AN ANALYSIS OF WINTER VENTILATION FOR POULTRY LAYING HOUSES

by

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INTRODUCTION

Ventilation of poultry laying houses has been studied by research men for nearly half a century. The objectives of some of the first studies were directed toward providing fresh air and improving sanitation. With advancing knowledge of ventilating requirements and the increasing use of electricity on farms, the objectives and goals of poultry house ventilation inquiries have been broadened as follows:

A. Control of Environment

1. Provide more uniform and higher minimum temperatures in order to:

    a. Maintain higher egg production during cold spells.

    b. Protect water pipes from freezing, and

    c. Provide more comfortable environment for workmen.

2. Provide low humidity in the house in order to:

    a. Maintain dry litter

        (1) More adequate sanitation

        (2) Less litter required

    b. Reduce moisture damage to structure

3. Provide fresh air without drafts.

4. Remove odors and carbon dioxide.

B. Reduction of Labor

1. Automatic control of ventilation.

2. Fewer eggs to be cleaned if dry litter is maintained.

3. Less work in changing litter.

Research workers have provided considerable information for practical design of poultry ventilating systems. However, most of the necessary data is hidden in numerous volumes of books and technical magazines; thus, a considerable amount of work is involved in the collection of design data. After these data are collected, several calculations are necessary to determine the ventilating rates for variable weather conditions. Several authorities have analyzed the formulas used in the design of ventilating systems. However, they did not present adequate procedures and data for the rapid solution of poultry ventilating problems in the field.

Essentially, the data necessary for design of a ventilating system is: (a) heat and moisture balance for laying house, (b) indoor and outdoor relative humidity and temperature and (c) house construction and size.

After these design data have been collected, the following formulas apply:

Heat Balance Equation:

$$Q_s = AU_{av}(T_i - T_o) + Mc_p(T_i - T_o)$$

Where:

Q_s is the sensible heat produced in the house (Btu/hr)

A is the exposed area (ft^2)

U_{av} is the average heat transmission coefficient (Btu/hr/ft^2/^oF)

T_i is the inside temperature (^oF)

T_o is the outside temperature (^oF)

M is the air flow (lbs/hr)

c_p is the specific heat of air (Btu/lb)

Moisture Balance Equation:

$$M = \frac{W_e}{W_i - W_o}$$

Where:

M is the air flow (lbs/hr)

W_e is the moisture to be removed from the house (lbs/hr)

W_i is the moisture contained in the inside air (lbs H_2O/lb dry air)

W_o is the moisture contained in the outside air (lbs H_2O/lb dry air)

Heretofore, it has been necessary to determine the values that should be substituted in the formulas and solve the formulas several times for different weather conditions in order to determine the rates of theoretical air flow.

Rather than spend the large amount of time required for theoretical design, most of the men in the field have resorted to the use of a constant rate of air flow of two, three, or four cfm per bird. Since house construction, relative humidity and temperature may take on a wide range of values, it is doubtful that a constant rate of air flow is sufficiently accurate for all installations. Thus, it is evident that, in order to apply these formulas to practical problems, a relatively rapid and reliable method for designing poultry ventilating systems suitable to variable weather conditions is needed.

OBJECTIVES

In view of the above statements, a study was conducted with objectives as follows:

1. To determine practical values of the following data for use in design of ventilating systems for poultry laying houses.

   a. Heat and moisture balance for house,

   b. Indoor and outdoor design temperature, and

   c. Indoor and outdoor design relative humidity.

2. To develop graphical solutions, with scales for practical use, of the theoretical heat balance and moisture balance equations for the ventilation of poultry laying houses.

FACILITIES

The published records of previous research on poultry house ventilation were available in the V. P. I. library.

Continuous records of outdoor temperature and relative humidity for Blacksburg, Virginia since 1940 were made available by the Agricultural Experiment Station.

Office space was obtained in the Agricultural Engineering Building. Consultants for the study were Professor J. L. Jones, Mechanical Engineering Department; Dr. J. H. Bywaters, Poultry Department; Professor U. F. Earp, Agricultural Engineering Department; and Mr. James M. Stanley, Agricultural Engineering Department.

ANALYSIS OF DESIGN DATA

The data needed for design of a ventilating system are: (a) water to be removed from the house, (b) sensible heat available and (c) indoor and outdoor design temperatures and relative humidities. In addition, the heat loss from the building must be calculated.

As an introduction to heat and moisture balance in poultry houses, a section on the chicken's body temperature regulation is presented.

Body Temperature Regulation:

Metabolism, according to Webster, is defined as,

> "The chemical changes in living cells, by which the energy is provided for the vital processes and activities, and new material is assimilated to repair the waste."

Basal metabolish is the minimum rate of metabolism and is measured by the minimum rate of heat production (9). In addition to the basal heat production there are increments of heat production due to muscular activity, digestion of food, and production of eggs (54).

According to Hill (32) the change of metabolism with changing environmental temperature is shown in Figure I. The body temperature of the hen is near 106 °F. If the hen's body temperature is to remain constant, the heat produced must equal the heat dissipated. Chickens dissipate heat by radiation, conduction, convection, and by evaporation of water from the lungs. Since chickens have no

METABOLISM VS. TEMPERATURE FOR ANIMALS[a]

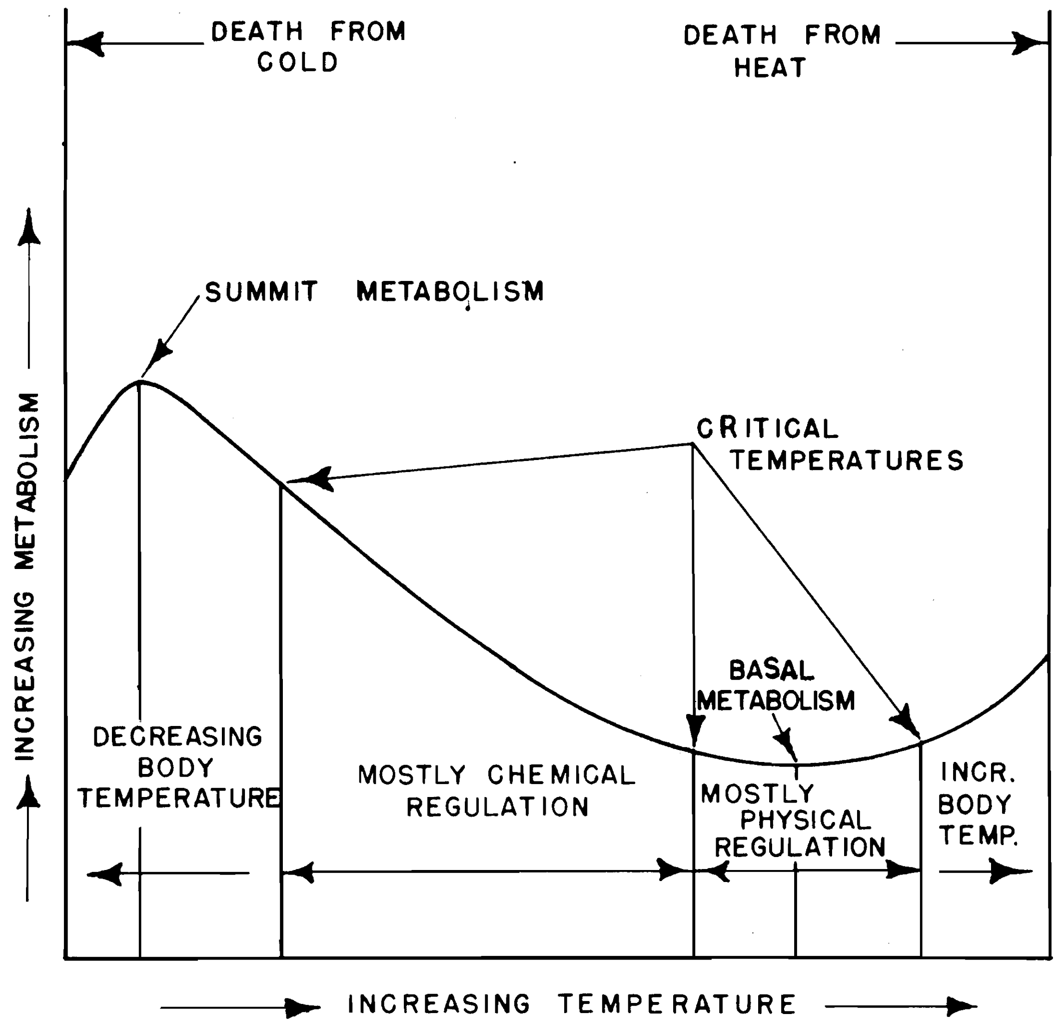


FIGURE I

[a] HILL (32)

sweat glands, no heat can be dissipated by evaporation of water from the skin.

Figure I shows an area of physical regulation and of chemical regulation. It is noteworthy that the distance from basal metabolism to decreasing body temperature is considerably greater than the distance from basal metabolism to increasing body temperature. This indicates that poultry can withstand low temperatures better than high temperatures.

Concerning the regulation of body temperature of farm animals, Barre and Sammet (5) state:

> "In cold weather the rate of heat generation rises through an increase in metabolic rate stimulated by secretion of thyroxine and adrenaline (substances that appear to act as governors on the rate of metabolism), by the consumption of larger quantities of high-energy feed, and by increased muscular activity, such as by working or shivering. Cooling by evaporation is reduced by restricting secretion of sweat or decreasing the rate of respiration. Surface losses by radiation, conduction, and convection are reduced by lowering the skin temperature through restriction of blood circulation in the subcutaneous tissue. They are reduced also by increasing surface insulation, accomplished by increasing the amount of subcutaneous fat; by thickening and ruffing the coat of fur or feathers or by wearing more clothing, as appropriate for the particular species; by huddling together; and by drawing on the sensible heat of the body through reduction of the tissue temperature, particularly in the body extremities and near the skin surface.
>
> "The processes of adjustment to cold environment are reversed in hot weather; metabolism is reduced, evaporation of moisture increased, blood circulation increased in the extremities and subcutaneous tissue, surface insulation reduced, etc."

Hill (32) discussed high environmental temperatures as follows:

> "In a hot environment, animals maintain stability of body temperature by increasing the amount of water vaporized from the lungs and skin. It is to be noted at this point that the domestic fowl (as with all birds) possesses no sweat glands in its skin and that no heat loss can be effected, therefore, by water evaporation from its peripheral surface unless externally applied. As a result, it must depend upon vaporization from the lungs in order to keep cool in a hot environmental temperature in contrast to sweating animals which accomplish from 40% to 95% of their heat losses under similar circumstances via the skin. As the temperature rises, so does the percentage of the total heat produced which is dissipated as heat of vaporization."

An approximate relationship showing the percentage of total heat which appears in latent form versus environmental temperature is plotted in Figure II. As the environmental temperature approaches the body temperature of the chicken, 106 °F, heat transfer by radiation, conduction and convection decrease to zero; therefore, all heat must be dissipated by evaporation of water from the lungs. This is shown as 100 per cent of the total heat in latent form at a temperature of approximately 106 °F (Figure II).

<u>Moisture Balance for House</u>:

The moisture balance may be stated as follows:

$$\text{Moisture sources} \pm \text{moisture stored} = \text{moisture removed}$$

Chickens eliminate considerable moisture. Below temperatures of about 70 °F, a large part of this moisture is excreated in the droppings; the remainder is evaporated from the lungs. Water expired and water excreted will be considered separately. Other sources of moisture will also be included in the analysis.

