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Poultry housing : basic data useful for design purposes in the Northeastern States

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POULTRY HOUSING

Basic Data Useful For Design Purposes In the Northeastern States

WEST VIRGINIA UNIVERSITY
AGRICULTURAL EXPERIMENT STATION

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Prepared by the NE-8 Technical Committee

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AGRICULTURAL EXPERIMENT STATION

Preparation of Manuscript

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Much of the credit for assembling the data is due to the untiring efforts of H. L. Garver, Consulting Agricultural Engineer.

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A. D. LONGHOUSE, G. O. BRESSLER, C. S. SHAFFNER, and H. L. GARVER

IN ORDER to design any building properly it is necessary to know first the purpose for which it is to be constructed. In addition, the designer must know the nature and number of units to be housed, their size and the space required for each, conditions required for best operation or production, and effects the items housed may have on the structure. He must be aware of the natural weather conditions in the area, and have a knowledge of the available materials that are best suited for use under the given conditions.

It is the purpose of this publication to report the results of studies conducted to determine some of these basic points.

THE CHICKEN

Standard Weights

The size of the chicken is best described by its weight. This will vary, depending upon breed, sex, age, and physical condition. Physical condition will be governed somewhat by rate of production and housing conditions. Table 1 lists standard weights of five common breeds of laying hens.

Growth Rates

The type and size of house required for growing chicks will depend upon whether the chicks are to be used as layers or sold as broilers. In either case, except perhaps for the first few weeks, they will be kept in a single house to maturity or to time of sale. Thus, the house will be sized to accommodate them at that time. Table 2 shows the weekly weights of broilers up to ten weeks of age.

Feed Consumption

Feed requirements of poultry are directly related to the weight of the chicken, ambient temperature, and to the rate of egg production. Byerly (1) developed the following equations for annual feed requirements for laying hens:

For Leghorns: (15 W) + (E/8) = annual feed consumption in pounds.

For New Hampshires: (13 W) + (E/8) = annual feed consumption in pounds. In these equations, W = body weight in pounds and E = number of eggs.

Table 1. Standard Body Weights (Pounds) of Laying Hens.

Breed	Mature Hen	Pullet*
Single Comb White Leghorn	4.5	4.0
Rhode Island Red	6.5	5.5
New Hampshire	6.5	5.5
White Plymouth Rock	7.5	6.5
Cornish	8.0	6.5

*Less than 12 months old.

Table 2. Weekly Average Weights (Pounds) of Broilers (N. H. 1958-59).

Week	Males	Females	Mixed Sexes
1	0.19	0.18	0.19
2	0.38	0.35	0.37
3	0.69	0.62	0.65
4	1.11	0.98	1.04
5	1.63	1.39	1.51
6	2.19	1.78	1.99
7	2.78	2.23	2.50
8	3.35	2.66	3.01
9	4.02	3.13	3.57
10	4.57	3.53	4.05

Table 3. Weekly and Cumulative Feed Consumption (Pounds) and Feed Conversion for Mixed Sex Commercial Broilers (N. H. 1958-59).

Week	Feed Consumption Per Broiler		Feed Conversion*	
	Weekly	Cumulative	Weekly	Cumulative
1	0.14	0.14	0.74	0.74
2	0.30	0.44	1.67	1.19
3	0.49	0.93	1.75	1.43
4	0.68	1.61	1.74	1.55
5	0.92	2.53	1.96	1.68
6	1.06	3.59	2.21	1.80
7	1.25	4.84	2.45	1.94
8	1.44	6.28	2.82	2.09
9	1.56	7.84	2.79	2.20
10	1.55	9.39	3.23	2.32

*Pounds of feed to produce one pound of live weight.

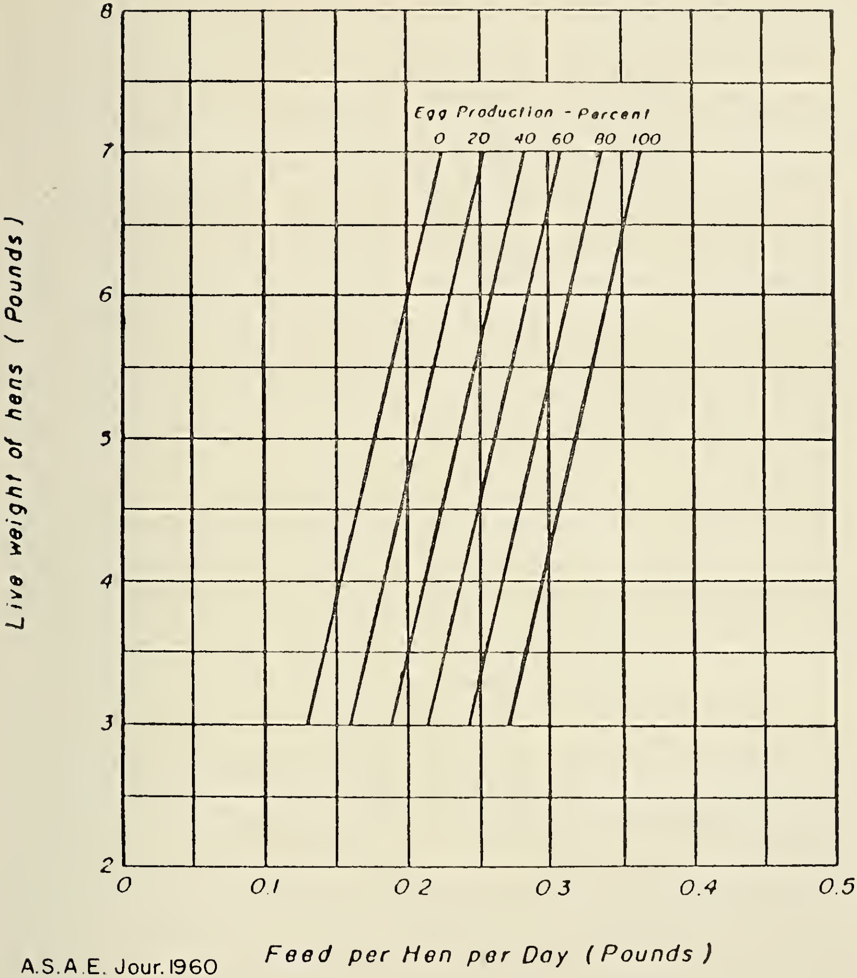

FIGURE 1. Daily feed requirements for hens of varying weight and egg production rates (1).

Figure 1 was developed from Byerly's equations. The estimates agree quite closely with results obtained in the calorimeters at temperatures between 40° and 75° F, but are as much as 100 per cent higher than the calorimeter results at temperatures above 85° F, and 10 to 15 per cent lower at temperatures below 40° F. It is recommended that, for design purposes, feed consumption be based on 75 per cent of egg production.

Studies at the Maryland Agricultural Experiment Station indicate that levels of added fat, up to eight per cent, favorably influenced growth at 90° F.

Heat Production

Since chickens grow and produce best within given temperature ranges, it is important to know the amount of heat produced by the chicken itself. Heat production depends upon body weight of the chicken, age, environmental conditions, and breed.

The total heat production per pound of live weight, as reported by Ota and McNally (2) for White Leghorn and Rhode Island Red hens at temperatures of 25° to 94° F are shown in Figure 2. At constant temperature, total heat production per pound of body weight decreases as the body weight increases. This is probably due to the fact that surface area and metabolism of the chicken increase only at approximately the 0.7 power of the increase in body weight (3). This ratio holds fairly true, for the two breeds as shown in Figure 2, in the range of temperatures between 45° and 65° F.

In using the values presented in Figure 2, it should be kept in mind that the chicken has a remarkable ability to adapt itself to wide variations in environmental conditions. At temperatures below 35° F, chickens can voluntarily alter their body insulation and body area by fluffing feathers and placing their heads under their wings. The daily variation in heat production may easily be as much as 15 to 25 per cent.

The percentages of latent and sensible heat vary widely with the temperature. Note in Figure 2 that at 90° F the percentage of latent heat is 60 per cent of the total, while at 35° F it is only 20 per cent. Ota shows only about 3/4 as many Btu/pound of live weight produced at night as in daylight, perhaps due mostly to difference in activity. Deighton and Hutchinson (4) reported that hens produce 40 to 45 per cent more heat while standing than when sitting.

The report of research with small groups of S.C.W.L. hens in calorimeters at the Beltsville Research Center covers, in brief, information on environmental factors needed in the design of the poultry house. One group of ten hens (Group "A") was subjected to a sudden drop of 10° F every 3 weeks. The temperature during the first test period was 95° F and during the final period was 25° F. Another ten hens (Group "B") were kept as nearly as possible at 65° F. An additional ten hens (Group "C") were similarly caged and managed, except that they were exposed to fluctuations of outdoor conditions. All three groups were kept in individual wire laying cages and exposed to 14 hours of artificial light. With few exceptions, the same hens were kept in their respective groups during the course of the experiment.

Droppings from these hens were caught in individual pans containing sufficient automotive oil to cover the fecal matter. Data

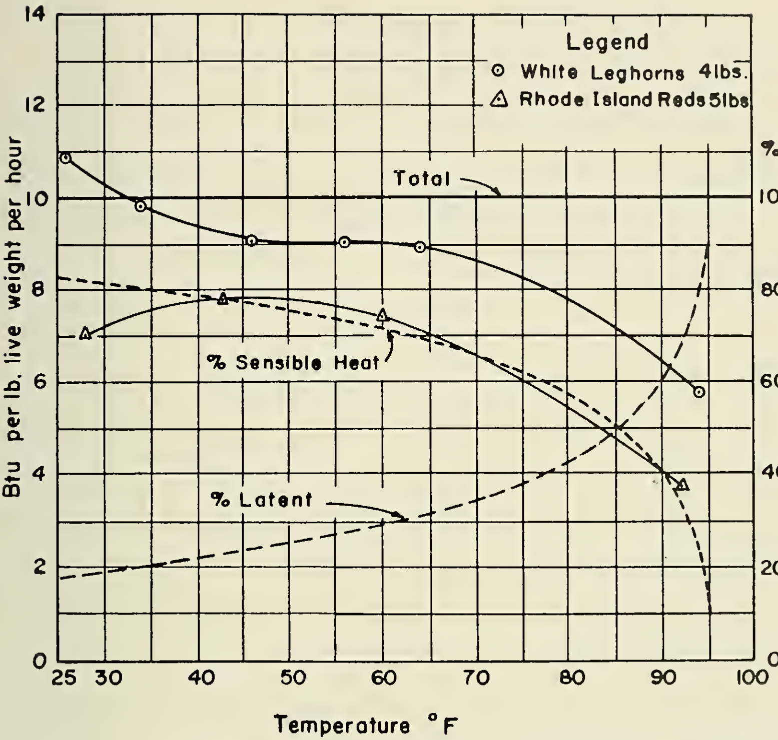

FIGURE 2. Total heat per pound of weight and percentage of sensible and latent heat produced by caged layers in relation to temperature. USDA data used in preparing this figure agrees with findings of the West Virginia University Agricultural Experiment Station. See ARS Report No. 42-43.

were collected on heat and moisture production by the hens, individual feed and water consumption, egg size, hen live weights, and the individual production of droppings. Some of the results are:

1. Total heat produced by a 3.5-pound hen [using equation: surface area S (cm^2) = W (in grams) 0.705] was nearly constant at 32.5 to 35 Btu/hen/hr between 85° and 45° F ambient temperature.

