portland OR	819	817	815
Grand Rapids MI	774	769	751
Spokane WA	725	723	718
Fort Dodge IA	770	766	743
Minneapolis MN	736	730	706

Table A2.11. Annual Emissions: Hydrogen Sulfide, Manure Storage for 1 Manure Belt House (IN)

TMY Station	Annual Hydrogen Sulfide Emissions (mg hen^{-1} yr^{-1}) Manure Storage with 280,000 hens:(NAEMS IN Site)		
	Daily T/RH Average	Monthly T/RH Average	Annual T/RH Average
San Antonio TX	8	8	8
Orlando FL	8	8	8
Phoenix AZ	7	7	7
Jackson MS	10	10	9
Charlotte NC	10	10	10
Modesto CA	10	10	10
Columbia MO	12	12	12
Portland OR	12	12	12
Grand Rapids MI	14	14	13
Spokane WA	14	14	13
Fort Dodge IA	14	14	13
Minneapolis MN	15	15	14

Table A2.12. Annual Emissions: Hydrogen Sulfide, Manure Storage for 2 Manure Belt Houses (IN)

TMY Station	Annual Hydrogen Sulfide Emissions (mg hen^{-1} yr^{-1}) Manure Storage with 519,580 hens:(NAEMS IN Site)		
	Daily T/RH Average	Monthly T/RH Average	Annual T/RH Average
San Antonio TX	25	24	24
Orlando FL	24	23	23
Phoenix AZ	22	22	22
Jackson MS	27	26	26
Charlotte NC	28	28	27
Modesto CA	27	27	27
Columbia MO	32	31	30
Portland OR	31	31	31
Grand Rapids MI	35	34	33
Spokane WA	34	34	33
Fort Dodge IA	35	35	33
Minneapolis MN	36	36	34

Table A2.13. Annual Emissions: PM$_{10}$, High-Rise Housing, CA2H Inventory

TMY Station	Annual PM$_{10}$ Emissions (mg hen^{-1} yr^{-1}) High-Rise House with 38,000 hens: (NAEMS CA2H Site)		
	Daily T/RH Average	Monthly T/RH Average	Annual T/RH Average
San Antonio TX	10,560	10,538	10,466
Orlando FL	10,603	10,589	10,558
Phoenix AZ	13,128	13,085	12,907
Jackson MS	9,717	9,696	9,615
Charlotte NC	9,660	9,637	9,568
Modesto CA	10,147	10,121	10,003
Columbia MO	8,798	8,767	8,623
Portland OR	8,318	8,295	8,232
Grand Rapids MI	8,080	8,052	7,906
Spokane WA	8,403	8,366	8,200
Fort Dodge IA	8,199	8,164	7,984
Minneapolis MN	8,184	8,150	7,978

Table A2.14. Annual Emissions: PM$_{10}$, High-Rise Housing, NC2H Inventory

TMY Station	Annual PM$_{10}$ Emissions (mg hen^{-1} yr^{-1}) High-Rise House with 95,000 hens:(NAEMS NC2H Site)		
	Daily T/RH Average	Monthly T/RH Average	Annual T/RH Average
San Antonio TX	7,597	7,583	7,538
Orlando FL	7,624	7,615	7,596
Phoenix AZ	9,190	9,164	9,053
Jackson MS	7,074	7,061	7,011
Charlotte NC	7,039	7,025	6,982
Modesto CA	7,341	7,325	7,252
Columbia MO	6,504	6,485	6,396
Portland OR	6,206	6,192	6,153
Grand Rapids MI	6,059	6,042	5,950
Spokane WA	6,259	6,236	6,133
Fort Dodge IA	6,133	6,112	5,999
Minneapolis MN	6,123	6,102	5,995

Table A2.15. Annual Emissions: PM$_{10}$, High-Rise Housing, IN2H Inventory

TMY Station	Annual PM$_{10}$ Emissions (mg hen^{-1} yr^{-1}) High-Rise House with 218,000 hens:(NAEMS NC2H Site)		
	Daily T/RH Average	Monthly T/RH Average	Annual T/RH Average
San Antonio TX	9,841	9,826	9,776
Orlando FL	9,871	9,861	9,839
Phoenix AZ	11,631	11,601	11,477
Jackson MS	9,254	9,239	9,182
Charlotte NC	9,214	9,198	9,149
Modesto CA	9,553	9,535	9,453
Columbia MO	8,613	8,591	8,491
Portland OR	8,279	8,262	8,219
Grand Rapids MI	8,113	8,093	7,991
Spokane WA	8,337	8,312	8,196
Fort Dodge IA	8,195	8,171	8,046
Minneapolis MN	8,185	8,161	8,041