PERCENT OF TOTAL HEAT IN LATENT FORM VS. ENVIRONMENTAL TEMPERATURE[a]

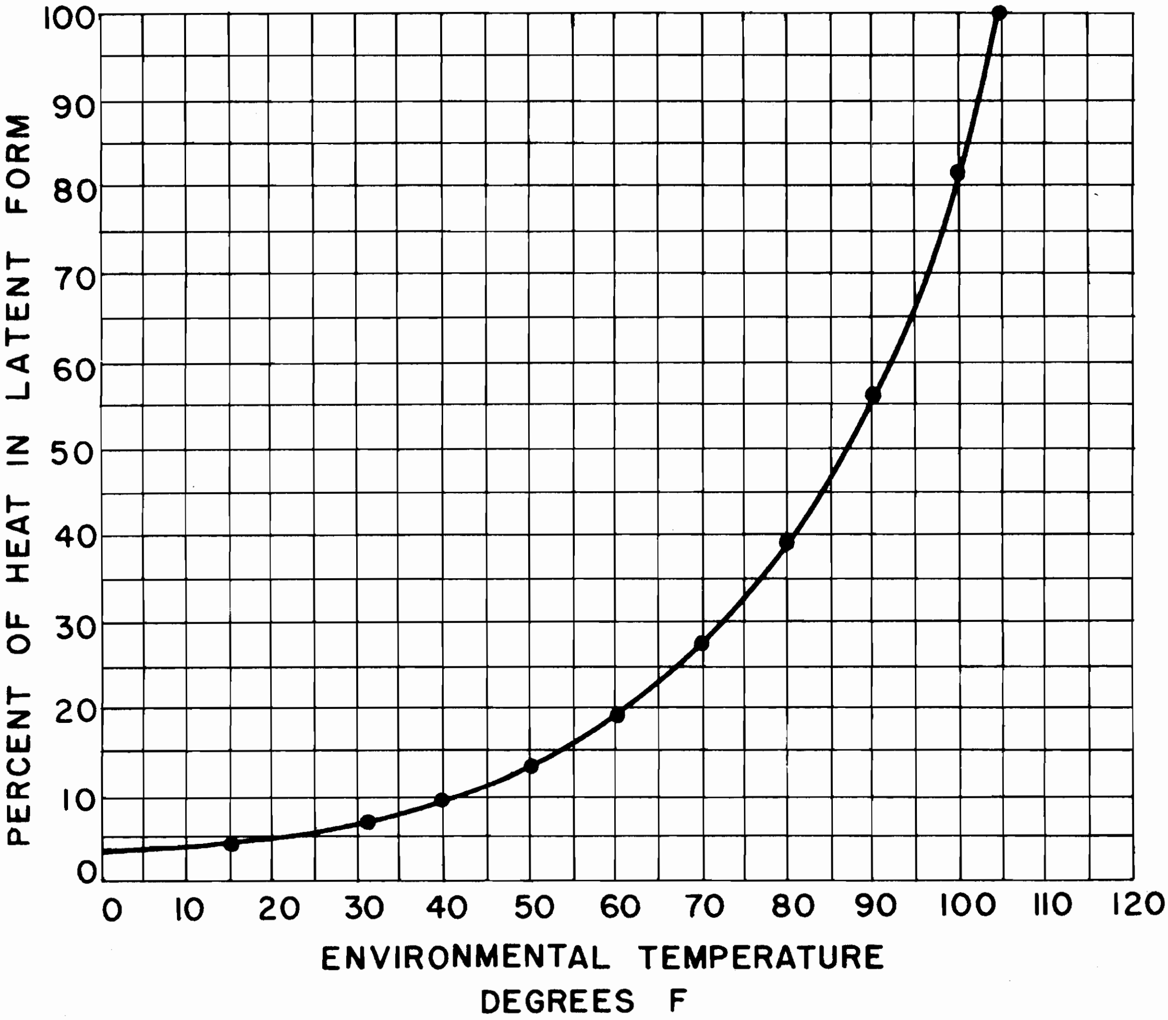


FIGURE II

[a] STRAHAN (71) AFTER MITCHELL AND KELLEY (54)

Water Expired by Chickens: Mitchell and Kelley (54) derived the following formula from Hari's respiration experiments on geese reported in 1917.

$$W = 7.14\, e^{0.06438t}$$

Where:

W is the percentage heat production which is dissipated as heat of vaporization of water.

t is the temperature in °C.

They stated that the temperature range for Hari's experiments was 60 to 104 °F. The per cent of total heat in latent form versus temperature from this equation is shown in Figure II.

The amount of water expired at a given temperature may be calculated if the total heat production is known. For example, if a hen produces 50 Btu/hr at 40 °F, the heat produced in latent form is 5 Btu/hr; that is, 10 per cent of the total heat (see Figure II). Five Btu/hr divided by 1033 Btu/lb (the heat of vaporization of water at the chicken's body temperature, 106 °F) equals 0.00484 pounds of water expired/hour. This calculation shows that the water expired is directly proportional to the per cent of heat in latent form. According to this information the quantity of expired moisture increases with temperature as illustrated in Figure II.

Barott and Pringle (3) indicated from their basal metabolism experiments, that below the temperature for basal metabolism, about 70 °F for hens in their experiments, the rate of water respiration is practically constant and as near as their chart can be read, amounts to 0.60 milligrams of water/gram of live weight/hour (0.0144 pounds/pound of live weight/day). This does not agree with Mitchell and Kelley's (54) work which indicated a continuous rise in water expired as the temperature increased.

Since the data used by Mitchell and Kelley (54) was obtained in experiments on geese above a temperature of 60 °F, the basal metabolism work of Barott and Pringle (3) seems to be the best information available on moisture respiration and will be used herein as the water expired by chickens. The moisture expired by chickens of various sizes was calculated from Barott and Pringle's (3) data by the author and tabulated in Table II.

Since the droppings are warm when voided, some water is evaporated from the droppings soon after being voided. It seems that this water vapor should be included as vaporized moisture. However, since no estimates for this factor are available, it is included in the analysis of moisture in the droppings.

Water Excreted in Droppings: Total water eliminated by chickens was calculated by Mitchell and Kelley (54). They state the water balance for chickens as follows:

Water Consumed = water vaporized + water excreted in droppings + water stored - metabolic water produced.

They assumed that the dry matter consumed by the chickens was 20 per cent indigestible and that the mixed excreta contained 27 per cent of dry matter. Also, the stored water was computed from the daily gain in weight and the metabolic water was taken as 48 per cent of the dry matter consumed. They cited research work to substantiate their estimates and calculations.

Their results were presented in grams/day/hen. The units were changed to lbs/day/100 hens and the data tabulated in Table I. It is noted that more water was eliminated than consumed. This indicates that considerable metabolic water was produced.

The water excreted in the droppings may be obtained by subtracting the water expired from the total water eliminated. This calculation was made and the results tabulated as shown in Table II.

White (79), at the Pennsylvania Experiment Station, reported on tests that included 405 birds of New Hampshire, Barred Plymouth Rock, Rhode Island Red, and White Leghorn breeds. The weight of the droppings and 76 per cent moisture content (wet basis) was given in White's results. Moisture excreted in the droppings was calculated by the writer to be 28.7 lb/day/100 hens. Data for the different breeds of hens were not given separately.

Yushok et al (85) at the New Jersey Station reported that the droppings voided by 47 White Leghorn hens in a 14 day test amounted to 259.6 pounds. Since the moisture content was 77.8 per cent

TABLE I

WATER CONSUMED AND ELIMINATED BY HENS*

Weight in Pounds	Water Consumed (54)	Total Water Eliminated (54)	Comments
3	35.0	39.2	White Leghorns
4	41.0	47.3	White Leghorns
5	48.8	55.8	White Leghorns (males)
3	36.8	41.8	White Plymouth Rock
4	42.6	49.0	White Plymouth Rock
5	49.0	52.1	White Plymouth Rock
6	54.8	61.6	White Plymouth Rock
7	59.0	69.8	White Plymouth Rock (males)

* Water in Pounds/day/100 hens

TABLE II

WATER EXPIRED AND EXCRETED IN DROPPINGS*

Average Wt. of hens (pounds)	Total Water** Eliminated (54)	Water Expired below 70 °F (3)	Water Excreted in droppings
3	41.8	4.3	37.5
4	49.0	5.8	43.2
5	52.1	7.2	44.9
6	61.6	8.6	53.0
7	69.8	10.1	59.7 (male)

* Water in pounds/day/100 hens

** For White Plymouth Rocks; however, Table I indicates very little difference in moisture production of the two different breeds considered. It will be assumed that these figures apply to all birds of the same weight.

(wet basis) in their test, the water voided in the droppings would be 30.7 pounds/day/100 hens. This agrees rather closely with White's results.

Wheeler (77) reported that the amount of water eliminated by growing chickens varied almost directly with the protein level of the diet. He stated that increasing the amount of soybean meal or fish and meat protein resulted in proportional increases in water eliminated. The opinion was expressed that these feeds may be a factor in causing wet litter.

In an experiment at the Massachusetts Station, Sanctuary and Vondell (65) conducted tests on four pens of laying hens. Two pens were fed three parts mash and one part grain. The other two pens were fed grain and mash ad lib.; less than 1/2 mash was eaten by these birds. Those on the three parts mash ration soon had a litter moisture content of 48 per cent (wet basis) compared to 33 per cent for those on the ad lib. diet. By switching the rations for one week the moisture content of the litter changed to 49 per cent for the former 33 per cent pen and to 42 per cent for the former 48 per cent pen. This work indicates that water eliminated varies considerably with diet fed.

Jull (38) reported that tests at the Illinois Station have provided the following figures on water consumption of hens producing eggs.

First Yr. Egg Prod./Hen	180	215	230	240
Lbs. Water Cons./Day/100 Hens	25.6	42.5	46.5	49.4

Although neither the weight of the hens nor the diet was reported, this evidence indicates that the rate of lay influences the water consumed and perhaps water eliminated.

<u>Other Sources of Moisture</u>: In experiments, water spilled from waterers amounted to about three per cent of the water consumed (14, 38) and water evaporated from waterers was about two per cent of water consumed (29). This represents a rather small quantity of moisture and since the amount is not known for actual laying houses, these sources are not included in the analysis. Good management should reduce water spilled on the litter. Also, hens laying eggs may void more water in the droppings than given by Mitchell and Kelley (54); this quantity is unknown and is omitted. There is a small amount of water on the egg when laid which is evaporated; this source of water is considered negligible.

Stapleton (69) stated that unless the area was well drained water may seep in through floors placed on the ground. Giese (22) indicated that organic matter decay may cause an increase in litter moisture. However, he states that the decay process is slow; therefore, the small amount obtained from this source may be neglected. Rain and snow, where houses are not well constructed, might be an important source of moisture.

<u>Moisture to be Removed</u>: It is assumed that for good construction, rain, snow, and ground water seepage will be negligible. Water brought in by the ventilating air must be considered, but this water

is not usually a source of moisture since the warm air leaving the house should contain at least as much water as the entering air. Thus, the main source of moisture in poultry houses is the water eliminated by the birds.

The quantity of water eliminated by chickens as given by Mitchell and Kelley (54) is about 7 to 10 pounds higher than the values presented by White (79) and Yushok et al (85). However, since the evidence indicates that the moisture excreted in the droppings varies considerably with the diet fed (65, 77) and the rate of lay (38), it seems advisable to use the higher values.