2. Feed consumption for 170- to 190-day-old Group "A" pullets at 95° F was 0.12 lb/hen/day, which was 45 per cent less than the hens in the "B" group at 65° F (58.5 and 62.5 per cent egg production, respectively). A similar comparison at 85° F showed that Group "A" consumed 23 per cent less than Group "B" at 65° F. Egg production rates were 65 and 78 per cent, respectively. Data at 65° ("B" group) and 55° F ("A" group) showed both groups ate about the same amount, 0.22 lb/hen/day.

3. Group "A" hens required 12 to 15 weeks, after the extreme 3-week temperature stress of 95° F, to increase average egg size to that of hens kept at nominal 65° F.

4. Daily fluctuations of temperature were not harmful to egg production of the "C" group. This group had a better record of production than either of the other two groups.

5. Based on the rise of both day total and sensible heat production from temperatures below 45° F, this temperature may be considered the beginning of low temperature stress for S.C.W.L.

6. Hens at 95° F consistently lost weight. When the temperature was dropped to the 85° F level, the hens gained weight and continued to gain until the 35° F level was reached, when hens again lost weight (Table 4).

Water Consumption and Production

The quantity of water consumed depends upon the body weight of the chicken, its physical activity, rate of production, and the ambient temperature. In addition to water from fountains, the hen gets an appreciable amount of water from the feed. This consists of free, hygroscopic, and metabolizable water. Table 5 suggests constants for determining water requirements and feces and water elimination in relation to feed consumption for layers. Refer to Figure 1 for feed requirements.

Moisture and heat eliminations are both related to metabolism, and amounts are based on the same factors. The house will be designed for hens laying at a 75 per cent hen-day rate, because this is when they consume a maximum of feed and water, and therefore give off the most moisture. Because the metabolic rate, and hence the heat and moisture emissions, does not increase directly with the weight, it is safe to design the house and equipment on the basis of the weight of the chicken.

Water output includes the water that is respired, water in the feces, and water in the eggs. In houses using litter, there may be additional moisture (and heat) from litter decomposition. Little information concerning litter decomposition is currently available. Tests at the Maryland Station show that the rate of water consumption by broilers increases somewhat as the relative humidity decreases. The same thing is probably true for laying hens.

Note that, in using Table 5, the weights of eggs have been reduced to 24 ounces per dozen; the per cent of free, hygroscopic, and metabolizable water in the feed estimated at 54 per cent: and—for the sake of convenience—the heat of vaporization has been taken as 1,100 Btu per pound.

In studies made at the Maryland Station, it was noted that broilers consumed water at the highest rate immediately after the lights were turned on. During the first hour of illumination, 9-week-old broilers drank at the rate of around ten gallons

Table 4. Comparison of Performance of Single Comb White Leghorn Laying Hens Under Various Temperature Conditions (USDA 1957).

Ambient Temperature (°F)	Feed Consumed (lb/hen/day)	Water Consumed (lb/hen/day)	Egg Production (per cent)	Hen Weight (lb)	Droppings (lb/hen/day)	Moisture Removed* (lb/hr) day	Moisture Removed* (lb/hr) night
95	.120	.606	58.5	3.07	.377	.207	.112
65	.220	.400	62.5	3.54	.342	.150	.077
84	.170	.460	65.0	3.11	.308	.159	.114
65	.220	.393	78.0	3.49	.344	.138	.066
73	.192	.386	67.0	3.11	.304	.134	.075
65	.220	.400	67.0	3.49	.336	.125	.079
64	.220	.420	63.3	3.38	.341	.134	.076
65	.186	.373	67.5	3.33	.346	.099	.045
56	.220	.507	62.0	3.68	.418	.170	.087
65	.220	.384	62.0	3.52	.336	.123	.064
47	.240	.470	58.6	3.77	.422	.118	.073
65	.192	.362	60.0	3.60	.329	.111	.046

*Ventilation rate of 0.93 to 1.0 cfm/hen/hr.

Table 5. Constants for Determining Water Consumption, Elimination of Feces, and Elimination of Water in Relation to Feed Consumption (A.S.A.E. 1960).

	Ambient Temperature (°F) 20-40	41-60	61-80	81-100
Water (lb)/Feed (lb)	1.5-1.7	1.7-2.0	2.0-2.5	2.5-5.0
Water (lb) + Feed (lb)/Feces (lb)	1.7	1.7*	1.8*	1.9*
Water Content of Feces (per cent)	75	75	77	80
Egg Weight (oz/doz)	24	24	24	24
Water Content of Eggs (per cent)	65	65	65	65
Hygroscopic and Metabolizable Water in Feed (per cent)	54	54	54	54
Heat of Vaporization (approximate Btu/lb)	1100	1100	1100	1100
Respired Water/Water Input	0.30-0.33 0.22-0.35 0.25	0.33-0.40 0.35 0.25-0.35**	0.40-0.45 0.35-0.42 —	0.45-0.55† 0.42-0.55‡ —

*For White Leghorns, add 0.30 to these values.
†Single Comb White Leghorn hens.
‡Rhode Island Red hens.
**New Hampshire x Cornish hens.

per hour per 1,000 chickens. Again, just before the lights were turned off, consumption was slightly above six gallons per hour. During the other hours of light, water consumption was about four gallons per hour for 1,000 chickens. High relative humidities

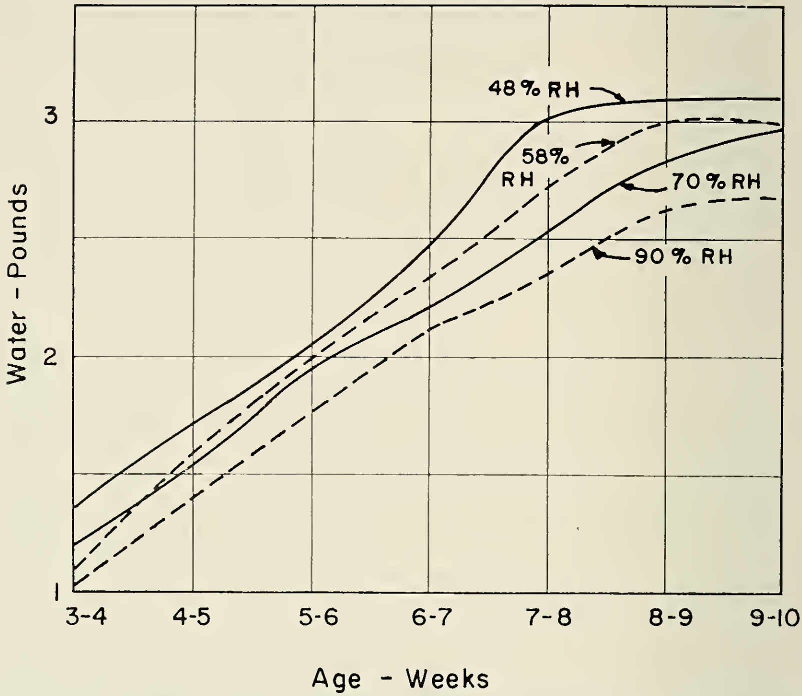

FIGURE 3. Effect of relative humidity on water consumption, in pounds per bird per week, at a constant temperature of 70° F. Maryland data, 1962.

decreased the rate of water consumption (Figure 3). Further discussion of water consumption will be found under the discussion of environment, Table 12.

Egg Production

The production of eggs was generally used as a measure of performance of layers in studies conducted under the NE-8 project. Due to wide variations in stock and to different environmental conditions under which tests were conducted, the reader is referred to a current issue of the **Report of Egg Production Tests,** ARS 44-79.3, USDA, or to records obtained through the Pennsylvania Cooperative Extension Service. See Table 6 for estimates of the production potentials of current stock.

Fecal Production

Ota found that at temperatures between 30° and 70° F fecal production in the calorimeters was around 1.4 times the feed consumption. Above 70° F the ratio of fecal production to feed con-

Table 6. Production Factors on Five Top Pennsylvania Commercial Flocks (1961).

Production Factors	Flock A	Flock B	Flock C	Flock D	Flock E
Av. No. of Hens	11,842	9,972	2,487	3,781	6,737
No. Pullets Added	8,677	10,251	2,083	4,061	6,710
Mortality (%)	11.7	9.4	10.2	20.4	10.9
Production* (%)	64.7	64.2	67.5	60.6	61.9
Eggs/Hen	236.2	234.3	246.4	221.2	225.9
Feed (lb)/Eggs (doz)	4.2	4.6	4.4	4.5	4.2

*Hen-day egg production.

Table 7. Feed Consumption and Manure Production of Cage-Managed and Floor-Managed Egg-Production Type Hens (W. Va. 1962).

Management	Number of Hens	Feed Consumption (lb/hen/day)	Manure Production (lb/hen/day)	Manure Production (per cent moisture)	Egg Production (per cent)
Cage	960	0.233	0.242	74.3	75
Floor	1,240	0.253	0.304*	70.2	70

*Based on 63.5 per cent excreted in pits; feeders and waterers over pits; floor space of 1.5 sq. ft. per hen.

sumption increased, due most likely to increased water intake and to the decrease in amount of feed consumed. The number of eggs decreased, if anything, leaving more water to be eliminated with the feces. Table 7 is a summary of data on fecal production in a study conducted at the West Virginia University Agricultural Experiment Station.

ENVIRONMENTAL FACTORS

Since environment includes the building, equipment, and surrounding conditions that may affect the chicken, it is difficult to consider the subject as a separate entity. For convenience of reference, an effort is made to set it apart from the chicken, the methods of management, and the purely engineering and architectural considerations of the house. Only four aspects of the subject are considered in this section. Others, such as ventilation, materials of construction, and solar radiation are discussed beginning on page 26.

Temperature

Among all the factors that make up the environment of the chicken, temperature appears to be the most thoroughly investigated. The results indicate that, within the range of 45° to 75° F, little difference in flock performance can be attributed to temperature alone.