Table A2.16. Annual Emissions: PM$_{10}$, Manure Belt Housing, IN2B Inventory

TMY Station	Annual PM$_{10}$ Emissions (mg hen^{-1} yr^{-1}) Manure Belt House with 280,000 hens:(NAEMS IN2B Site)		
	Daily T/RH Average	Monthly T/RH Average	Annual T/RH Average
All Stations	9,430	9,430	9,430

Table A2.17. Annual Emissions: PM$_{10}$, Manure Storage for 1 Manure Belt House (IN)

TMY Station	Annual PM10 Emissions (mg hen^{-1} yr^{-1}) Manure Storage with 280,000 hens:(NAEMS IN Site)		
	Daily T/RH Average	Monthly T/RH Average	Annual T/RH Average
All Stations	182	182	182

Table A2.18. Annual Emissions: PM$_{10}$, Manure Storage for 2 Manure Belt Houses (IN)

TMY Station	Annual PM10 Emissions (mg hen^{-1} yr^{-1}) Manure Storage with 519,580 hens:(NAEMS IN Site)		
	Daily T/RH Average	Monthly T/RH Average	Annual T/RH Average
All Stations	124	124	124

Table A2.19. Annual Emissions: $PM_{2.5}$, High-Rise Housing, CA2H Inventory

TMY Station	Annual $PM_{2.5}$ Emissions (mg hen^{-1} yr^{-1}) High-Rise House with 38,000 hens: (NAEMS CA2H Site)		
	Daily T/RH Average	Monthly T/RH Average	Annual T/RH Average
San Antonio TX	1,467	1,417	1,317
Orlando FL	1,367	1,341	1,301
Phoenix AZ	4,028	3,845	3,269
Jackson MS	1,073	1,040	946
Charlotte NC	1,124	1,076	1,005
Modesto CA	1,533	1,457	1,221
Columbia MO	869	827	683
Portland OR	652	611	535
Grand Rapids MI	653	619	483
Spokane WA	921	841	612
Fort Dodge IA	721	677	516
Minneapolis MN	749	704	548

Table A2.20. Annual Emissions: $PM_{2.5}$, High-Rise Housing, NC2H Inventory

TMY Station	Annual $PM_{2.5}$ Emissions (mg hen^{-1} yr^{-1}) High-Rise House with 95,000 hens:(NAEMS NC2H Site)		
	Daily T/RH Average	Monthly T/RH Average	Annual T/RH Average
San Antonio TX	1,008	976	913
Orlando FL	945	928	903
Phoenix AZ	2,624	2,509	2,145
Jackson MS	759	739	679
Charlotte NC	791	761	716
Modesto CA	1,050	1,002	852
Columbia MO	630	604	513
Portland OR	493	468	420
Grand Rapids MI	494	473	387
Spokane WA	664	613	469
Fort Dodge IA	537	509	408
Minneapolis MN	555	527	428

Table A2.21. Annual Emissions: $PM_{2.5}$, High-Rise Housing, IN2H Inventory

TMY Station	Annual $PM_{2.5}$ Emissions (mg hen^{-1} yr^{-1}) High-Rise House with 218,000 hens:(NAEMS NC2H Site)		
	Daily T/RH Average	Monthly T/RH Average	Annual T/RH Average
San Antonio TX	1,278	1,242	1,168
Orlando FL	1,205	1,186	1,157
Phoenix AZ	3,163	3,028	2,604
Jackson MS	989	965	896
Charlotte NC	1,026	991	939
Modesto CA	1,327	1,272	1,098
Columbia MO	839	808	702
Portland OR	679	649	593
Grand Rapids MI	680	655	555
Spokane WA	877	819	650
Fort Dodge IA	730	697	579
Minneapolis MN	750	718	602

Table A2.22. Annual Emissions: $PM_{2.5}$, Manure Belt Housing, IN2B Inventory

TMY Station	Annual $PM_{2.5}$ Emissions (mg hen^{-1} yr^{-1}) Manure Belt House with 280,000 hens:(NAEMS IN2B Site)		
	Daily T/RH Average	Monthly T/RH Average	Annual T/RH Average
All Stations	17,556,566,943	17,556,566,943	17,556,566,943

Table A2.23. Annual Emissions: $PM_{2.5}$, Manure Storage for 1 Manure Belt House (IN)