Since the upper limit of litter moisture content is considered to be 40 per cent (wet basis) (1, 14), if the droppings are dried to 35 per cent, a small factor of safety will be included. Therefore, using the moisture content of fresh droppings as 77 per cent (79, 85), the amount of water to be evaporated from the droppings and removed by ventilation is calculated as follows:

53 pounds of water excreted in droppings of 100 six-lb. hens/day

$\frac{53}{0.77}$ = 68.9 as the weight of droppings at 77 per cent M. C. (wet basis)

68.9 - 53 = 15.9 pounds of dry matter in droppings

$\frac{15.9}{0.65}$ = 24.4 pounds as weight of droppings at 35 per cent M. C. (wet basis)

24.4 - 15.9 = 8.5 pounds of water remaining in droppings at 35 per cent M. C. (wet basis)

53 - 8.5 = 44.5 pounds of water to be evaporated from the droppings

The water to be evaporated from the droppings plus the water expired equals the total water to be removed by ventilation. The water to be removed by ventilation based on these calculations is given in Table III.

In these estimates no allowance has been made for water absorbed by new litter added to the house or the water that may be removed in wet litter; such factors cannot be estimated without specific information on each problem. The design engineer may include such values when applicable; however, the water to be removed as presented in Table III is suggested for general design.

Diffusion of moisture through walls has been mentioned as a means of moisture disposal (69). If vapor barriers are used with insulation, as recommended for good construction, this value should

TABLE III

TOTAL WATER TO BE REMOVED BY VENTILATION*

Average Wt. of hen (pounds)	Water to be ** evaporated from droppings	Water expired below 70 °F (3)	Total water to be removed by ventilation
3	31.5	4.3	35.8
4	36.3	5.8	42.1
5	37.7	7.2	44.9
6	44.5	8.6	53.1
7	50.1	10.1	60.2 (males)

* Water in Pounds/day/100 hens

** See Table II

be very small; therefore, in the absence of better information and as an additional safety factor, diffusion of vapor through the walls is neglected.

Heat Balance:

Since heat is more critical during periods of low outdoor temperature than at any other time, this analysis deals with the coldest design periods. The sources of heat considered are:

1. Produced by birds
2. Generated in litter
3. Radiated from sun
4. Transferred from earth through floor

Heat dissipation is considered at follows:

1. Transferred through walls and ceiling
2. Removed by ventilating air
3. Used as latent heat to evaporate moisture

Heat Produced by Chickens: Mitchell and Kelley (54) made estimates of the heat production of active, non-producing hens (See Figure III). The estimates were based on the following:

1. Basal heat production was taken from previous research (53).
2. Heat due to voluntary activity was assumed to be approximately one half the basal heat on the basis of work reported by Mitchell, Card, and Hamilton (52).
3. The heating effect of the feed was taken as 68 calories/100 grams of dry matter consumed. This is the heat increment of wheat for chickens (54).

HEAT PRODUCED BY CHICKENS VS. BODY WEIGHT

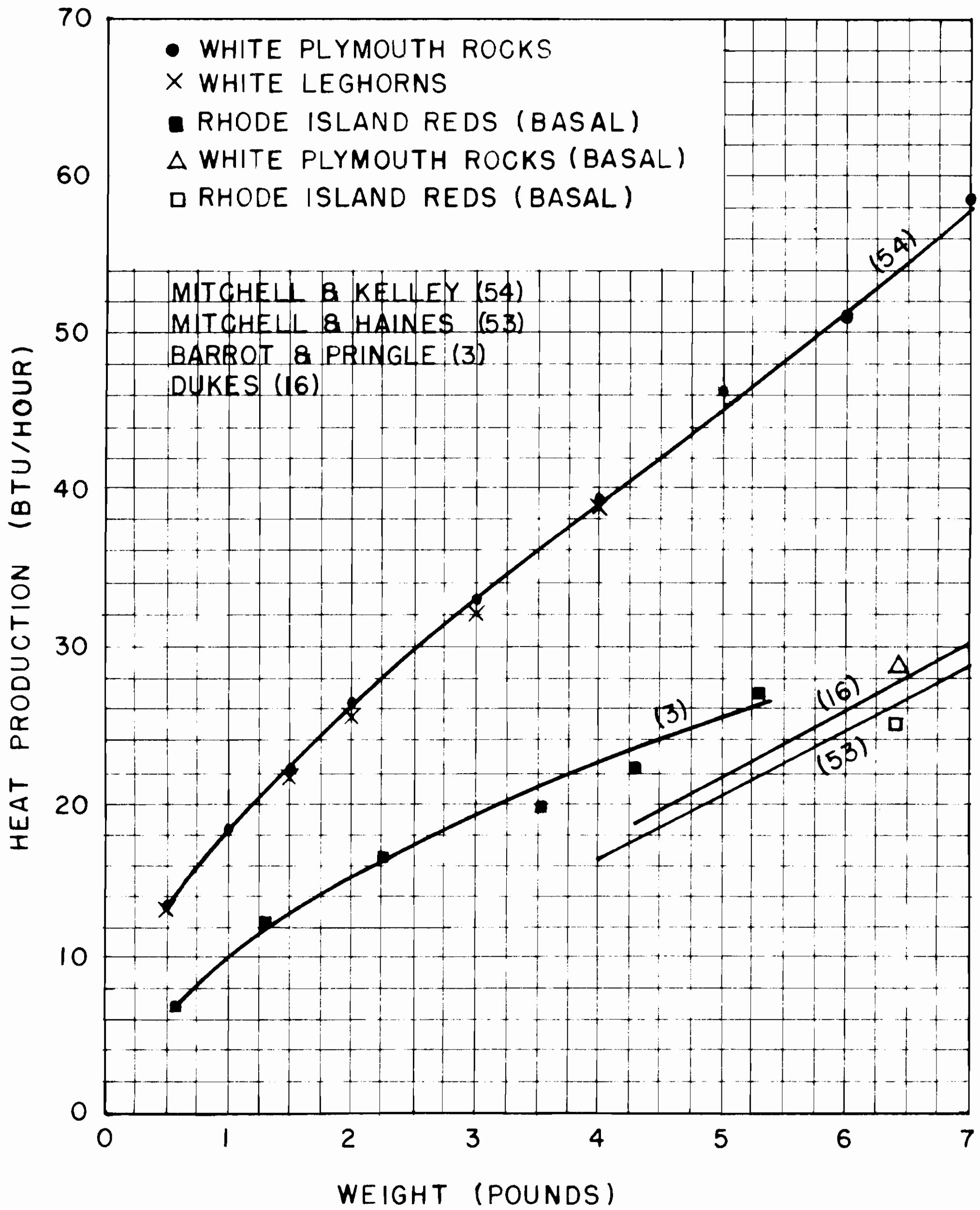


FIGURE III

They recognized that an increment of heat should be added for hens producing eggs, but no allowance was made for egg production in their estimates. Near the end of the work they estimate that the energy requirement of the hen is increased by 95 calories and heat production by 23 calories on the day in which an egg is produced. Thus the heat production would be increased 3.8 Btu/hr if an egg were produced each day.

Barott and Pringle (3) reported on the basal metabolism of Rhode Island Red chickens from hatch to one year of age. A curve, based on their work, showing the basal heat production at a temperature of 80 °F is shown in Figure III. No estimates were made for active, producing hens.

Dukes (16) gives the average basal metabolism for mature hens over 12 months of age, at a temperature of approximately 75 °F, as 2.4 calories per kilogram of body weight per hour; which amounts to 4.315 Btu/lb of body weight/hr when engineering units are applied. This value is plotted in Figure III. A small increase in heat production was noted for laying hens, but Dukes stated that no conclusion as to the amount could be drawn from his work. He points out that his work agrees closely with Mitchell and Haines (53) who reported an average basal heat production of "54.9 calories per day per Kilogram of body weight" for non-laying hens. This quantity is equal to 4.11 Btu/lb of body weight/hour (See Figure III).

It appears that the basal heat production measured by Mitchell and Haines is verified by Dukes and is closely related to the values found by Barott and Pringle. The slightly higher values presented by Barott and Pringle may be due to the younger chickens used in their work. Mitchell and Kelley (54) used the basal heat production of Mitchell and Haines (53) in estimating the heat produced by active non-laying hens. Thus, the basal heat production used in Mitchell and Kelley's (54) estimates for non-laying hens seems to be approximately correct.

Recent calorimeter tests reported by Ota et al (59) give the total heat production of active five-lb. laying hens as 53.5 Btu/hr at a temperature of about 40 °F. Mitchell and Kelley calculated the heat production of active five-lb. non-laying hens as 46.2 Btu/hr with about 3.8 Btu/hr to be added for the day that an egg is produced. The environmental temperature for Mitchell and Kelley's (54) data is presumed to be that of basal metabolism, 62 °F in the work of Mitchell and Haines (53). Chickens produce more heat at low temperatures (3,59). Thus, for the lower range of temperatures, with which this report is concerned, it seems that the estimates made by Mitchell and Kelley are on the conservative side.

Barre and Sammet (4) used heat production estimates made by Mitchell and Kelley (54) to approximate the heat production of a four-lb. hen when laying eggs. Mitchell and Kelley's estimate of heat production for a non-laying four-lb. hen was approximately

40 Btu/hr. This estimate was based on the heat production for maintenance, voluntary activity, and a heat increment of feeding 72 g. of dry matter per day. Barre and Sammet (4), taking values of feed consumption from Jull (38) as 109 g. per hen per day for hens producing 375 eggs per year and assuming the heat production proportional to the feed consumed, arrived at 60 Btu/hr for the heat production of a four-lb. hen when producing eggs. That is, $\frac{40}{x} = \frac{72}{109}$; $x = 60$. They admit that this proportion is a rough assumption.

In an analysis of the poultry ventilating problem, Giese (22) states that research by Mitchell and Kelley (54) and Barott and Pringle (3) indicates, "the average heat production for a 4-lb. hen is 40 Btu per hour. This is considerably lower than suggested by Sammet and Barre . . . . but has been verified in correspondence from Barott who states further that combustion of fat gives over twice as much heat as the combustion of carbohydrates or protein for the same unit weight." From this statement it seems that the estimate of Barre and Sammet (4) may be high. Apparently the estimates of Mitchell and Kelley represent the best information available and their values will be used in this analysis.

Other Sources of Heat: Litter decomposition was considered an important source of heat by Stapleton and Cox (68). These men, after conducting a heat balance test on a poultry house containing 140 six-lb. hens, concluded that 2284 Btu/hr was produced in the litter. In the writer's opinion, their conclusions were not completely valid since solar radiation and especially heat production of the chickens could not be definitely determined. Furthermore, handbook values for air infiltration and calibrated electric fans were used to determine the air change; it is known that the wind might affect these values considerably. Heat production was obtained from Strahan (71) who had used the estimates made by Mitchell and Kelley (54). Therefore, it seems that some heat was produced in the litter, but that the amount is uncertain.

Analysis of Heat Available: Little information is available on the heat produced in deep litter. New shallow litter would produce very little heat, if any. Therefore, this heat source, where available, is considered as a factor of safety. Heat from the earth may help considerable in preventing rapid temperature drops during short cold spells. As no information is available on this topic, this source is likewise considered as a factor of safety.

Since the coldest periods usually occur as night, solar radiation will not be considered as a source of heat. Thus, the heat produced by the chickens is the only source of heat used in this analysis for design during the critical cold periods.

Mitchell and Kelley (54) suggested that 3.8 Btu/hr be added to their estimates of heat production for the day in which an egg is produced. After talking with poultrymen, it seems advisable to add about 3 Btu/hr/hen since not all hens would lay each day. The larger increase of heat production used by Barre and Sammet (4) for laying hens does not seem to be justified.