At the Maryland Station, 13 trials were conducted on the influence of slow and rapid changes in temperature on the reproductive performance of White Leghorn, New Hampshire, and Rhode Island Red pullets. There was little difference in response to fast rises (4° F/hr) compared to slow rises (5° F/day) in temperature, except that mortality was greater, and, in the fall of 1957, egg production was lowered more with the fast rises. The temperature was raised as high as 105° F for the White Leghorns, but only to 100° F for the New Hampshires and the Rhode Island Reds. At high temperatures there was little effect on egg production, but there was a pronounced decrease in shell thickness, egg weight, and feed consumption, and an increase in albumen height.

There was also little difference in response of the pullet under cold treatment to fast drops (2° F/hr) compared to slow drops (.5° F/hr) in temperature. Temperatures were lowered to 10° F for the White Leghorns and 0° F for the New Hampshires. At 10° F there was a drop in egg production lasting from 1 to 2 days and at 0° F egg production stopped for about one week. No noticeable changes occurred in egg size, shell thickness and albumen height, but there was a drop in feed consumption. At the lowest temperatures used for White Leghorns and New Hampshires, up to one-half of the comb and some of the toes were frozen; these frozen parts later dropped off. A number of layers went into full molt and did not return to production for three to four weeks.

Replicated trials on pullets with rapid change in temperature between 39° and 88° F showed no pronounced effect on any of the characteristics studied. No appreciable effect on production traits or on mortality of laying pullets was observed in tests involving fluctuations in temperature between 30° and 88° F. It may be said that rate of temperature change alone did not exert marked influence on most of the production traits and on the mortality of laying pullets.

The New Jersey Agricultural Experiment Station reports that no significant differences were observed in response of layers housed in a cold conventional house, the New Jersey solar-front poultry house, and in a house maintained at a uniform ambient temperature of 50° to 55° F. Layers in the cold conventional house consumed more feed.

Control of temperature and moisture under crowded conditions seemed to be no problem, according to experience at the Pennsylvania Agricultural Experiment Station. The combination of a well-insulated house, thermostatically-controlled forced ventilation, supplementary heat from the sun, and arrangement of feeders, waterers, and roosts over dropping pits were adequate to keep wintertime house temperatures around 50° F and summertime house temperatures no higher than outside temperatures, even when they reached 90° F.

The Connecticut Agricultural Experiment Station reports the results of tests on broilers at 65° and 45° F in 1957 and 1958. Results of these tests are shown in Table 8. Feed used during the 1957 test consisted of a commercial broiler mash (22 per cent protein) and pellets (24 per cent protein) at eight weeks of age. In another test, starting with day-old chicks, the average feed consumption during a 12-week growing period was 0.13 lb/chick/day in an 85° F chamber and 0.17 lb/chick/day in a 65° F chamber.

Maryland, at its Salisbury Sub-Station, conducted during the 1960-61 season two temperature studies on broilers after four and one-half to five weeks and running to eight weeks of age. Results of these studies are reported in Table 9. It appears evident that,

Table 8. Effect of Temperature on Feed Conversions (Conn. 1957-58).

	65°F		45°F	
	1957	1958*	1957	1958*
Number of Chickens	368	79	368	79
Feed Consumption (lb)†	8.35	6.3	9.3	6.95
Weight Gains (lb)‡	2.76	2.33	2.89	2.26
Feed Conversion†	3.0	2.7	3.2	3.1

*Test ran through fifth through eighth week of age.
†Cumulative values.
‡40 days 1957; 28 days 1958.

Table 9. Ambient Temperature and Broiler Performance During the Finishing Period (Md. 1961).*

Temp. (°F)	Av. Weight (lb) 5 weeks	Av. Weight (lb) 8 weeks	Av. Gain (lb) 5th to 8th weeks	Feed/Weight 0 to 5 weeks	Feed/Weight 0 to 8 weeks	Feed (lb)/Gain (lb) 5th to 8th weeks
	Trial No. 1					
51	1.75	3.73	1.98	1.60	2.14	2.62
59	1.77	3.65	1.88	1.57	2.09	2.60
	Trial No. 2					
53	1.51	3.07	1.56	1.73	2.02	2.29
63	1.53	2.99	1.46	1.70	2.02	2.37

*Sixteen groups of 150 broilers each reared at each ambient temperature in each trial.

in the absence of any disease outbreak, mean ambient temperatures of 51° and 53° F at three feet above the floor are as desirable for chickens of this age as are temperatures of 59° and 63° F.

In these tests, four broiler crosses were fed the same ration. The average weights were approximately 10 per cent higher and approximately 10 per cent more feed was required per unit weight for the winter brood. Since mean ambient temperatures within the range 51° to 63° F made no difference on performance during either this or the previous winter study, it appears that some factor other than ambient temperature was responsible for poorer feed efficiency during the winter period. It cannot be attributed to differences in disease in the trials. It has been suggested that length of day, total exposure to light, and possible duration of cold exposure may have had some influence (Figure 4).

Hens on commercial type poultry farms are not likely to be subjected to constant temperatures. In order to approximate natural conditions, workers at the Delaware Agricultural Experiment Station used a diurnal shift to determine its effect on broiler performance. Groups of broilers housed at temperatures fluctuating between 70° and 90° F were compared with a similar group at constant temperature of 80° F, and in another test chickens subjected to diurnal shifts from 75° to 95° F were compared with chickens held at constant temperatures of 75° and 95° F. Results are shown in Table 10. The fluctuation schedules consisted in holding temperatures six hours at each high and each low value with six-hour shifting time.

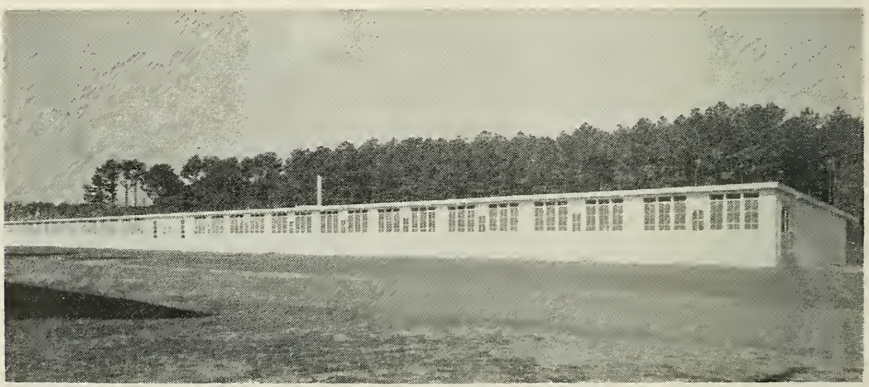

FIGURE 4. The Maryland Experimental Broiler House. This cinder-block building, 360 feet long and 25 feet wide, contains 32 experimental pens. A forty-foot section in the center is devoted to feed storage, and a five-foot aisle runs along the front of the house. The central heating system uses hot water and finned-tubing. Windows on part of the house have been sealed up for experiments with controlled ventilation. The roof, covered with rolled asbestos shingles, is insulated.

Table 10. Effect of Diurnal Fluctuations of Temperature on Body Weight of Broilers at Four to Nine Weeks of Age (Del. 1959).

	First Test Temperature Regulation		Second Test Temperature Regulation		
	Fluctuating	Constant	Fluctuating	Constant	Constant
Temperatures (°F)	70-90	80	75-95	75	95
Birds Started	75	75	75	75	75
Rel. Humid (per cent)	60	60	60	60	60
Floor Space (sq ft/bird)	1	1	1	1	1
Av. Weight (lb) - 4 weeks	1.16	1.16	1.24	1.25	1.17
Av. Weight (lb) - 9 weeks	3.40	3.33	3.54	3.33	3.01
Av. Mortality (per cent)	1.5	1.5	4.0	2.6	2.6
Feed Conversion	2.17	2.22	2.22	2.34	2.25

Note: Air flow was sufficient to hold ammonia below 25 ppm.

Similar tests, conducted in 1961, used somewhat different temperatures and, in one case, high relative humidity. Equal numbers of males and females were placed in the pens at three weeks of age and held under the given conditions to maturity. Results are given in Table 11.

Although very young chicks like a warm atmosphere, by five weeks of age high temperatures are no longer tolerated. In three tests—using 120 chicks in each of three pens starting at three weeks of age and running through the eighth week—all survived at 85° F; at 85-105° F 19 died beginning with five in the sixth week; at 105° F constant temperature 35 died beginning with four in the fifth week and 13 in the sixth week. As seen in Table 12, high temperatures inflict heavy losses, especially when coupled with high relative humidities.

Research at the Maryland Station in 1962 consisted of three experiments with four treatments each. Tests were conducted in constant-environmental-temperature and humidity rooms. Chickens used in the tests were Arbor Acre L-50 cockerels. Tests started when they were five weeks of age and ran to ten weeks of age. Results of the tests are given in Table 12. Cumulative data cover the five weeks.

Lights

Studies of the effects of lights on layers and broilers were conducted at the New Hampshire Agricultural Experiment Station. Several lighting schedules were tried, as were different light sources and intensities. Little, if any, difference between incandescent and fluorescent lights—in respect to their influence on physical conditions of the chicken—was noted when good manage-

Table 11. Effect of Diurnal Fluctuations of Temperature on Body Weight of Broilers at Three to Eight Weeks of Age (Del. 1961).

	Temperature Regulation								
	Constant	Constant	Fluctuating	Constant	Fluctuating	Fluctuating	Constant	Constant	Fluctuating
Temperatures (°F)	80	100	80-100	80	80-100	80-100	80	105	85-105
Rel. Humid (per cent)	60	60	60	60	60	80	60	60	60
Birds Started/Pen	50	50	50	60	60	60	60	60	60
Floor Space (sq ft/bird)	1	1	1	0.8	0.8	0.8	0.8	0.8	0.8
Av. Weight (lb) - 3 weeks	0.79	0.78	0.78	0.83	0.83	0.83	0.63	0.61	0.63
Av. Weight (lb) - 8 weeks	3.12	2.69	2.94	2.84	2.86	2.87	2.86	1.53	2.24
Av. Mortality (per cent)	2.0	4.0	5.0	5.0	3.00	28.0*	0.0	29.0	16.0
Feed Conversion	2.06	2.00	2.07	2.14	2.18	2.20	2.21	....†	....†

*Failure of cold-water solenoid in eighth week allowed temperature to rise above 105° F for three hours in one pen. Twenty birds were lost. The matching pen had six per cent mortality.
†No feed conversion ratios given for 105° F, because of extremely high mortality at this temperature.

Table 12. Summary of Results of Studies on Influence of Environment on Broilers (Cumulative Five to Ten Weeks of Age) (Md. 1962).