TMY Station	Annual $PM_{2.5}$ Emissions (mg hen^{-1} yr^{-1}) Manure Storage with 280,000 hens:(NAEMS IN Site)		
	Daily T/RH Average	Monthly T/RH Average	Annual T/RH Average
All Stations	1.92×10^{-5}	1.92×10^{-5}	1.92×10^{-5}

Table A2.24. Annual Emissions: $PM_{2.5}$, Manure Storage for 2 Manure Belt Houses (IN)

TMY Station	Annual $PM_{2.5}$ Emissions (mg hen^{-1} yr^{-1}) Manure Storage with 519,580 hens:(NAEMS IN Site)		
	Daily T/RH Average	Monthly T/RH Average	Annual T/RH Average
All Stations	107	107	107

Table A2.25. Annual Emissions: TSP, High-Rise Housing, CA2H Inventory

TMY Station	Annual TSP Emissions (mg hen^{-1} yr^{-1}) High-Rise House with 38,000 hens: (NAEMS CA2H Site)		
	Daily T/RH Average	Monthly T/RH Average	Annual T/RH Average
San Antonio TX	26,013	25,936	25,821
Orlando FL	25,740	25,703	25,658
Phoenix AZ	33,353	33,199	32,788
Jackson MS	24,179	24,126	23,999
Charlotte NC	24,624	24,539	24,450
Modesto CA	25,990	25,901	25,571
Columbia MO	22,967	22,891	22,661
Portland OR	21,829	21,760	21,610
Grand Rapids MI	21,667	21,601	21,342
Spokane WA	22,896	22,778	22,352
Fort Dodge IA	21,988	21,909	21,607
Minneapolis MN	22,266	22,185	21,917

Table A2.26. Annual Emissions: TSP, High-Rise Housing, NC2H Inventory

TMY Station	Annual TSP Emissions (mg hen^{-1} yr^{-1}) High-Rise House with 95,000 hens:(NAEMS NC2H Site)		
	Daily T/RH Average	Monthly T/RH Average	Annual T/RH Average
San Antonio TX	16,323	16,274	16,203
Orlando FL	16,152	16,129	16,101
Phoenix AZ	20,930	20,833	20,575
Jackson MS	15,173	15,140	15,059
Charlotte NC	15,452	15,399	15,343
Modesto CA	16,310	16,253	16,046
Columbia MO	14,412	14,365	14,220
Portland OR	13,698	13,654	13,560
Grand Rapids MI	13,596	13,555	13,392
Spokane WA	14,368	14,293	14,026
Fort Dodge IA	13,797	13,748	13,558
Minneapolis MN	13,972	13,921	13,753

Table A2.27. Annual Emissions: TSP, High-Rise Housing, IN2H Inventory

TMY Station	Annual TSP Emissions (mg hen^{-1} yr^{-1}) High-Rise House with 218,000 hens:(NAEMS NC2H Site)		
	Daily T/RH Average	Monthly T/RH Average	Annual T/RH Average
San Antonio TX	18,797	18,741	18,658
Orlando FL	18,599	18,572	18,541
Phoenix AZ	24,101	23,990	23,692
Jackson MS	17,472	17,433	17,341
Charlotte NC	17,793	17,732	17,668
Modesto CA	18,781	18,716	18,477
Columbia MO	16,596	16,541	16,374
Portland OR	15,774	15,723	15,615
Grand Rapids MI	15,656	15,609	15,421
Spokane WA	16,545	16,459	16,151
Fort Dodge IA	15,888	15,831	15,612
Minneapolis MN	16,089	16,031	15,837

Table A2.28. Annual Emissions: TSP, Manure Belt Housing, IN2B Inventory

TMY Station	Annual TSP Emissions (mg hen^{-1} yr^{-1}) Manure Belt House with 280,000 hens:(NAEMS IN2B Site)		
	Daily T/RH Average	Monthly T/RH Average	Annual T/RH Average
All Stations	27,622	27,622	27,622

Table A2.29. Annual Emissions: TSP, Manure Storage for 1 Manure Belt House (IN)

TMY Station	Annual TSP Emissions (mg hen^{-1} yr^{-1}) Manure Storage with 280,000 hens:(NAEMS IN Site)		
	Daily T/RH Average	Monthly T/RH Average	Annual T/RH Average
All Stations	244	244	244

Table A2.30. Annual Emissions: TSP, Manure Storage for 2 Manure Belt Houses (IN)

TMY Station	Annual TSP Emissions (mg hen^{-1} yr^{-1}) Manure Storage with 519,580 hens:(NAEMS IN Site)		
	Daily T/RH Average	Monthly T/RH Average	Annual T/RH Average
All Stations	243	243	243