Part of the heat produced by chickens is given off as latent heat in the expired moisture. For example:

Six-lb. hen expires 0.00358 lb. moisture/hour (Table II)

Heat of vaporization at body temperature of hen = 1033 Btu/lb.

0.00358 x 1033 = 3.7 Btu/hr

This amount must be subtracted from the total heat in order to get the sensible heat produced. On the basis of the above information, the sensible heat produced has been computed as shown in Table IV.

Barre and Sammet (4) subtracted a portion of the sensible heat produced by hens as an allowance for evaporation of water from the litter. During cold snaps, unless the cold outside air is allowed to infiltrate under the floor, the air temperature in the house will be lower than the temperature of the litter; therefore, no allowance should be made for transfer of heat to the litter when designing for critical cold periods. Thus, the sensible heat available for the coldest design periods is taken as the heat produced by the birds as given in Table IV.

Since chickens produce more heat in cool environments, it is believed that the values in Table IV are conservative; as such, they should be applicable for use, with safety, in the coldest periods of winter.

TABLE IV

HEAT PRODUCED BY HENS*

Average Weight of hens (pounds)	Heat produced by non-laying hens (54)	Heat produced [a] by laying hens	Latent heat [b] produced	Sensible heat produced
3	33.0	36.0	1.8	34.2
4	39.3	42.3	2.5	39.8
5	46.2	49.2	3.1	46.1
6	51.2	54.2	3.7	50.5
7	58.5 (males)	----	4.4	54.1

* Heat in Btu/hr/hen

a Calculated by adding 3 Btu/hr to column 2

b Calculated from the repired moisture as given by Barott and Pringle (3)

Indoor Design Temperature:

Willham (80) reporting research at the Oklahoma Panhandle Experiment Station states, "Long continued trends in temperature either downward or upward do not seem to effect egg production nearly as much as the sudden changes either downward or upward. The changes in trend downward seem to effect the egg production more than the changes upward."

Huttar et al (34) conducted tests in New York state using two 20' x 20' pens; one pen was insulated. The uninsulated and the insulated pens maintained a temperature difference of about 12 °F and 20 °F, respectively. He concluded that temperature drops caused a check in egg production and that the activity of the birds decreased and production lagged when the temperature went below 10 °F for more than three or four hours.

Mayer and Carrick (49) at the Indiana Experiment Station reported temperatures as low as -8 °F inside open front houses. In a brief report, concerning these low temperatures, they state, "This resulted in a drop in egg production from December to February of over 50% in the uninsulated partially open front pens, a drop of 37% in the insulated pens and no decrease in the production in the heated pens where temperatures above 40 °F were maintained."

Bruckner (12) summarized Cornell University's research work on environmental temperature. Parts of his summary are quoted as follows:

"Single Comb White Leghorn pullets can adjust themselves to different environments readily, providing the change is not too sudden and too extreme.

"Sudden and extreme drops in temperature affect mash consumption materially, grain consumption shows a slight increase as a rule. Total food intake is lowered slightly.

"If a poultry house is to be artificially heated, temperatures between 35 degrees and 50 degrees are to be preferred to those above 50 degrees.

"The use of temporary sources of heat during cold weather gives promise of being a practical method of preventing production slumps during sudden cold waves. This practice failed to increase winter egg production significantly."

Gutteridge et al (25) presented data obtained from four years of research at Ottawa, Canada on heated, insulated, semi-insulated, and uninsulated pens. No significant difference is noted in the egg production records for the different pens. Gutteridge comments on the study as follows:

"Experiments covering four years have consistently shown as high egg production in uninsulated, unheated pens as under conditions of heat or insulation. Mean temperatures in the pen during the winter months of 37.8 °F, 39.1 °F, and 42 °F gave as high egg production as did those of 45.3 °F, 50.6 °F, or 59.9 °F. Body weight gain also was not affected by temperatures within this range, variations which did occur being obviously unrelated to environmental temperature and caused by other factors.

"It is concluded that laying pullets will produce well under a very wide range of temperatures and conditions of humidity, and that neither artificial heat nor insulation, as herein defined, would be justified under temperature conditions similar to or less severe than those experienced in this area. These conclusions have been arrived at under conditions of severe cold and therefore constitute a severe test of the housing conditions investigated."

It is of interest to note that the uninsulated pens contained considerable insulation according to Virginia standards. Also the pens were in a continuous row with interior partitions between the heated, insulated, and uninsulated pens in that order. Although the outside minimum temperatures each year were -25 °F, -38 °F, -19 °F, and -21 °F, the indoor minimums were only 10 °F, 16 °F, 26 °F, and 20 °F, respectively, for the uninsulated houses. In several cases there was little or no difference of temperature in the different unheated pens. Temperature fluctuations or the frequency of low temperatures were not given for the various pens. This does not seem to represent a true test of the severe outdoor conditions. It does indicate that hens may lay as well in unheated as in heated houses provided there are no sudden severe changes in the house temperature.

Using the average weekly outside temperature as recorded at a local weather station, Hays (27) working at Amherst, Massachusetts reported on winter pause incidence of laying hens. Winter pause is defined as the cessation of egg production from November 1 to March 1. He states that winter pause decreases annual egg production. From observation covering ten years and over 2,000 Rhode Island Red hens, he states, "Low temperatures of winter seem to stimulate a higher incidence of pause." Complete housing conditions were not specified.

Research reported by the U. S. D. A. (61) is quoted as follows:

"In poultry-house tests at Beltsville relating to the effect of heat and humidity on egg production, 6 tests were conducted, each with 10 laying hens. One pair of tests was at 55 °F, another at about 82 °F, and a third at about 36 °F. Greatest egg production and eggs averaging the most weight were from 13-month-old hens in an environment of 36 °F and 75% relative humidity and from 10-month-old hens at 55 °F and 68% relative humidity."

Barre and Sammet (4) as agricultural engineers considered the proper design temperature for poultry laying houses. They state than an optimum temperature has not been established; however, research indicates that above 70 °F or below 10 °F production is adversely affected. Since the problems of freezing water fountains and comfort for workers must be faced, they assumed a temperature range of 30 to 70 °F as desirable temperatures.

Ashby et al (1) in a U. S. D. A. summary of poultry house design features gives Table V as a guide to minimum temperatures in laying houses. The zones given in the table are from the U. S. D. A. zone map and range from 1 in the north to 4 in the south.

TABLE V

RECOMMENDED INDOOR MINIMUM TEMPERATURE FOR POULTRY (1)

Zone	Ordinary °F	Extreme °F
1	32	15
2	40	20
3	45	25
4	50	32

Since this work is concerned with winter ventilation only, the research work on high environmental temperatures and egg production is not reviewed here.

No definite environmental temperature standards can be established from the research data reviewed. However, the data substantiates the conclusion of Barre and Sammet (4) that below 10 °F or above 70 °F production is decreased. They raised the lower limit to 30 °F in order to prevent freezing of water and to provide more comfortable working conditions. Thus, for ordinary weather, the practical range of indoor design temperatures is considered as 30 to 70 °F. During extremely cold snaps, a minimum of 25 °F or even 20 °F might be more economical for Virginia conditions than providing heat or extra insulation for the few extremely cold periods.

The evidence indicates that sudden temperature fluctuations should be avoided. It seems that low temperatures are not as detrimental to egg production as rapid changes in temperature.

Indoor Design Relative Humidity:

Smith (66), at the Nebraska Experiment Station, reported research covering eight houses of birds for a period of seven years. His conclusions stated, "No correlation was found between humidity and winter egg production."

Huttar et al (34), in tests already mentioned, states, "Relative humidity, ranging from 40 per cent to 95 per cent but never remaining above 90 per cent longer than twenty-four hours, seemed to have no effect on pen conditions or on the activity of the birds throughout this test."

Gutteridge et al (25) reported that, "Restriction of ventilation to a minimum, all ventilators being completely closed with a resulting temperature of 45.6 °F and very high humidity and carbon dioxide content of the air had no detrimental effect upon egg production."

Lippincott and Card (48) in their text book, Poultry Production, state, "There is no condition under which poultry is kept, unless it is a state of starvation, that is more surely and quickly fatal to profitable production than dampness in the roosting and scratching quarters."

At another point, "Damp air compels fowls to increase their already rapid respiration. It is not uncommon to see chickens, confined in a damp house, panting on a day that is rather cold. That such a condition is undesirable is so obvious as to need no argument. Relative humidity in an ideal poultry house would never exceed 75, or perhaps 80 per cent."

Oliver (58) in his theoretical analysis of air flow in poultry houses states, "Most litter material will remain relatively dry where the relative humidity of the air next to the litter is 80% or less, and will still be quite serviceable where 90% relative humidity prevails part of the time." He gives no experimental evidence to verify his statement.

As an aid in determining the value of relative humidity that should be used for design, actual relative humidity records were checked on three available experiments. Otis and White (60) at the University of Minnesota experimented with insulated houses and natural draft ventilation. The relative humidity ranged from 70 to 90 per cent during January and February. Most of the time the relative humidity was between 75 and 85 per cent. In the cooler periods of inside temperature, the relative humidity was in the higher range (near 85 per cent) and during the warmer periods, the relative humidity was in the lower range (near 75 per cent). This was a well insulated two story house and the inside temperatures ranged from about 45 to 65 °F as the outside temperature varied from about -15 to 40 °F.

White and Schwantes (78) at the Minnesota Agricultural Experiment Station presented continuous records of relative humidity for six two-week winter periods. The relative humidity varied from about 70 to 87 per cent with an approximate average of 80 per cent. The houses were well insulated. Natural draft, straw loft, and fan ventilating systems were used. No comparison could be made for the different ventilating systems since the weather was not the same for all charts.

Bates (6) shows six hour averages of relative humidity in two 20' x 20' poultry houses at Cornell University. House A, equipped with a single speed fan, had an average heat transmission coefficient of 0.137 and house B with natural draft ventilation possessed an average heat transmission coefficient of 0.29. In house A with a 300 cfm air change the relative humidity ranged from 58 to 82 per cent with a weekly average of 74 per cent. For the same outside conditions, in house B the relative humidity ranged from 59 to 80 per cent with a weekly average of 73 per cent. For a one week period of the year before, in house A, with a ventilating rate of 520 cfm, the relative humidity ranged from 45 to 83 per cent with a weekly average of 70 per cent. For the same outside conditions, house B had a range of relative humidity from 49 to 81 per cent with a weekly average of 69 per cent. The records of temperatures and relative humidities from Bates' (6) work are reproduced in Figures VII and VIII in the appendix.

Bates states that in 1950 the condition of the litter in house A was better than in house B. One high value in the litter moisture contents is stated as 37 per cent in A and 41 per cent in B. Also, "The birds could scratch the litter in A readily while it was difficult for them to do so in B." Since there was very little difference in the relative humidity in the two houses, other factors must have contributed to the condition of the litter in the houses.

The analysis of research literature fails to show any correlation between relative humidity and egg production.

Since maintaining dry litter is a major objective of ventilation, an absolute maximum of 90 per cent will be considered as satisfactory for short periods; ordinarily, a maximum of 80 per cent will be used for design. These maximums are in general agreement with reports of the various investigations and the actual conditions reported in insulated houses.

No minimum relative humidity will be set, since under winter operation, unless heat is added, the lowest relative humidity obtainable will not be too low.

Outdoor Design Temperature:

Only one reference to a method of determining outdoor design temperature was found. Barre and Sammet (5) state, "Outdoor design temperatures for heating usually are assumed as 15 °F higher than the extreme recorded low temperature for the locality, although this guide cannot be applied uniformly."