Temperature (°F)	100	80	60	47	70	70	70	70	95	95	80	80
Relative Humidity (per cent)	60	60	61	80	48	58	70	90	35	90	90	45
Number of Birds	48	49	48	48	55	55	55	55	55	55	56	55
Water Consumed (gal/hr/1000 birds 9th-10th week)	58.2	56.2	53.5	50.2	51.6	54.7	55.3	48.2	95.6	59.4	55.3	59.2
Feed Consumed (lb/bird/week 4-10 weeks)	4.1	7.5	8.8	9.0	8.6	8.7	8.5	8.5	4.7	4.1	6.1	6.0
Feed Conversion (cumulative, 4-10 weeks)	2.8	2.3	2.4	2.4	2.2	2.2	2.2	2.2	2.5	2.8	2.2	2.2
Av. Weight (lb) per Bird (10th week)	2.5	4.3	4.8	4.8	4.5	4.5	4.5	4.5	3.7	3.0	4.2	4.1
Water Consumption (lb/bird/wk, 9th-10th week)	3.6	3.7	3.2	3.0	3.1	3.0	3.0	2.7	5.4	3.3	3.4	4.7
Water (lb)/Feed (lb), cumulative total	4.5	2.0	1.5	1.4	1.9	1.8	1.7	1.6	4.8	5.0	2.2	2.4
Water (lb)/Gain (lb), cumulative	14.8	4.7	3.8	3.4	4.6	4.3	3.8	3.6	12.0	13.9	4.9	5.3
Mortality (per cent)	20.8	2.0	2.1	0.0	0.0	3.6	0.0	0.0	9.9	31.4	1.9	3.8
Av. Pigment Score*	3.0	3.9	4.6	4.5	3.0	3.1	3.1	3.0	2.1	2.1	3.3	3.3
Av. Feathering Score†	2.3	1.6	1.5	1.8	1.8	1.6	1.4	1.4	1.3	2.0	1.3	1.3

*Scored from one to six; six most desirable.
†Scored from one to three; three most desirable.
Note: All values rounded to one decimal.

Table 13. Performance of Layers Under Three Lighting Schedules.*

Hatch	Schedule A		Schedule B	Schedule C	
April					
Weight (lb) at 20 Weeks	4.70		4.44	4.38	
Age (days) at 25 Per Cent Production	149		163	164	
Production (eggs/hen/52 weeks)	237.8		228.3	221.1	
November					
Weight (lb) at 20 Weeks	4.65			4.58	
Age (days) at 25 Per Cent Production	154			169	
Production (eggs/hen/52 weeks)	230.3			216.7	
April					
Weight (lb) at 16 Weeks	3.74		3.86	3.54	
Age (days) at 25 Per Cent Production	162		182	185	
Production (eggs/hen/52 weeks)	227.9		222.9	221.1	
	14-hr day	15-hr day		Step-down	Step-up
February					
Weight (lb) at 22 Weeks	4.77	4.70		4.54	4.41
Age (days) at 25 Per Cent Production	151	154		156	152
Production (eggs/hen/40 weeks)	168.9	161.2		150.5	181.7
May					
Age (days) at 25 Per Cent Production	150	150		156	
Production (eggs/hen/50 weeks)	225.5	218.7		210.3	
February **					
Weight (lb) at 20 Weeks	3.04			2.83	
Age (days) at 25 Per Cent Production	155			165	
Production (eggs/hen/48 weeks)	206.2			204.9	

*Schedule A: Natural Light to 20 Weeks, Then 14-Hour Day; Schedule B: Natural Light to 16 Weeks, Then 6 Hours to 20 Weeks, Then 18 Minutes Added per Week; Schedule C: 6 Hours Stimulight to 20 Weeks, Then 18 Minutes Added per Week.

**White Leghorns. Other trials were with heavy breeds.

ment prevailed. Cannibalism, as indicated by feather picking, was not a problem. Table 13 gives the results of five trials with heavy breeds and one with White Leghorns. Attempts to stimulate the rate of egg production among heavy breeds by starting with a short lighting period and providing periodic increases were not as effective as the traditional 14-hour day.

Since broilers receiving low levels of light intensity tended toward slightly superior weights at market time, it seemed desirable to determine the absolute lowest level that would result in optimum conditions for economic returns. Table 16 shows results obtained with 15 trials (on broilers), going to less than 1 foot-candle (f.c.) at feeder height.

Table 14. Effect of Light Intensity and Daily Light Duration on Broilers (N. H. 1958).*

	Duration (hours) and Intensity (foot candles)						
	12 hours			24 hours			
	15 fc	60 fc	120 fc	15 fc	60 fc	120 fc	Natural Light
Av. Body Weight (lb)†	3.29	3.25	2.25	3.31	3.24	3.22	3.30
Feed Conversion (lb feed/lb bird)	2.64	2.60	2.60	2.64	2.63	2.64	2.59
Mortality (per cent)	1.30	2.22	1.30	1.30	1.11	2.04	1.39

*Average of three trials with three replications.
†At ten weeks of age.

Table 15. Effect of Various Lighting Schedules upon Economic Factors in Broilers (N. H. 1959).

Treatment	Body Weight (lb)			Feed Consumption	Feed Conversion
	3 wks.	6 wks.	9 wks.	(lb)/Bird	(lb feed/lb bird)
Bright Lights, All Night	0.83	2.41	3.60	8.07	2.25
Dim Lights, All Night	0.84	2.41	3.63	8.17	2.26
Lights, 11:00 P.M. to 1:00 A.M.	0.83	2.39	3.59	8.00	2.25
Natural Light	0.79	2.28	3.49	7.82	2.27

Table 16. Effect of Light Intensity (foot candles) on Body Weight (Pounds at Nine Weeks of Age) of Broilers (N. H. 1961).

	>1 fc	2 fc	5 fc	10 fc	120 fc
Av. of 3 Trials		3.42	3.45		3.34
Av. of 4 Trials		3.82	3.79	3.76	
Av. of 4 Trials	3.66	3.61	3.60		
Av. of 4 Trials	3.61	3.56			

>:Symbol for "less than"

Litter

The composition and condition of poultry house litter and its effect on the chickens have been subjects of investigation and discussion for many years. The New Jersey Station describes litter as a heterogeneous mixture of litter material, poultry droppings, feathers, moisture, and possibly some feed and broken eggs. Litter material may be crushed corncobs, sawdust, shavings, chopped straw, oat hulls, bagasse, peat moss, or sand. Whatever the mixture, it probably abounds with microorganisms which produce varying amounts of heat, moisture, and gases.

Dry litter and good nesting material minimizes the number of dirty eggs. Dry litter, below 20 per cent wet basis, generates little ammonia. The same basic factors affect all litter materials. Figure 5 shows moisture equilibrium of several litter materials over a range of relative humidities.

Droppings contain from 70 to 80 per cent moisture. Chickens—depending somewhat upon the breed and the type of drinking fountain—shake water from their beaks and wattles after drinking. Placing the drinking fountains and perches over the dropping pit will alleviate much of the problem. Moisture respired by the chickens will increase the relative humidity in the house, unless means are provided for its removal. The higher the relative humidity the greater the probability of moisture absorption by the litter.

It is apparent that no single factor is wholly responsible for the accumulation of moisture in the litter.

Milled corncob litter has been extensively studied at the New Jersey Station. The weight per cubic foot is set at 11 pounds at 13 per cent moisture, wet basis. One per cent of the particles was longer than two inches; 26 per cent passed through common half-inch hardware cloth, and the remainder was of intermediate sizes. Most of the particles retained much of their original size throughout the winter.

When particles of corncobs become coated with wet droppings, a large surface area is exposed for drying. By the end of two months the particles are somewhat rounded and covered with a hard coating of manure. When the moisture content of the litter becomes 36 per cent (wet basis) or more, the mass will pack and become unworkable by the chickens. Figure 5 shows the moisture equilibrium for corncob and shredded begasse litter, and for droppings. Henderson and Perry (5) have defined such curves mathematically.

In an attempt to determine the influence of temperature and humidity on litter, chickens at the Delaware Station were dosed with sporulated oocysts of **Eimeria tenella** in drinking water, and placed in four pens under different conditions. In Pen No. 1, temperature was 70° F and relative humidity was 60 per cent; in Pen No. 2, 85° F and 60 per cent; in Pen No. 3, 70° F and 80 per cent; and in Pen No. 4, 85° F and 80 per cent. The number of oocysts after about a week began to rise — very sharply at 70° F and 60 per cent relative humidity and slower at the higher temperatures. As the chickens reached seven to eight weeks of age the number of oocysts suddenly dropped in Pens 1 and 4. No correlation

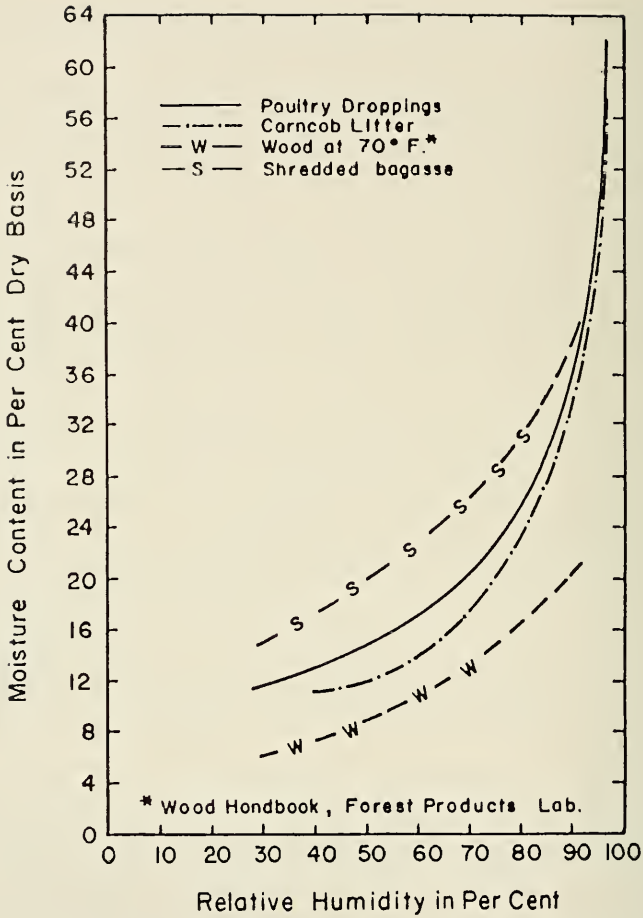

FIGURE 5. Equilibrium moisture curves for shredded bagasse, corncob litter, poultry droppings, and wood.

between either temperature or humidity and the disease was noted. It was concluded that, in a disease free situation, acceptable birds may be produced over a wide range of temperature and moisture conditions.

Flock Density

Attempts to determine the effect of population density upon growth and egg production have been made from time to time at several stations. Results of these tests indicate that space allotment is not a critical factor in production. The Massachusetts Agricultural Experiment Station in 1958 reported on three groups

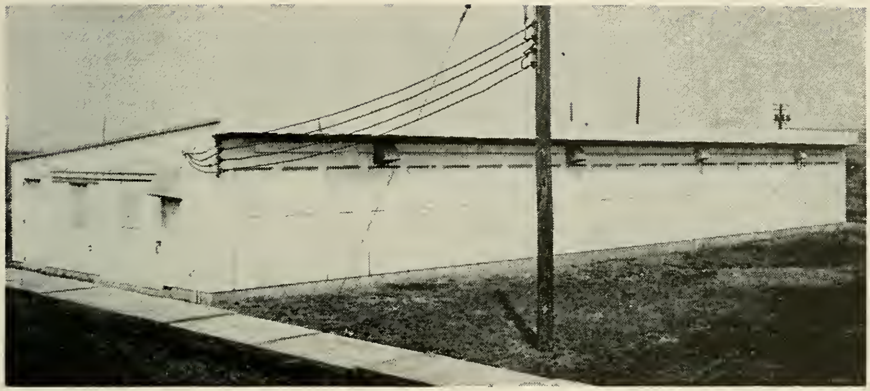

FIGURE 6. A conventional poultry house converted to a windowless house at the Pennsylvania State University Agricultural Experiment Station. Type and arrangement of equipment was similar to the latest installation in the solar house.

of 30, 60, and 100 chickens allowing 1, 2, and 3 square feet per chicken. Examination of the data shows no significant difference in performance due to either the size of the group or to the area of floor space allowed.

Stanek and Bressler (6) state that research and development work has shown that—by controlling temperature, moisture, air volume, and air distribution—high density housing of Single Comb White Leghorn pullets is economically sound. High density housing means as little as 0.75 to 1.00 square foot per chicken.

MANAGEMENT SYSTEMS

In general, three types of houses have been used in studies of environment and management in poultry. They are the conventional, windowless, and solar. Briefly, the conventional house is the house commonly used in the specific area. The windowless house may be the same as the conventional house, except that no provision is made for windows, or it may be a conventional house with the windows covered, as in Figure 6. The solar houses used in Pennsylvania and West Virginia were insulated structures with insulating glass windows having areas equal to at least 15 to 20 per cent of the floor areas. Figure 7 shows the front of the West Virginia solar house.

Solar Energy

Solar energy, instead of being an environmental factor in itself, is responsible for producing environmental conditions. Much of the data on solar energy obtained from studies conducted by the NE-8

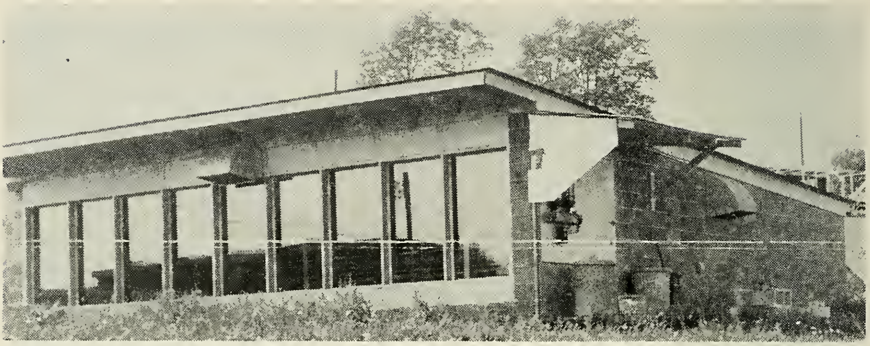

FIGURE 7. The West Virginia Experimental Solar Poultry House. This house, except for the windows, is identical to the windowless house in Figure 10.

project resulted from comparison of performance of chickens in solar and windowless houses. Preliminary results from these comparisons seem to indicate a thicker egg shell from hens receiving sunlight, indicating some benefit from the sunlight in producing egg shell. Practically no differences were noted in the rates of egg production. Cannibalism was more prevalent in the solar house, probably due to greater light intensity or of a different quality. Less feed was required to produce a dozen eggs in the solar house.

Results of studies conducted at the Pennsylvania Station show some of the ways that solar energy entering a house affects the management of the flock:

1. Poultry house litter exposed to solar radiation through insulating glass windows on sunny days in winter attained temperatures as much as 20° F higher than ambient temperatures.

2. The total amount of solar heat gain to buildings during the winter season was determined by making continuous daytime measurements of solar heat transmission through insulating glass windows. The values are reported in Table 20.

3. An analysis was made of a solar collector installation for heating the incoming ventilation air as it was drawn in through a long air space, 2 inches by 8 feet in size, under a black, metal heat-absorbing surface on the south building wall. Results showed that the air, in passing through the heat collector, was warmed as much as 20° F during periods of high solar heat intensity and approximately 5° F during periods of low solar heat intensity; with an air velocity of approximately 400 ft/min this system absorbed approximately 30 per cent of the available total daily solar heat.

This solar house, Figure 8, served as a pilot for the study of the effect of sun heat on the control of litter moisture and house temperature with layers housed at 1.9, 1.3, and 1.0 sq ft of floor

FIGURE 8. Experimental solar poultry house at the Pennsylvania Station. This 30- by 100-foot house has two inches of Fiberglas insulation in the walls, and four inches in the ceiling. The vapor barrier is aluminum foil. The concrete floor is also equipped with a vapor barrier. Insulating-glass windows are exposed due south. The ventilation system consists of thermostatically-controlled pressurized inlet fans.

space per layer (7). The basic house has not been materially changed, but equipment and arrangement inside have undergone considerable change. The most satisfactory flock performance was achieved during the past three years, as shown in Table 17. The type and arrangement of the equipment is shown in Figure 9. Actually, changes in the biological performance of layers without regard to their environment over the past ten years make it impractical to compare the results of performance tests from one year to another. (Pa. Progress Reports 183 and 184.)

In 1959 an insulated, gravity-ventilated conventional house, the same size as the solar house, was made windowless and equipped similar to the solar house. Flocks were housed in this structure at about 1.0 sq ft of floor space per layer and the performance of layers in the two houses compared. The results are given in Table 18.

Results of comparison between the solar and windowless houses at the West Virginia Station indicate that the only significant variation is the greater consumption of electrical energy required for lighting the windowless house. See Table 19. Condition of the litter, per cent of time fans were operating, and temperatures inside the houses were not significantly different in the two houses.

Conclusions drawn in comparing solar and windowless houses were:

1. High density housing of layers (as low as one square foot of floor space per layer) can be practiced and excellent performance of layers achieved in either a solar or a windowless house.

2. Moisture and temperature can be adequately controlled in the solar house so as not to be a serious management problem. Extra labor and litter material were required to keep the litter in a desirable condition in the windowless house.

Table 17. Ten-Year Summary of Performance of Layers in Solar House (Pa.).

	1952-53	1953-54	1954-55	1955-56	1956-57	1957-59	1959-60	1960-61	1961-62
Layers (number)	1,508	2,134	2,757	2,730	2,760	2,715	2,959	2,840	2,807
Age (weeks) at Start	20	20	20	20	20	20	22	22	22
Days of Lay	334	316	327	322	335	336	365	365	364
Floor Space Allowance (approx. sq ft/layer)	1.9	1.3	1.0	1.0	1.0	1.0	1.0	1.0	1.0
Egg Production (Hen-Housed)									
Number	170	150	125	173	182	176	238	236	244
Per Cent	50.9	47.4	38.2	53.7	54.3	52.3	65.2	64.7	67.0
Egg Production (Hen-Day)									
Number	210	176	148	196	206	201	255	251	266
Per Cent	62.9	55.7	45.2	60.8	61.5	60.0	70.0	69.9	73.8
Loss to Mortality and Culling (per cent)	44.0	38.9	29.5	25.4	24.4	31.1	10.4	11.5	14.1
Feed Consumption (lb/doz eggs)	5.29	6.47	6.20	5.71	5.50	5.55	4.17	4.25	4.28

Table 18. A Three-Year Comparison of the Performance of Layers in Solar and Windowless Poultry Houses, 1959-1962 (Pa.).

	1959-60		1960-61		1961-62	
	Solar	W'less	Solar	W'less	Solar	W'less
Number of Layers Housed*	2,959	2,948	2,840	2,839	2,807	2,807
Floor Space Allowance (approx. sq ft/pullet)	1	1	1	1	1	1
Days of Lay	365	365	365	365	364	364
Egg Production (Hen-Housed)						
Number of Eggs	238	242	236	241	244	252
Per Cent	65.2	66.3	64.6	66.0	67.0	69.2
Egg Production (Hen-Day)						
Number of Eggs	255	250	251	251	266	267
Per Cent	69.9	68.5	68.8	68.8	73.0	73.3
Losses to Mortality and Culling (per cent)	10.4	6.1	11.5	9.4	14.1	10.9
Feed Consumption (lb/doz eggs)	4.17	4.25	4.25	4.54	4.28	4.46

*At 22 weeks of age.

Table 19. A Three-Year Comparison of the Performance of Layers in Solar and Windowless Poultry Houses, 1959-1962 (W. Va.).

	1959-60		1960-61		1961-62	
	Solar	W'less	Solar	W'less	Solar	W'less
Number of Layers Housed	462	461	446	447	550	550
Floor Space Allowance (approx. sq ft/hen)	1.9	1.9	2.0	2.0	1.6	1.6
Days of Lay	350	350	317	317	335	335
Egg Production (per cent)						
Hen-Housed	58.3	54.0	70.7	60.9	66.9	69.3
Hen-Day	65.1	62.3	73.7	67.1	71.4	70.7
Losses to Mortality and Culling (per cent)	20.6	25.4	7.6	13.4	14.9	8.7
Feed Consumption (lb/doz eggs)	4.77	4.94	4.08	4.30	4.84	4.92

3. Solar energy was an excellent supplementary source of heat for drying litter in a poultry house.

4. The windowless house, being darker than the solar house, kept cannibalism to a minimum. This resulted in higher hen-housed egg production than in the solar house.

5. Extra electricity was required for lighting the windowless house.

6. Feed, over a three-year period, required to produce a dozen eggs was less in the solar house than in the windowless house.

7. Development and installation of mechanical and other labor saving equipment in the solar house reduced labor to 1/4 of original requirements over a 10-year period.

8. The choice between a solar and a windowless poultry house is not clear cut. In addition to the differences mentioned above, preliminary studies in egg quality suggest a possible difference in this area.

NOTE: Restricted, or controlled, lighting is receiving considerable attention by poultrymen at the present time.

Solar energy can be an important source of supplemental heat through insulating glass windows. During the winter months it will range between 12,000 and 20,000 Btu/sq ft/month (Table 20).