The extreme low temperature for Blacksburg, Virginia was -27 °F on December 30, 1917. This would give a temperature for design of -12 °F if the above recommendation were followed. It is evident that such a low design temperature is not practical in this area.

Since no information was available on outside design temperatures for animal structures, a study of actual weather records for Blacksburg, Virginia was undertaken. The range of temperatures from -5 °F to 20 °F were considered. Minimum temperatures and the amount of time that the temperature remained below -5, 0, 5, 10, 15, and 20 °F were recorded from Agricultural Experiment Station Records. A twelve year continuous temperature record from November 1, 1940 to April 1, 1952 was examined. (The data for temperatures below 10 °F are given in Table VI in the appendix). It appeared that approximately 5 °F would be a satisfactory outdoor design temperature. Therefore, the data was analyzed for the number of expected failures if 5 °F were considered the design temperature. A failure was counted when the temperature remained (a) between 3 and 5 °F for ten hours or more and (b) below 3 °F for three hours or more.

The results showed eight failures in 12 years or an average of 0.667 failures per year. Drs. R. A. Bradley and D. B. Duncan of the statistics department indicated that a Poissom distribution should apply to this type of data; if so, the following calculations apply:

$$\bar{x} = \frac{8}{12} = 0.667$$

$$s^2_{\bar{x}} = \frac{0.667}{12} = 0.0556$$

$$s_{\bar{x}} = 0.236$$

Where:

$\bar{x}$ is the average number of failures per year, and

$s_{\bar{x}}$ is the standard variation, accurate for two years in three.

Therefore, the expected number of failures per year should fall between 0.431 and 0.903 two-thirds of the time. Several of the failures counted in the analysis were for two, three, and four degrees, which are not considered to be severe. Thus, 5 °F is taken as the outdoor design temperature for Blacksburg, Virginia.

In the writer's opinion, other sections of the state may use this information by making comparisons according to the weather in their locality. Since 0 °F is recommended for residential heating design at Blacksburg, Virginia (28), it appears that the practical winter design temperature for poultry ventilation may be considered as five degrees higher than the heating design temperature where the temperature fluctuations are similar to those at Blacksburg. In the writer's opinion, this general analogy should only be applied in adjacent states or with caution in other areas.

Outdoor Design Relative Humidity:

Barre and Sammet (4) used an outdoor design relative humidity of 80 per cent for the purpose of drawing their air flow chart. No research information was found on this particular topic. Since a relative humidity of 100 per cent exists during rainy or foggy periods and these conditions may last for several days, 100 per cent relative humidity will be used for design during the critical periods. It is believed that this value should be applicable to the humid east.

The Wet Litter Problem:

The water eliminated in the droppings must be evaporated from the litter before it can be removed by ventilation. According to Thornthwaite (73), evaporation of moisture from a free water surface is proportional to the difference in the vapor pressures at the water surface and the vapor pressure of the overlying air. Ashby et al (1) state that this basic principle applies to evaporation of water from poultry litter. The amount of exposed surface area and air movement also affect evaporation. Therefore, the following points are considered aids to evaporation of litter moisture.

1. Lower absolute humidity of the air. There is less water in air of low relative humidity and low temperature.
2. Higher moisture content of litter, up to a point near saturation.
3. Higher temperature of litter; heat is a critical factor.
4. Air movement; which serves to bring air of lower absolute humidity into contact with the litter.
5. Stirring the litter; which usually brings litter with higher moisture content into contact with the air.
6. Maintaining a rough surface so that a greater surface area will be exposed to the air.

If the litter is to remain dry, heat must be provided for the evaporation of moisture from the droppings. This heat may be transferred to the litter or generated in the litter. According to Stapleton and Cox (68) a rather large amount of heat is generated in deep litter.

White and Schwantes (78), who conducted tests on well insulated laying houses in Minnesota, stated that in four houses the litter became objectionably wet until built-up litter was used. After this the litter remained in good condition. In one other similar house the litter became objectionably wet and was changed every three to five weeks.

Winter (83), Kennard et al (41, 42) and James (35) advocated built-up litter on the basis that it produced some heat, remained dryer, and did not have to be changed until the end of the season. These men also presented information on built-up litter management practices.

Concerning the decomposition and possible heat production of built-up litter, the author consulted a bacteriologist, Dr. F. S. Orcutt of Virginia Polytechnic Institute. He stated that anerobic bacteria produce considerably more heat than aerobic bacteria; therefore, conditions that promote the growth of anerobic bacteria should be best from the standpoint of heat production in the litter. These conditions are: (a) no oxygen, (b) high temperatures, (c) high moisture content, and (d) large numbers of bacteria for starting the process.

Some poultrymen have been rather cautious in recommending built-up litter because they believe it presents a disease hazard. Dr. P. P. Levine (46) of the New York Veterinary College, in personal correspondence, expressed his opinion that litter should not be reused for rearing young chicks. He did not express an opinion on laying hens.

According to Dr. W. B. Gross, a poultry disease specialist at Virginia Polytechnic Institute, the most important litter problem, from the standpoint of disease, is to keep the litter dry. He stated further that unless litter is kept in a dry condition it constitutes a definite health hazard; this is particularly true for internal parasites and is probably more serious when deep litter is employed.

From the standpoint of ventilation, any heat produced in built-up litter would be helpful in evaporating and removing moisture. It is generally known that some heat is produced in deep litter, but the amount of heat from this source is uncertain and perhaps quite variable. Although it appears that the ventilation problem would benefit from the use of built-up litter, it is left to poultrymen to recommend this practice and to give advice on proper management practices.

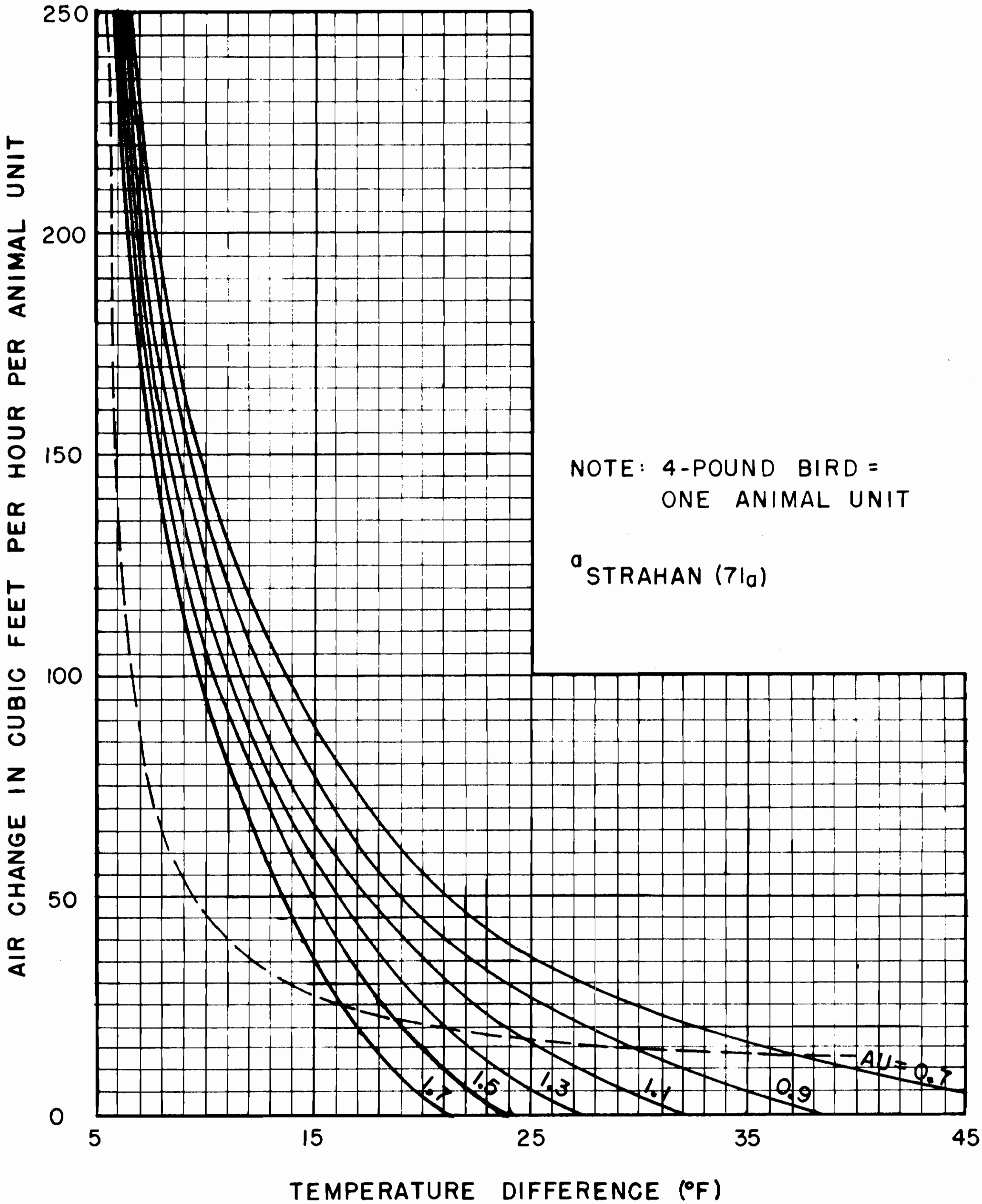
<u>Engineering Literature</u>:

Mitchell and Kelley (54) suggested the application of the heat balance and moisture balance equations to poultry house ventilation. In their analysis they considered the removal of expired moisture, but neglected the moisture in the droppings. Other writers have since pointed out that the moisture in the droppings must be removed by ventilation if dry litter is to be maintained.

Strahan (71a), using the heat and moisture production data presented by Mitchell and Kelley (54), further analyzed the poultry house ventilation problem. In order to explain Strahan's analysis, his air flow chart is reproduced in Figure IV. On the chart, "A" represents the square feet of exposed surface per animal unit (four-lb. bird), and "U" represents the average heat transmission coefficient expressed in Btu/hr/ft^2/^{o}F. In the construction of this chart, Strahan used the total heat production of four-lb. birds as 38.9 Btu/hr; 7.9 per cent of this heat being in latent form. A temperature of 35 ^{o}F was used to estimate the expired moisture.

According to Strahan the solid curves on the chart represent the way the air flow must vary in order to maintain a constant temperature of 35 degrees in poultry houses with "AU" values as shown on the curves. The dotted line shows the air flow required to remove the respired moisture with inside conditions of 85 per cent relative humidity and a temperature of 35 ^{o}F, and outside conditions of 100 per cent relative humidity and temperatures as indicated by the temperatures difference from the 35 ^{o}F inside temperature. The moisture curve is limited strictly to these conditions and may not be used for other temperatures and relative humidities. If the sensible heat produced is correct, the air flow curves should apply for temperatures up to about 70 ^{o}F.

AIR FLOW CHART[a]



NOTE: 4-POUND BIRD = ONE ANIMAL UNIT

[a]STRAHAN (71a)

FIGURE IV

In Figure IV, it is noted that the dotted line for removing respired moisture crosses each solid line for temperature control at only one point; this shows clearly that for a given set of conditions only one rate of air flow will satisfy both the heat balance and the moisture balance equations. Furthermore, when the outside temperature changes from the given point where these lines intersect, no rate of air flow will satisfy both equations.