In December approximately 50 per cent of the daily solar radiation striking a south-facing 67-degree tilted clear plastic-film front will enter the house. According to observations made over a five-year period at the New Jersey Station, the daily horizontal insolation at New Brunswick, N. J., during December has averaged 720 Btu/sq/ft. The amount of this radiation that reaches the litter will depend upon the location of equipment and density of chicken population. Some of this heat will eventually warm the atmosphere in the house.

Floor- and Cage-Managed Laying Flocks

Whether chickens are kept on the floor or in cages may be considered either a management or an environmental problem, depending upon the effect the system may have on the chicken or the pleasure of the operator. Studies comparing the two systems of management on the performance of various sizes of flocks under the NE-8 project were made by the West Virginia, New Jersey, and Rhode Island agricultural experiment stations. The performance results of these tests are summarized in Table 21.

Data presented in Table 21 do not show conclusively any advantage in keeping White Leghorns either on the floor or in the cages, but they indicate that the larger breed produces better when kept on the floor.

Equipment

Commercial poultrymen, especially those producing broilers, frequently have difficulty in disposing of dead chickens. The Connecticut Station has developed a method of using an insulated septic tank. After tests at temperatures of 50°, 80°, and 100° F, it was concluded that 100° F is the most satisfactory. Practical use of these tanks indicates that a 500-gallon liquid capacity tank will be necessary for flocks of 10,000 hens or of 20,000 broilers. The tank recommended is surrounded with 4 inches of foam glass or equivalent moisture-proof insulation. The tank contents can best be heated by means of a soil heating cable. Otherwise the tank

Table 20. Total Monthly Solar Heat Gain (Btu/sq ft/month) to Poultry-Type Building Through Vertical Insulating Glass Window (Pa.).

Period	Total Heat Gain (Btu/sq ft)
Dec 1-31, 1957	12,151
Jan 1-31, 1958	14,136
Feb 1-28, 1958	18,524
Mar 1-15, 1958	5,398
Dec 1-31, 1960	19,439
Jan 1-31, 1961	21,516
Feb 1-28, 1961	16,436
Mar 1-15, 1961	7,818

Table 21. Summary of Performance Tests with Floor-Managed and Caged Laying Hens.

Test Location	Breed	Management	Birds Started (number)	Mortality (per cent)	Feed Consumption (lb/doz eggs)	Egg Production* (per cent)
W Va†	WL	Floor	960	12.5	4.41	65
W Va	WL	Cage	960	11.5	4.35	66
W Va	WL	Floor	1,278	5.5	4.17	67
W Va	WL	Cage	957	5.3	4.38	72.5
N J	WL	Floor	71		5.0	63
N J	WL	Cage	26		4.82	63
Rh I	RIR	Floor			5.94	59
Rh I	RIR	Cage			6.42	52
Rh I	WL	Floor			5.25	58.8
Rh I	WL	Cage			5.43	55.5

	Egg Production, Hen-Day Basis (per cent)			
	1959-60 (1 bird/cage)	1960-61 (1 bird/cage)	1961-62 (1 bird/cage)	1961-62 (2 birds/cage)
WL, Caged	55.8	55.8	60.0 66.3‡	60.9 64.4‡
WL, Floor Housed	58.8	54.2	64.4	
RIR, Caged	52.0	48.2	55.7 56.1‡	50.0 50.5‡
RIR, Floor Housed	59.0	48.4	56.9	

*Hen-Day basis.
†Only the West Virginia house was insulated.
‡Heat was supplied to one-half of the cage area in order to provide a minimum winter temperature of 45° F.

design is similar to that of the ordinary septic tank for household wastes. The cover of the tank must be gas tight, but readily opened for loading. In one installation where the soil was quite sandy, 50 feet of drain tile laid in a 12-inch gravel bed within a 24-inch trench was found to be sufficient.

CAUTION: The local health authority should be consulted before equipment of this kind is installed.

Trends in Labor Requirements

The installation of modern equipment and improved arrangement of pits, roosts, feeders, waterers, and nests have contributed to more satisfactory management in the poultry house. The Pennsylvania Station reported a reduction of labor requirements, over a 10-year period, to 1/4 of the original requirements. This was possible through the development of mechanical equipment and high density housing of layers. See Table 22. Figure 9 illustrates an arrangement of equipment to keep the distance traveled by the operator to a minimum.

THE HOUSE

Materials and Construction

Reference has already been made to the types of houses used in studies conducted under the NE-8 project. Since there were differences in results obtained with these houses, a fuller description may suggest reasons for the differences.

The conventional house is the type of building ordinarily used in the given area and was already available for use. This house may be concrete block or wood frame with wood or metal siding, insulated or uninsulated, with raised wood floor or concrete slab on grade, and it may have a shed or gable roof with ceiling and attic space. Figure 6 shows a typical conventional laying house used in tests at the Pennsylvania Station.

The windowless house used in tests at the Pennsylvania Station consisted of a conventional house with the windows covered to exclude the light (Figure 6). The windowless house used in tests at the West Virginia Station (Figure 10) was built of cinder blocks

Table 22. Reduction in Labor Time Requirements, in Minutes per Dozen Eggs, for Feeding, Watering, Egg Gathering, and Pit Cleaning Achieved Through Development of Labor-Saving Equipment and Employment of High Density System of Housing Layers in Solar House (Pa. 1952-1962).

	1952-53	1953-54	1954-55	1961-62
Floor Space Allowance (sq ft/layer)	1.9	1.3	1.0	1.0
Number of Layers	1,508	2,134	2,757	2,807
Eggs Produced (doz)	23,055	27,540	35,611	57,159
Reduction in Labor Time*	2.7	1.9	1.1	0.7

*Does not include miscellaneous chores and egg processing.

FIGURE 9. The interior of the Pennsylvania solar poultry house shows latest improvements in equipment and its arrangement. Space allotted for the Single Comb White Leghorns is one square foot per bird.

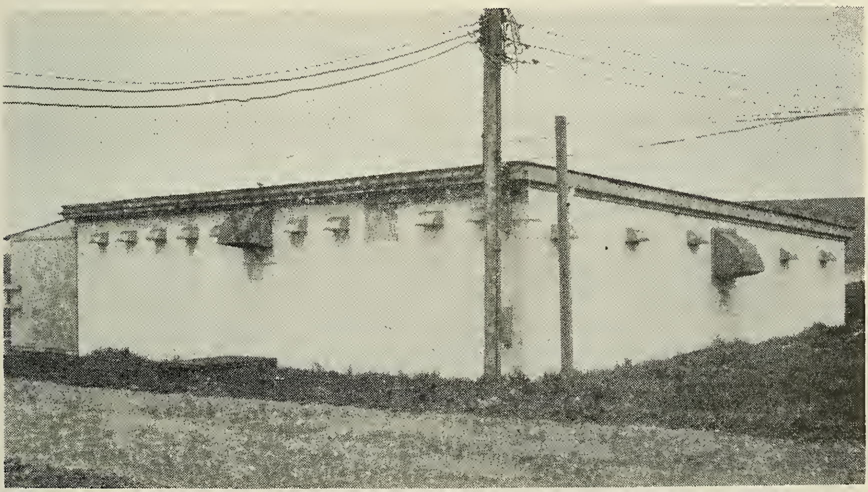

FIGURE 10. The experimental windowless house at the West Virginia University Agricultural Experiment Station, with a floor area of 900 square feet, is constructed of cinder blocks. Cores are filled with expanded vermiculite.

with cores filled with expanded vermiculite. Heat loss from this building was determined to be 0.20 Btu/hr/sq ft/°F. The house was not considered to be well insulated (8).

The solar poultry house may be described simply as a structure with its front wall fitted with sufficient insulating glass to permit mid-winter radiation from the sun to flood a large part of the floor area. The area of glass should equal 15 to 20 per cent of the floor area. Solar houses, shown in Figures 7 and 8, have been built at both the Pennsylvania Station and the West Virginia Station. Details of construction of the Pennsylvania solar house and arrangement of equipment have been described in that Station's Progress Report 185. The West Virginia solar house is similar to its windowless house, except that it has insulating glass windows.

A low-cost solar poultry house was developed at the New Jersey Station (Figure 11). Requirements for this house are that the solar front must face south, be unshaded, and have a minimum area equal to 25 per cent of the floor area. Any type of transparent material having a light transmission of at least 85 per cent may be used, such as glass, Plexiglas, or clear plastic film. A tilted front of 67 degrees from the horizontal plane adds to the usable floor area, is self-cleaning, and, in winter, admits from 10 per cent to 20 per cent more insolation than does a vertical front. This tilt is a compromise between 55 degrees, the ideal for solar heat collection in winter in New Jersey, and a tilt which will permit the snow to slide off.

The house appears to be very satisfactory for the eastern coastal area, where average possible sunshine from December to February is greater than 50 per cent and where severe winter blizzards are not frequent.

In midsummer, the 3-foot roof overhang shades the upper half of the front from direct radiation from the sun. With the upper sashes completely lowered, much of the direct radiation striking the lower half of the front is reflected because of the large angle of incidence.

At the Pennsylvania Station, insulated poultry house ceiling temperatures were measured, both with and without ventilation through the air space beneath the roofing, and with both reflective and nonreflective roofing materials. The results show that natural ventilation of the air space significantly reduced the temperature of the air under the nonreflective roofing; there was no significant heat build-up under the reflective roofing; and no substantial reduction of temperature by ventilating.

Size and Shape

Little work on the problems involved in planning poultry houses, especially with regard to shape, has been done under the NE-8 project. The size of the building, or buildings, will depend,

FIGURE 11. The New Jersey experimental solar poultry house. This house will maintain excellent litter with the equivalent of one Leghorn layer per two square feet of floor area. The six easterly panels on this house are covered with plywood. Experimental work was done with an uninsulated house 30 feet in width.

of course, upon the extent of the proposed operation, the size of chickens, and the method of management. Whether the plant is intended for layers or broilers will be an important consideration in design. It has been demonstrated that, with good management practices, population density of layers may equal or even exceed one layer per square foot of floor space for White Leghorns.

A study of the results of research discloses several factors involved in selecting a shape for the house. These include the amount of floor space that may receive winter sunshine, ease of ventilation, arrangement of equipment, and amount of labor required for operation. A long narrow house with a south-facing front, sloped so as to be normal, or nearly so, to the rays of the sun, will have more of its floor flooded with winter sunshine.

In the matter of arrangement of equipment, it appears that waterers placed over the dropping pit prevent a lot of moisture from getting into the litter. The shape of the house may be influenced somewhat by the kind of labor saving devices that may be installed. For example, the cost and reliability of a long pit cleaner may need to be considered.

A house with a ceiling some distance below the roof provides a space from which air warmer than outside may be delivered to the pen for ventilation in winter and will, if properly vented, result in a cooler house during hot summer days.