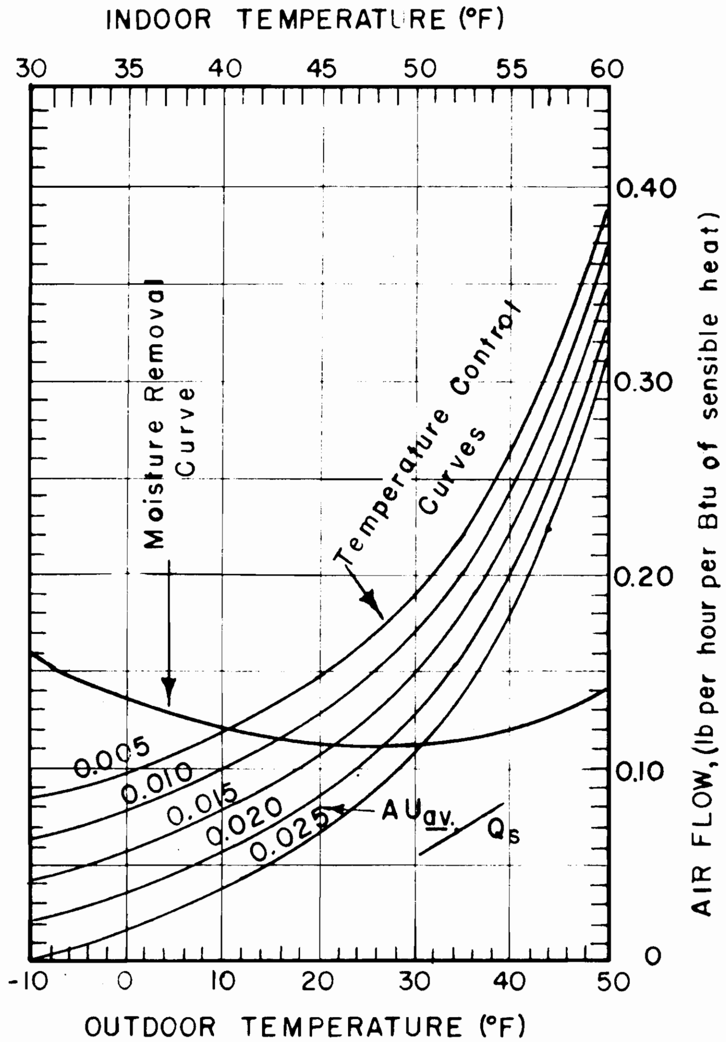
It is also evident that if a constant inside temperature is to be maintained, the air flow must be variable; it must decrease and increase directly with the outside temperature.

Barre and Sammet (4) presented a graphical analysis (Figure V) of the heat and moisture balance equations with the expressed purpose of application to poultry ventilating problems. This particular chart has several limitations in its application:

1. The relation of inside temperature to outside temperature is fixed.
2. The curve for moisture removal applies only when the inside and outside relative humidities are 80 per cent.
3. Several calculations are necessary to use the chart. Furthermore, no information on sensible heat available, except that produced by four-lb. birds, is presented.

In order to use the chart the indoor or outdoor design temperature is chosen, the other temperature is fixed and may be located by following a vertical line to the opposite side of the

AIR FLOW CHART[*a]



*AIR FLOW BASED ON FOLLOWING:

NO CONDENSATION, LATENT HEAT EQUIVALENT = 17 BTU PER HEN PER HOUR, SENSIBLE HEAT 43 BTU PER HEN PER HOUR, TEMPERATURE VARIATION AS INDICATED, MAXIMUM RELATIVE HUMIDITY 80%.

[a] BARRE & SAMMET (4)

FIGURE V

chart. The exposure ratio, AU_{av}/Q_s, must be determined. The air flow which is read at the right of the chart in pounds per hour per Btu of sensible heat, must be converted to cubic feet per minute before being used for determining fan sizes.

An example of the use of this chart will suffice to illustrate the meaning of the above statements. Suppose it is desired to maintain an indoor temperature of 40 °F; then, the outdoor temperature is set at 10 °F. The value of the exposure ratio, AU_{av}/Q_s, is to be determined. AU_{av} presents no problem; it may be calculated if the house construction, insulation, and size are known. For the purpose of this problem, suppose we assume AU_{av} = 300 for a house containing 500 four-lb. hens. According to their method of analysis, the available sensible heat, Q_s, would be obtained by the following procedure.

Mitchell and Kelley give the total heat production as approximately 40 Btu/hr for a four-lb. hen not producing eggs. As previously explained Barre and Sammet assumed the heat production for laying hens to be proportional to the feed consumed. By this method they calculated the total heat production for a four-lb. hen to be 60 Btu/hr. Part of the total heat is in latent form in the expired moisture; thus, the latent heat (approximately ten per cent at 40 °F according to the method used) must be subtracted since it is not available to heat the house. Furthermore, they estimated the heat necessary to evaporate moisture in the droppings as 11 Btu/hr/hen and this value was also subtracted from the total heat produced. Therefore, the total sensible heat production is equal to the total heat production minus the 11 Btu/hr/hen allowed for the evaporation of moisture and also minus the 6 Btu/hr/hen which is given off in the expired moisture. The result is approximately 43 Btu/hr/hen or 21,500 Btu/hr for 500 four-lb. hens. This quantity is the total sensible heat to be used for design.

Back to the problem; we now divide 300 by 21,500 to get:

$$AU_{av}/Q_s = 0.014$$

Start with 10 °F at the bottom of the chart and proceed vertically to an AU_{av} of 0.014; from this point move horizontally to the right side of the chart and read the air flow as 0.083 lbs. of air/hr/Btu of sensible heat produced.

To convert the ventilation rate to a useful figure multiply by Q_s = 21,500 and change pounds/hour to cubic feet/minute.

$$CFM = \frac{(0.083 \text{ lbs/hr/Btu})(21{,}500 \text{ Btu})(12.67 \text{ ft}^3/\text{lb})^*}{60 \text{ min/hr}}$$

CFM = 376 which is the final answer for the ventilating rate to maintain 40 °F when the outdoor temperature is 10 °F.

The fact that the point of intersection of 10 °F and the AU_{av}/Q_s value of 0.014 is below the moisture curve indicates

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*12.67 ft³/lb is the volume of one pound of air at 40 °F and 80 per cent relative humidity.

that the moisture is not being removed as rapidly as produced by the chickens.

Two points of interest are to be noted from this analysis and chart. First, the authors have assumed a sliding scale of indoor and outdoor temperatures so that the temperature difference varies from a large value at the lowest temperature to a small value at the highest temperatures. No effort is made to maintain a constant temperature. Secondly, an increment of heat was set in reserve as an allowance to evaporate the moisture in the droppings.

Reed (62) gave an analysis of the heat and moisture balance equations which was intended to supplement that of Strahan (70, 71, 71a). The analysis includes several detailed examples in which condensation of moisture on walls and windows was considered as an important factor. This is good material for one who desires to study the problem from a mathematical viewpoint. No additional information was gained from his analysis.

Oliver (58) stated the following purpose for his analysis.

> "What I propose to show in this article is that in certain locations, that is, where the average mean temperature during the winter months is 20 F or higher and where the relative humidity is 70 per cent or less, fan ventilation can keep the house dry; and that where the relative humidity is above 80 per cent or the mean temperature is much below 20 F, supplemental heat must be added at least a portion of the winter if dry litter conditions are to be maintained."

The writer cannot subscribe to the above statement of Oliver for two reasons. First, according to Barre and Sammet (4) with an AU_{av}/Q_s = 0.005, the moisture produced may be removed with constant outdoor temperatures as low as 10 °F. On the basis of Barre and Sammet's exposure ratio, Mr. Oliver's example house possessed an AU_{av}/Q_s = 0.0167. Using this exposure ratio on Barre and Sammet's chart, we find 23 °F as the minimum temperature for the removal of all moisture produced in the house when 80 per cent indoor and outdoor relative humidity are used. Then, for the assumed amount of insulation, Oliver is approximately correct for a constant temperature of 20 °F. However, the point is not proven for the mean temperature and the mean relative humidity.

The second reason is that mean temperatures and relative humidities are not completely valid for showing the amount of water removed from a house. At low temperatures the air holds much less water than at high temperatures. For instance, at 40 °F and 80 per cent relative humidity, the water vapor in the air amounts to 0.004169 lbs/lb of dry air; at 10 °F and 80 per cent relative humidity, the water vapor in the air amounts to 0.001180 lbs/lb of dry air. The average of these values would be 25 °F, 80 per cent relative humidity, and 0.002670 lbs/lb of dry air. Actually, at 25 °F and 80 per cent relative humidity the water vapor in the air amounts to 0.002261 lbs/lb of dry air. The error is more than 15 per cent. Since both indoor and outdoor temperatures and relative humidities are involved, the actual error for a particular day may be as much as twice this amount. It is recognized that the error for a period of one week may not be as great as indicated by the above calculation.

In order to further illustrate this point, the water removed from Cornell experimental house A was calculated from Figures VII and VIII and the results tabulated in Tables VII and VIII in the appendix. Six-hour, daily and weekly averages were considered. The results indicate that the error will be reduced over a period of one week. However, the temperatures and relative humidities in Figures VII and VIII did not fluctuate greatly and only two weeks of data were available. Therefore, no definite conclusion concerning the magnitude of the error may be drawn from this analysis.

The air flow must be variable to maintain a constant temperature or to maintain a sliding scale of temperatures as shown in Barre and Sammet's work (4). Since the ventilating rate should be higher at the higher temperatures and lower at the lower temperatures, and since much more moisture is contained at the same relative humidity in the warmer air, it is possible to remove more moisture than considered in the analysis by Oliver.

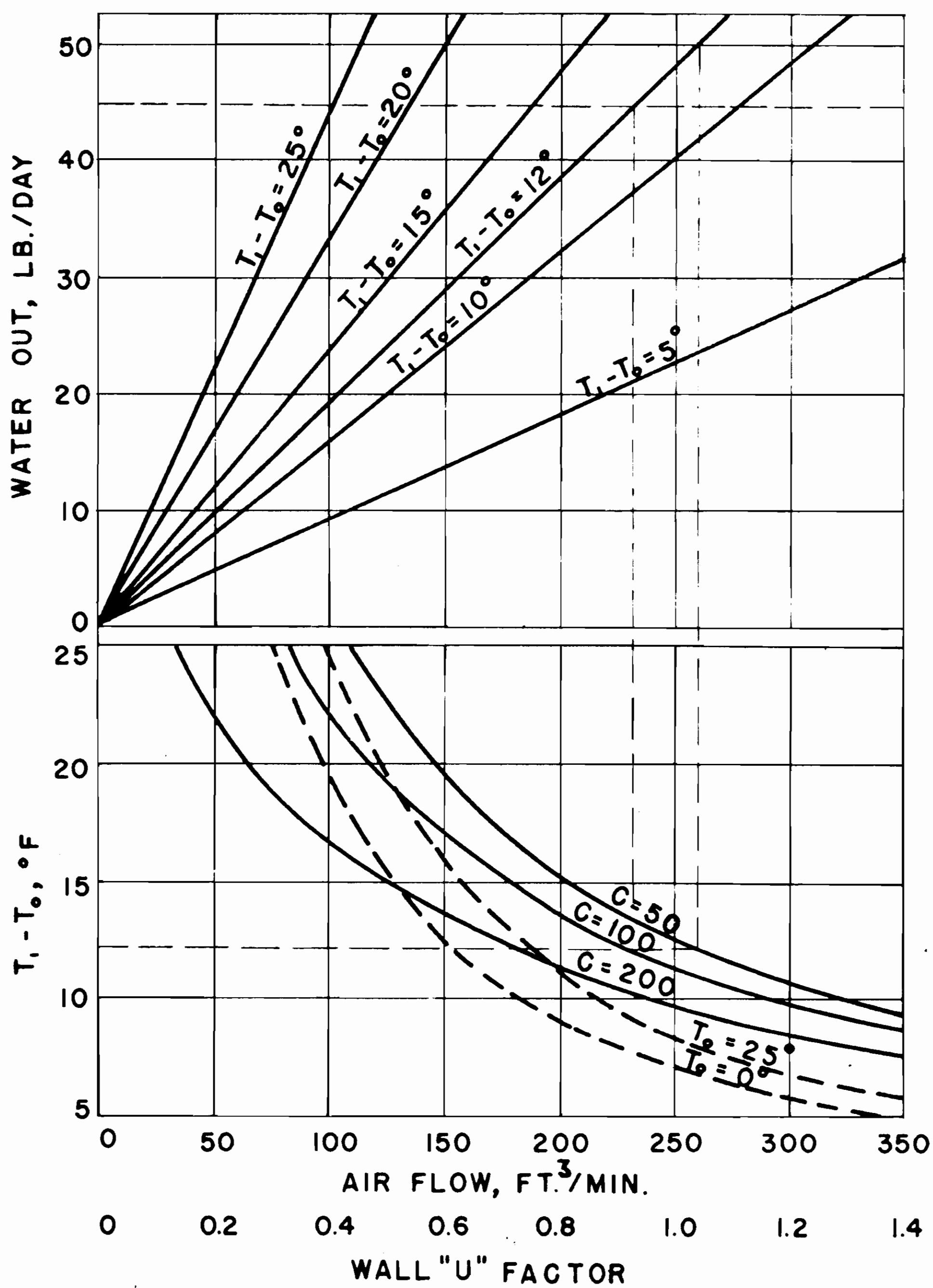
In order to correctly determine the moisture removal, the above calculation indicates that actual air flow, relative humidities, and temperatures should be considered over a shorter period of time than the daily periods assumed by Oliver.