Foundations

Studies at the Maine Station include observations on the movement of foundation beams due to frost action. Concrete beams were laid on gravel and clay beds and kept free of snow, and observed to determine the effect of freezing weather on foundations. It was noted that in some cases the beams raised over 3.5 inches.

Windows

The solar window has been described as a dual, or insulating, glass window having an area of 15 to 20 per cent of that of the floor. The solar front of the New Jersey house slopes 67° from the horizontal and consists of panels of clear plastic film instead of glass. The solar heat transmission efficiency of various window materials was determined by comparing the total daily solar heat transmission through the window material to the total daily solar radiation outdoors. The transmission efficiencies of the window materials studied are reported in Table 23.

Table 23. Solar Heat Transmission Through Various Window Materials in South-Facing Vertical Windows (Pa.).

Material	Heat Transmission (per cent)*
Single Glass (standard)	84
Insulating Glass (¼" x ½" air space)	63
Insulating Glass (⅛" x ¼" air space)	70
Fiberglas (white, 1/16")	76
Fiberglas (light green, 1/16")	50
Single Glass and Storm Sash (standard)	74
Single Glass and Plastic Film (clear)	76
Single Glass and Plastic Film (milky)	69
Single Glass and Frost	64
Single Glass and Dust	49
Insulating Glass (¼" x ½" air space) with Heavy Dust Coating	37

*Measured total daily radiation inside of glass x 100/measured total daily radiation out-of-doors.

Insulation

Although some of the houses used in the NE-8 investigations were insulated, little definite information regarding kinds or values was determined or reported. Fiberglas was used in most of the cases reported. The West Virginia Station reports a U-value of 0.10 in one of its houses and 0.34 in another, but states that the latter value is too high.

Investigations at the Maine Station were concerned with a study of moisture migration through Fiberglas insulation with vapor barriers of polyethylene film of various weights and of aluminum foil, .00035 inches in thickness, on both sides of 80-lb kraft paper.

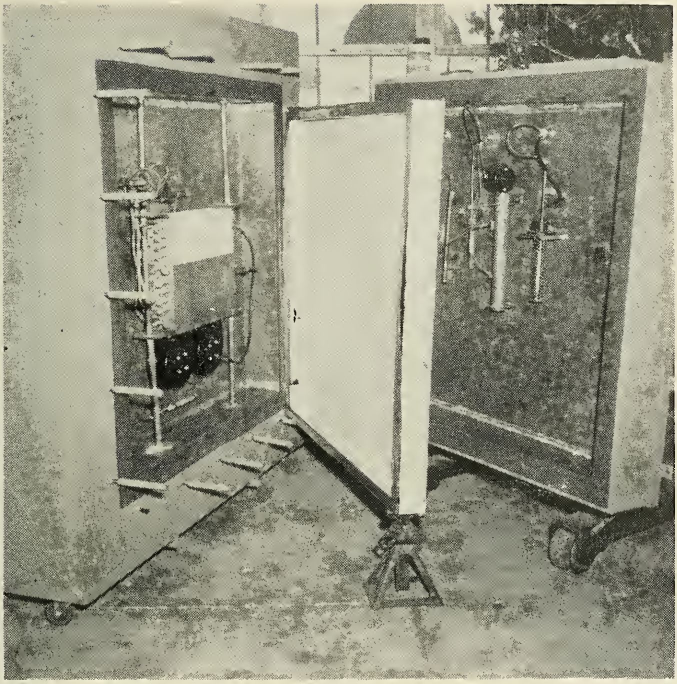

FIGURE 12. The testing chamber for measuring the vapor permeability for insulated wall panels at the University of Maine Agricultural Experiment Station.

A test chamber, shown in Figure 12, was used to determine the moisture permeability of 4-inch by 4-foot panels. Table 24 gives the results of the tests.

Ventilation

In reviewing reports of research on poultry housing, it is apparent that the reason for studying ventilation rates was more for the removal or dilution of polluted air than for the supplying of fresh air. It would be difficult to prevent oxygen from getting into the house in sufficient amounts to supply the requirement of the chickens. Actual results of the research point out several reasons for ventilation, aside from that of introducing fresh air. Bringing fresh air into the house drives out moisture, ammonia, dust, disease-polluted air, and odors, and in addition aids in the control of temperature.

The amount of fresh air does not seem to be critical. Ventilation rates ranging from about .25 cubic foot per minute per chicken to over 5 cubic feet per minute per chicken have been studied. According to results observed at the Delaware Station, enough fresh

Table 24. Permeance of Insulated* Test Panels (Maine).

Panel No.	Vapor Barrier	Joints, Fasteners, etc.†	Permeance Range‡ (Perms)**
1	4-mil Vinyl Sheet, Aluminum Coated	None	0.730-0.830
	Polyethylene Film		
2	2-mil Clear	None	0.153-0.156
3	4-mil Clear	None	0.096-0.130
4	6-mil Clear	None	0.064-0.070
5	4-mil Clear	5/16-in staples, 2' O.C. into studs 2' O.C.	0.108-0.128
6	4-mil Clear	5/16-in staples, 2' O.C. into studs 2' O.C. with one 1/4" diameter hole in film in center of Panel	0.275-0.321
7	4-mil Clear	6-mil polyethylene tape over 2" lap joint	0.115-0.199
	Aluminum Foil		
8	0.00035" foil on 2 sides of 80# kraft paper	2" lap joint w/adhesive (no sheathing) stapled to stud	0.066-0.077
9	0.00035" foil on 2 sides of 80# kraft paper	2" lap joint held between sheathing and stud (no adhesive)	0.071-0.074
10	0.00035" foil on 2 sides of 80# kraft paper	2" lap joint w/adhesive (same as Panel No. 8, but poorly made)	0.250-0.300
11	0.00035" foil on 2 sides of 80# kraft paper	2" lap joint w/adhesive aged for one year under poultry house conditions (no sheathing)††	0.091-0.100

*All panels insulated with 6 inches of Fiberglas, except for Panel No. 1, which was insulated with four inches of Fiberglas.
†Ratio of length of joint to area of vapor barrier: 3" per square foot.
‡Lower value indicates moisture leaving panel; higher value indicates moisture entering panel.
**1 perm=1 grain per hour per square foot per inch of mercury (vapor pressure difference).
††Slight mechanical damage noted.

air will be supplied if the rate of change is sufficient to control ammonia below 50 ppm at 60 per cent relative humidity. This amounts to approximately one cfm per 10-week old broiler.

The Massachusetts Station reports that three systems of ventilation have been studied. They are the pressurized duct system with blending chamber for automatically mixing outside and recirculated pen air, exhaust system, and gravity system. The pressurized system maintained somewhat drier litter.

As shown in Figure 2, the amount of heat that the hen emits is around 8 to 9 Btu/hr/lb of live weight. The value decreases somewhat as higher ambient temperatures are reached. The decrease in heat emission is of advantage from the standpoint of temperature control in the house during warm weather. The problem then is to rid the house of enough heat to maintain a temperature in the range where the hen is not stressed (45° to 85° F).

Hens produce moisture as well as heat. If this moisture must be removed during cold weather, the ventilation rate required to keep moisture at a desirable level may remove so much heat that temperatures below 40° F result. Ventilation fans are operated intermittently to maintain a reasonably dry house and as nearly the ideal temperature as practicable. (See discussion of heat and moisture production, pages 4 and 6.) In all of the studies reported the fans were thermostatically controlled. In some cases some of the fans operated continuously, or at half-speed, while the others operated under thermostatic control. As shown at the Maryland Station and at the Beltsville Agricultural Research Center, hens will produce eggs satisfactorily at lower than ideal temperatures. It is, therefore, logical to suppose that a compromise on temperature and moisture may be reached. Some stations have felt it necessary to recommend adding supplementary heat.

Hens eliminate moisture in several ways. Eggs are about 65 per cent water. Feces will be around 70 per cent water. At temperatures between 40° and 80° F, respired water may equal 30 to 45 per cent of the water consumed. Also, a certain amount of water will be evaporated from the waterers and from water spilled into the litter. Removal of water in the eggs is no problem. If roosts, feeders, and waterers are placed over the droppings pit, much of the eliminated water may be removed with automatic mechanical equipment, since 60 to 65 per cent of the droppings will fall into the pit. The remaining moisture must be carried out by the ventilation system. The amount of air that must be moved depends upon the temperature, the amount of moisture in the entering air, the rate at which the litter will give up its moisture, etc.

The Rhode Island Station had a problem with moisture condensation on poultry house windows during severely cold weather. It was necessary to keep the windows closed. Noting that the air in the attic space, which was ventilated at the eaves, was several degrees warmer than the space occupied by the hens, it was decided to ventilate the house by forcing the attic air into the room below. Although the entire house was found to be around 1.5° F cooler, the reduction of condensation on the windows more than offset the disadvantage. Figure 13 shows the interior of this house.

Investigations of the effect of high concentrations of ammonia and its control have been conducted at the Delaware Station. The presence of ammonia in concentrations of 15 ppm can be detected by smell. It begins to burn the eyes of the caretaker in concentrations of 25 to 35 ppm. Above 50 ppm keratoconjunctivitis (eye inflammation) develops in chickens. Chickens so affected have an unhealthy appearance, but will show no ill effects when dressed for market. A ventilation rate of 0.33 cfm per pound of chicken was found sufficient to hold the concentration below 25 ppm. Concentrations up to 75 ppm do not retard growth. For such a

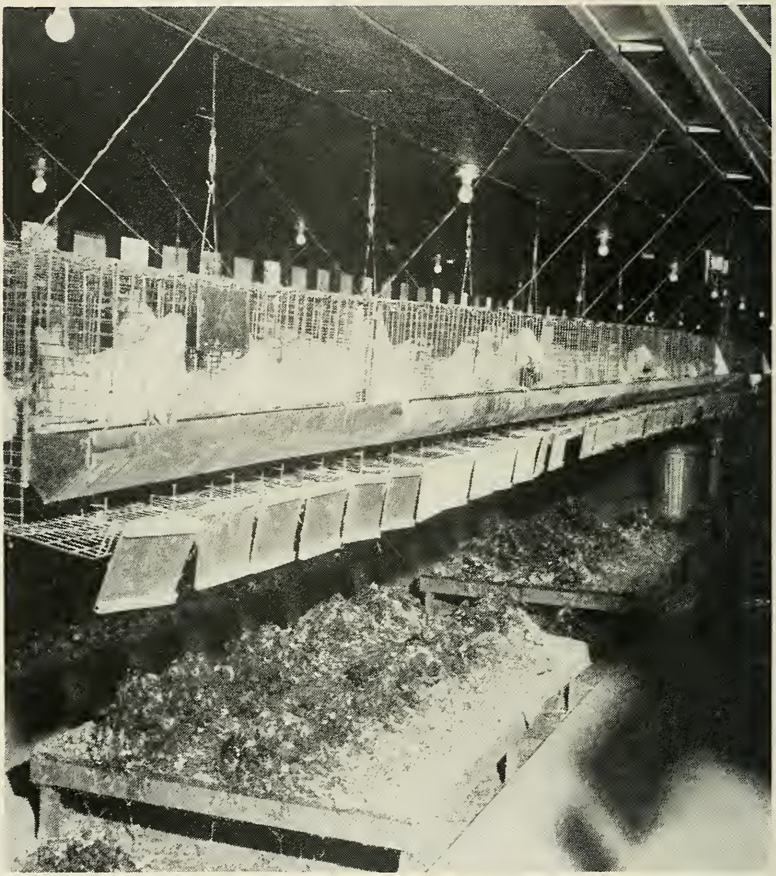

FIGURE 13. Laying cages and related equipment used in studying moisture content of droppings at the University of Rhode Island Agricultural Experiment Station. Ventilating air is taken in from the attic.

concentration, a ventilation rate of 0.15 cfm per pound of chicken was sufficient. Figure 14 shows the influence of various concentrations for given times of exposure at several different ages.