Stapleton and Cox (68) conducted an experiment on forced ventilation of laying houses and presented calculations and design charts for 100 six-lb. hens producing 6500 Btu/hr and 45 lbs. of water per day or hens with an equivalent heat and moisture production. They state that their chart (Figure VI) may be used to determine the ventilation requirements of poultry houses. The writer interprets their article to state that other sizes of birds may be used on the chart by establishing a ratio between the heat produced and the heat for which the chart is constructed. There are three parts to the chart. The use of each part and its limitations will be explained separately.

In the bottom section of the chart, "C" represents the heat loss through the walls and ceiling in Btu/hr/°F/100 birds. As an example of chart use, suppose the temperature difference is 12 degrees for a house containing 100 six-lb. birds. Read along the light broken line to "C" = 100 or 50 and the air flow is read at the bottom of the chart as 230 or 258 cfm/100 birds, respectively. If "C" is calculated for each problem, the air flow may be determined for the usual winter range of indoor and outdoor temperatures so long as the temperature difference stays within the limits of 5 to 25 degrees.

The top section of the chart, representing water removed, is constructed for outdoor conditions of 25 °F and 70 per cent relative humidity and an indoor relative humidity of 80 per cent.

AIR FLOW CHART [*][a]



[*] FOR 100 6-LB. BIRDS

[a] STAPLETON & COX (68)

FIGURE VI

This part of the chart may be used only for these conditions. The water removed is read by proceeding straight up from the cfm, found previously, to the temperature difference lines in the top section and then to the left of the chart.

The heavy broken lines in the bottom section of the chart apply when the indoor relative humidity is 80 per cent and for outdoor temperatures of 0 °F and 25 °F. Other outdoor temperatures may be sketched on the chart. With the temperature difference and the outside temperature known, the maximum "U" value to prevent condensation may be found. For example, with a temperature difference of 12 °F proceed to the right on the light broken line to an outdoor temperature of 0 °F or 25 °F and read the maximum "U" value as 0.61 or 0.75, respectively.

The limitation of the number of hens may be overcome by simple multiplication. For instance, the ventilation required for 1000 hens would be ten times the value read on the chart. However, the limitations of heat production of chickens causes extra calculations and interpolation on the chart. The indoor and outdoor relative humidity are fixed. These limitations are a hindrance to rapid field use of the charts.

Cropsey (15) presented a mathematical solution of ventilation showing the number of air changes that would produce the lowest relative humidity. In an attempt to prove that it is theoretically possible to obtain dry litter in poultry houses even under the most adverse weather conditions in the northwest United States, he derived a formula for the relative humidity in terms of the number of air changes. The formula is stated as follows:

$$R.H. = \frac{14.75\ (0.0082 + C\ (0.326)/NV)}{0.1217 + \frac{43C\ (0.0043)}{(SU + NV\ 0.0191)} + \frac{0.000095\ (43C)^2}{(SU + NV\ 0.0191)^2}}$$

Where:

R.H. is relative humidity (per cent)

S is the exposed area of the house (ft^2)

U is the average heat transmission coefficient for the house ($Btu/hr/ft^2/{}^{o}F$)

N is the number of air changes

V is the volume of the house (ft^3)

C is the number of chickens

Since all values in the formula are constant for a given house except the relative humidity and the number of air changes, by differentiating the relative humidity with respect to number of air changes and setting the results equal to zero, the number of air changes for maximum and minimum relative humidity may be determined. Since there are several maximum and minimum points, care must be exercised in choosing the correct minimum.

Cropsey's analysis (15), originally in error, was later corrected at Norton's (57) suggestion. However, this error indicates that the formula is too difficult to be dealt with in ordinary field problems.

GRAPHICAL SOLUTION OF HEAT BALANCE AND MOISTURE BALANCE EQUATIONS

In the design and construction of graphical solutions every effort was made to provide accurate, practical solutions. The nomograph was considered to be best suited in this respect.

The equations were written as follows:

$$Nq_s = (\Delta t)\ (AU_{av} + 60Vc) \qquad \text{Formula 1}$$

$$V = \frac{W_e}{w_i - w_o} \qquad \text{Formula 2}$$

Where:

N is the number of chickens

q_s is the sensible heat available (Btu/hr/hen)

Δt is the difference between indoor and outdoor temperature (°F)

AU_{av} is the total exposed area times the average heat transmission coefficient (Btu/hr/ft^2/°F)

V is the air flow (cubic feet/min., based on 45 °F dry air)

c is the specific heat of air (Btu/ft^3)

W_e is the moisture to be removed from the house (lbs/min)

w_i is the moisture contained in the indoor air (lbs. of H_2O/ft^3 of dry air)

w_o is the moisture contained in the outdoor air (lbs. of H_2O/ft^3 of dry air)

The practical limits of the variables in each equation were determined and the scales constructed on the nomograph as specified by a text on nomography (47). The factors w_i and w_o are dependent on both temperature and relative humidity. In order to locate points on the nomograph for w_i and w_o, a chart, with temperature and relative humidity as the axes, was constructed to the left of each scale. Thus, the temperature and relative humidity may be used directly without calculations.

In order to read the air flow directly in cfm instead of lbs/min, one small error is involved in the construction of the nomographs. On the nomograph for determining ventilating rates the value of c was obtained as follows:

$$c = \frac{0.24\ (\text{Btu/lb dry air})}{12.72\ (\text{ft}^3/\text{lb dry air at } 45\ ^\circ\text{F}} = 0.0189\ \text{Btu/ft}^3 \text{ of } 45\ ^\circ\text{F dry air}$$

Actually, c varies slightly since the conversion of pounds of air to cubic feet changes with the temperature and moisture content of the air. No constant value of conversion could give a precise answer. The conversion factor used, 12.72 cubic feet/pound, is the volume of one pound of dry air at 45 °F. This conversion factor varies from 12.388 at 32 °F to 13.096 at 60 °F for dry air. This is approximately the range of temperatures for which the air flow is desired. This small error can be tolerated in order to read the air flow directly in cubic feet per minute, the common unit used for rating ventilating fans.

On the nomograph for determining water removed, the units used for plotting the "w_1" and "w_o" scales were lbs. of H_2O/ft^3 based on the conversion factor at 45 °F. Thus, this small error is likewise included on this nomograph.

SUMMARY OF DESIGN DATA AND PRINCIPLES

Since the design of a poultry ventilating system is based on a number of variables and technical principles, the information needed for design is presented in this section as an aid in the application of the nomographic charts.

Design Data:

The following design data are given for the purpose of design of winter ventilating systems. As such, these data are intended to apply to environmental temperatures of approximately 20 to 70 °F.

Moisture to be Removed from House: Provided the house is well constructed, the only source of moisture should be the moisture given off by the hens. Poultry eliminate moisture in the droppings and by evaporation from their lungs. The suggested design values for moisture eliminated by laying hens is presented in Table III.

Sensible Heat Available: During the coldest design periods the only established source of heat is that produced by the chickens. Therefore, the sensible heat produced by the chickens as estimated in Table IV is presented for design during the coldest weather, since solar heat is usually not available. For warmer winter weather, the designer may include solar radiation as a heat source. Heat produced in built-up litter is not well established. This heat source is considered as a factor of safety. Sensible heat produced by hens is already plotted on the nomograph for determining air flow (Figure X).

<u>Indoor Design Temperature</u>: A variable environmental temperature from 30 to 70 °F is considered as satisfactory, provided rapid temperature fluctuations are prevented. During extremely cold periods, since the cost of insulation or of the heat necessary to maintain 30 °F may be excessive, it is not considered practical to strictly adhere to a minimum design temperature of 30 °F.

<u>Indoor Design Relative Humidity</u>: No definite relative humidity was established from the research data; however, the analysis of design data indicates that in ordinary weather the relative humidity should not exceed 80 per cent. For short periods 90 per cent does not seem to be detrimental. No attempt was made to determine the minimum relative humidity, since under winter conditions, the lowest relative humidity obtainable would not be too low unless heat were added.

<u>Outdoor Design Temperature</u>: The outdoor design temperature, determined on the basis of 12 years of weather data, is given as 5 °F for Blacksburg, Virginia. The design temperature recommended for residential heating in the Blacksburg area is near zero degrees F (28). For other localities in Virginia, unless better information is available, the writer suggests that the outdoor design temperature be taken as five degrees higher than that recommended for residential heating design.

<u>Outdoor Design Relative Humidity</u>: In the writer's opinion, the outdoor design relative humidity should be taken as 100 per cent for

the coldest design periods and for extended rains. These are the critical periods for moisture removal. Mean temperatures and relative humidities are of doubtful value in determining the water removed from a house.

Minimum Ventilating Rate: It is suggested that the minimum ventilating rate, which is used for the lowest outdoor temperature, be used as a basis for design. Then the AU_{av} value determined for this period will be used to arrive at the rate of ventilation for the warmer periods of winter. If this approach is accepted, a method for determining the minimum ventilating rate is needed. The following methods are considered.

First, an arbitrary rate of minimum ventilation may be set. Oliver (58) suggested a minimum rate of 1 cfm per hen. This rate is not substantiated by, or contrary to, the research work analyzed.

Second, the air flow required to remove carbon dioxide or odors might be used as the minimum rate. Mitchell and Kelley (54) state that 0.07 cfm per hen would be adequate to maintain a safe limit on carbon dioxide concentration. From the standpoint of practical control, such a ventilating rate could not be used. The rate necessary to remove odors would vary with the individual conditions. No estimates of this factor were available.

Third, the minimum ventilation may be taken as the rate necessary to prevent condensation on interior surfaces of the building. If the inside minimum temperature and the corresponding relative humidity and outside temperature are known, the maximum allowable heat transfer coefficient which will prevent condensation, may be read from a published chart (17). This method seems to be logical in its engineering approach; however, it is doubtful whether it is practical, from the standpoint of insulation, to attempt to prevent all condensation on windows during the cold spells. It might be desirable to check for condensation on the walls and ceiling. If this method were applied, the minimum ventilating rate would be the rate required to maintain the indoor relative humidity and temperature during the coldest design periods.