"Black foot," which has been associated with the presence of ammonia, does not occur in ammonia concentrations up to 175 ppm unless the litter moisture is well above 25 per cent wet basis.

Ammonia production is not dependent upon temperature in the range of between 60° to 95° F and 60 to 80 per cent relative humidity. It is limited when the relative humidity is less than 60 per cent. Table 25 recommends air change rates required to maintain ammonia concentrations below 25 ppm for several ages of chickens.

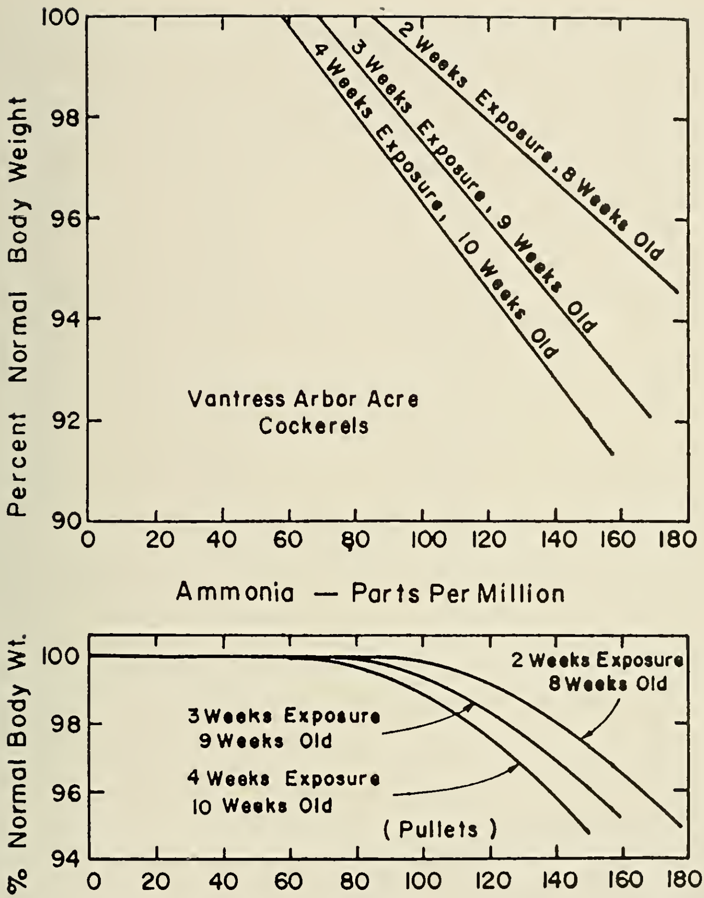

FIGURE 14. Effect of duration and intensity of ammonia upon body weight of Vantress Arbor Acre cockerels and pullets at 70° F and 70 per cent relative humidity. Delaware data, 1957.

The problem of controlling dust in the poultry house is an ever present one. Attempts to develop means of controlling dust were made at the Delaware Station. Two methods were tried. In one project, where an attempt was made to cool the building by refrigeration, dust accumulated on the coils so rapidly that some means of eliminating it had to be found. Fiber batt filters

Table 25. Air Flow Rates Required, for Different Ages of Broilers, to Maintain Ammonia Concentration at 25 Parts per Million.

Age of Birds (weeks)	4	5	6	7	8	9	10
Air Flow (cfm/bird - 10 per cent)	0.43	0.54	0.64	0.73	0.82	0.90	0.96

were tried, and even though they were vacuum cleaned every day, they were discarded as unsatisfactory. The second method tested used an electrostatic precipitator. This device removed nearly 90 per cent of the dust from recirculated air, as determined by the accumulation of dust in fiber batt filters placed in the air stream discharged from the precipitator. A third test involved the use of different litter materials, hoping to find one that would reduce the amount of dust.

Results of tests with screened sawdust and 1/4-in-particle-size vermiculite were as follows: Sawdust, without the precipitator, left 320 grams of dust on the filter in 96 hours of operation. With the precipitator, 33 grams were collected. In 96 hours of operation, without the precipitator, 584 grams of dust were left on the filter when vermiculite (expanded mica) was used as litter. From studies reported by Koon, Grub, and Howes (9), it would appear that only a small proportion of the dust in the poultry house comes from the litter and the remainder from the chickens themselves.

The Connecticut Station, where research in the field of disease control was conducted, reports the result of four trials with 20 White Plymouth Rock male chicks in each of four cabinets. All chicks in two of the cabinets were inoculated intranasally with doses of infectious bronchitis virus, while those in the other two cabinets were not inoculated. All groups were housed under the same conditions. Assignments to the cabinets were made according to a Latin square to assure a similar cross section of groups. Two ventilation rates were used: 3/4 cfm and 2 cfm per chicken.

The effect of ventilation rates on the performance of the chickens, even those with infectious bronchitis, does not appear to be a serious factor in chick growth. See Table 26. Outbreaks of disease in terms of weight loss are serious, but good performance can be expected in chicks with infectious bronchitis, if they are kept in a warm environment.

SUMMARY

The preparation of this summary is intended to bring together, in brief form, the information [presented in this bulletin] that is pertinent to the design of a poultry house.

1. The size of the house will be governed by the nature, number and size of units to be housed. See pages 1, 2, and 18.

2. Provision must be made for feed storage and feeders. The volume of feed depends upon the size of chicken, rate of growth, egg production, and environmental conditions. Figure 1 and Table 3 will be of value in determining feed space requirements.

Table 26. Summary of Performance of Chicks Infected with Bronchitis Virus and Housed in Cabinets at 49° F with Ventilation Rates of Three-Fourths and Two Cubic Feet Per Minute Per Bird.

Ventilation Rate	Non-Infected	Infected	Difference
		Weight (lb) at Eighth Week	
¾ cfm/chicken	3.209	2.835	0.374
2 cfm/chicken	3.128	2.834	0.294
Difference	0.081	0.001	
		Weight Gain (lb/chicken)	
¾ cfm/chicken	2.116	1.742	0.374
2 cfm/chicken	2.038	1.746	0.292
Difference	0.078	0.004	
		Feed Consumption (lb/chicken)	
¾ cfm/chicken	5.826	5.103	0.723
2 cfm/chicken	5.802	5.196	0.606
Difference	0.024	0.093	
		Feed Efficiency	
¾ cfm/chicken	0.364	0.342	0.022
2 cfm/chicken	0.351	0.336	0.015
Difference	0.013	0.006	

Note: In all the performance factors checked, the non-infected chicks did better than infected chicks. The higher rate of ventilation, two cfm per bird, was advantageous only in feed consumption and weight gain.

3. Provision must also be made for drinking water. The amount of water required for layers and broilers has a fairly fixed relationship to the amount of feed consumed. Table 5 shows this relationship for layers and Tables 10, 11, and 12 show it for broilers.

4. During hot weather it may become necessary to remove a large amount of heat from the shelter. During cold weather, heat must be conserved. Of primary interest is the best temperature for the chicken. Information obtained indicates that 50° to 70° F is the best range for producing eggs and growing broilers after 4 or 5 weeks of age. At temperatures below 45° and above 85° F, chickens are definitely stressed.

5. Since heat is an important property to be considered in design, it is necessary that the designer be acquainted with its sources, means of conservation, and removal, or cooling. The layer produces from 7 to 9 Btu/lb of hen/hr. Other sources of heat are solar radiation, heat caused by decomposition of litter, and heat from electrical and mechanical equipment in the house.

6. Moisture in the atmosphere has some bearing on the consumption of water, and also on the comfort of the chicken. The range of relative humidity in which no adverse effects were indicated seemed to be between 60 and 80 per cent. Removal of moisture by the ventilation system may present a serious problem, since the removal of excess moisture by means of air change during cold

weather may incidentally remove too much heat. Results of many tests of environmental control strongly indicate advantages in insulated houses, controlled forced ventilation, dropping pits with feeders, waterers, and roosts located over them, and devices for frequent removal of droppings.

7. Fecal production is related to both feed and water consumption. Tables 5, 10, 11, and 12 show this relationship.

8. Light is an important environmental factor. Too much light may lead to an increase in cannibalism and will influence nesting habits of layers. Studies of responses to light on layers and broilers indicate that the 14-hour day is usually best for layers, but may be influenced by the lighting schedule to start of laying and by hatching date. Intensity of light may be as low as 1 foot-candle.

9. Reasonably dry litter is essential. In order to maintain a satisfactory condition in litter, the moisture in the atmosphere must be kept below 80 to 85 per cent relative humidity (room temperature), droppings concentrated mostly in pits, and other sources of moisture controlled.

10. The sun is a good source of heat for drying litter.

11. A space requirement for layers may be as low as 1 sq ft of floor area per layer and 0.8 sq ft per broiler.

12. Labor requirements may be kept down by use of automatic equipment.

13. The rate of air change is not critical. Two cubic feet per minute per chicken may be considered sufficient for winter conditions.

14. Ammonia does not become a problem, so far as the chicken is concerned, until it becomes a problem for the attendant. Ventilation at a rate of one cfm per chicken will maintain ammonia concentration at a safe value.

15. Buildings should be constructed tight enough to require mechanical ventilation. Fans should provide at least 6 cfm per sq ft of floor area for summer conditions, and should be controlled by a thermostat.

16. Buildings should be insulated. It is suggested that there be at least 2 inches of insulation in the walls and 4 inches in the ceiling. There should be enough insulation to give an average R value between 8 and 10 or a U-value between 0.10 and 0.125.

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