Fourth, the minimum rate of ventilation may be taken as the rate required to remove the moisture expired by the hens. If the moisture expired by the hens is not removed continuously, the relative humidity would soon reach 100 per cent; if this condition were allowed to continue, condensation and wet litter would result. Therefore, this method seems to be the most practical basis for determining the minimum rate of ventilation. If the expired moisture is removed during the critical cold periods, then, in moderate weather the extra heat available and a high rate of ventilation should help considerably in removing the moisture from the droppings. A method of determining the rate of ventilation necessary to remove the expired moisture during the critical cold periods is presented in the example problems.

Design Principles:

The writer feels that the following principles should be understood by the designed.

1. The water eliminated by the birds plus or minus the quantity stored in the litter is equal to the water removed by ventilation.
2. The heat gain plus or minus the heat stored in the house is equal to the heat loss by ventilation and by conduction through the exposed building surfaces.
3. The rate of ventilation must be variable if indoor temperature fluctuations are to be materially reduced without the addition of heat.
4. The critical temperature design period is the coldest period being considered for ventilation design and the minimum rate of ventilation should be used during this period in order to prevent excessively low temperatures.
5. Two critical moisture removal design periods are:
   a. The coldest design period with 100 per cent outdoor relative humidity, when a low ventilating rate is being used.
   b. Extended rainy periods with 100 per cent outdoor relative humidity.

APPLICATIONS OF NOMOGRAPHS

In order to illustrate the design procedure two example problems will be used.

Example I:

A Poultry laying house for 1000 five-lb. hens is to be built near Blacksburg, Virginia. If the minimum rate of ventilation is to be adequate to remove the expired moisture during the critical cold periods, find the AU_{av} value for the house and determine maximum, minimum and several intermediate rates of ventilation.

The summary of design data gives the following

Minimum outdoor design temperature: 5 °F
Minimum indoor design temperature: 30 °F
Outdoor design relative humidity: 100 per cent for critical periods
Indoor design relative humidity: 80 per cent maximum

It is assumed that no moisture will condense or evaporate during this period. Thus, if part of the expired moisture condenses in the building the indoor relative humidity should be lower than 80 per cent and if moisture evaporates from the litter the relative humidity should be higher than 80 per cent.

The water expired by 1000 five-lb. hens is found from Table II to be 72 pounds per day. On Figure IX, Chart A locate the outdoor temperature of 5 °F at 100 per cent relative humidity and on Chart B the indoor temperature of 30 °F at 80 per cent relative humidity. Project the indoor conditions horizontally to the right edge of the Chart B. The outdoor relative humidity of 100 per cent is already on the right edge of the Chart A (otherwise it would be projected to the right edge of Chart A). Use a ruler to draw a line through the two points established on the right edges of Charts A and B to the pivot line. Holding this pivot line point move the ruler to 72 pounds per day on the "Wr" scale and read the minimum rate of ventilation as 380 cfm on the "V" scale. Four hundred cfm will be used as a practical minimum ventilating rate.

The AU_{av} value, exposed area times the average heat transmission coefficient, necessary to maintain the indoor temperature under these conditions will now be determined. On Figure X locate the five-pound mark on the "W" scale and 1000 on the "N" scale; draw a straight line to the "Q_s" scale. The total sensible heat is 46,100 Btu/hr. Pivot on this point and draw a straight line through 25 °F on the "Δt" scale and to the pivot line. Rotate on this pivot line point to 400 cfm on the "V" scale and read the maximum AU_{av} value as 1400.

The amount of insulation may be calculated from the following formula:

$$AU_{av} = A_g U_g + A_w U_w + A_r U_r \qquad \text{Formula 3}$$

<u>Where</u>:

A is the total exposed area (ft^2)

U_{av} is the average heat transmission coefficient ($Btu/hr/ft^2/^oF$)

A_g is the exposed glass area (ft^2)

U_g is the heat transmission coefficient of glass ($Btu/hr/ft^2/^oF$)

A_w is the exposed wall area (ft^2)

U_w is the heat transmission coefficient of the wall ($Btu/hr/ft^2/^oF$)

A_r is the exposed roof area* (ft^2)

U_r is the heat transmission coefficient of the roof ($Btu/hr/ft^2/^oF$)

*If there is attic space in the building, the following formula is applicable to the ceiling area (28).

$$U_c = \frac{U_r U_{ce}}{U_r + U_{ce}/n} \qquad \text{Formula 4}$$

<u>Where</u>:

U_c is the combined coefficient to be applied to the ceiling area

U_r is the average heat transmission coefficient for the roof and gables of the building

U_{ce} is the heat transmission coefficient for the ceiling

n is the ratio of roof plus gable area to ceiling area

When formula 4 is used, $A_{ce}U_c$ is substituted for A_rU_r in Formula 3.

The various exposed areas are to be measured or calculated. Many common U values may be obtained from standard references (2, 20).

The maximum rate of ventilation will now be determined. About 5 °F is the minimum practical temperature difference since the air flow increases rapidly when smaller temperature differences are attempted (see Figure IV). Begin with 46,000 Btu on the "Q_s" scale and construct a line through five on the "Δt" scale to the pivot line. Rotate on this pivot line point to 1400 on the "AU_{av}" scale. Read 6900 cfm on the "V" scale. Higher rates of air flow will reduce the temperature difference only slightly. Therefore, higher rates should not be harmful from the standpoint of temperature so long as drafts are avoided. It is recognized that heat from solar radiation was neglected in determining the maximum rate of ventilation.

If an estimate of this heat were available, it should be added to the 46,000 Btu/hr before using the "Δt" scale.

The intermediate rates or air flow may now be determined. For example, construct lines from 46,000 on the "Q_s" scale through 7, 10, and 15 on the "Δt" scale to the pivot line. Hold one end of the straight edge at 1400 on the "AU_{av}" scale and read 1400, 2870, and 4600 cfm, respectively, on the "V" scale. These values give the field engineer an estimate of the size fans and the thermostat settings that should be used for temperature regulation.

Example II:

Design a ventilating system for a poultry laying house near Richmond Virginia. Information is as follows:

Number of hens: 500

Average weight of hens: six pounds

Size of house: 40' x 50'

Roof slope: 4 in 12

Materials:

Roof—Asphalt shingles, 1" solid sheathing, Rafters, and 25/32" fiber board under rafters

Walls—3/4" drop siding on 2" x 4" studs 8' long

Windows—200 square feet of single pane glass

Floor—Concrete on well drained soil.

The following information is taken from the summary of design data.

Indoor design temperature: 30 to 70 °F
Indoor design relative humidity: 80 per cent

Outdoor design relative humidity: 100 per cent for critical periods.

A standard reference map for residential heating design temperatures (28) indicates that the design temperature at Richmond is slightly more than five degrees higher than for the Blacksburg area. Since 5 °F is considered satisfactory for Blacksburg, an outdoor design temperature of 10 °F will be used.

The heat transmission coefficients are: *

$U_r = 0.19$

$U_w = 0.58$

$U_g = 1.13$

The exposed areas are calculated as follows:

Wall and gable area:

8' x 180' + 40' x 6.66' - 200 = 1500 ft^2

Roof area:

42' x 50' = 2100 ft^2

Window area: 200 ft^2

The AU_{av} value is obtained by the following calculations:

Roof—A_rU_r = 211 x 0.19 = 400

Walls--A_wU_w = 1500 x 0.58 = 870

Windows-A_gU_g = 200 x 1.13 = 226

AU_{av} = 1496

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* From reference (20).

The nomograph for determining ventilating rates will be used (Figure X). Locate 6 on the "W" scale and draw a line through 500 on the "N" scale to the "Q_s" scale. The total sensible heat is 25,200 Btu/hr. Rotate on this point and draw a line through 20 on the " t" scale to the pivot line. Holding the pivot line point set the straight edge on 1496 on the "AU_{av}" scale. With this setting the straight edge reads below zero on the "V" scale. This means that all the heat produced by the chickens is lost by conduction through the building surfaces and no heat is available for heating the ventilating air. If a ventilating system is to be installed, insulation must be added or the indoor temperature will fall below the 30 °F desired.

Suppose 25/32" fiber board were added inside the studs. The new value for U_w would be 0.20 and AU_{av} would be reduced to 926. Returning to the pivot line point previously established, place the straight edge at 926 on the "AU_{av}" scale and read the minimum ventilating rate as 300 cfm on the "V" scale.

Next, the minimum ventilating rate of 300 cfm will be checked on the nomograph for moisture removal. Locate 10 °F and 100 per cent relative humidity on Chart A of Figure IX and 30 °F at 80 per cent relative humidity on Chart B. Project the point on B horizontally to the right edge of Chart B. Draw a line through the established points to the pivot line. Rotate the straight edge on the pivot line point to 300 cfm on the "V" scale and read 46 pounds/day on the "W_r" scale. Since the water expired by the chickens is only 43 pounds/day (see Table III), the indoor relative humidity should not rise above 80 per cent unless water is evaporated from the litter during this cold period.

Other ventilating rates may be established as illustrated in Example I.

If the designer knew the mean relative humidities and temperatures, the author believes that a rough approximation of the total water removed may be made by use of Figure IX.

As an example problem the conditions may be assumed. Suppose it is estimated that a mean temperature of 40 °F and a mean relative humidity of 80 per cent will be maintained indoors during one of the cooler weeks of winter. Assume the outdoor mean temperature is 25 °F and the mean relative humidity is 80 per cent. If the air flow is estimated to average 1500 cfm, the water removed per day would be found as follows:

Locate 25 °F at 80 per cent relative humidity on Chart A; project this value horizontally to the right edge of Chart A. Locate 40 °F and 80 per cent relative humidity on Chart B; project this value horizontally to the right edge of Chart B. Draw a line through the two established points to the pivot line. Rotate on the pivot line to 1500 cfm on the "V" scale and read 346 pounds/day on the "W_r" scale. Since the water to be removed from a house with 500 six-lb. hens is 264 pounds/day (Table III), these calculations indicate that either the indoor relative humidity would be reduced or water would be evaporating from the litter more rapidly than water is added to the litter.

The above approximation of the total water removed is at best a rough estimate. Even though the weather conditions were known, the error involved in using the mean weather conditions may be considerable. Since the magnitude of the error is not known for a given problem, it is suggested that the design be based mainly on temperature and a minimum ventilating rate. With temperature as the basis for design, a high rate of air flow occurs during the warm periods of winter. This should also be the best time for removing the moisture from the droppings.

SUMMARY AND CONCLUSIONS

A review of literature and analysis of the essential data for the design of poultry ventilation systems was undertaken in an effort to establish design information for use in Virginia; most of the work applies as well to other section of the United States. In the analysis, research reports and engineering literature on poultry ventilation were considered.

In winter, according to the information available, the practical range of indoor temperature is about 30 to 70 °F where insulation and forced ventilation are used. Strict adherence to a minimum temperature of 30 °F is not considered practical during extreme cold spells. Based on a 12 year weather record the minimum outdoor design temperature was found to be near 5 °F for the immediate vicinity of Blacksburg, Virginia. It is believed that this value may be used as a basis for determining the minimum outdoor design temperature in other sections of the state.

The maximum desirable indoor relative humidity is about 80 per cent. An outdoor design relative humidity of 100 per cent seems applicable for the critical cold periods and rainy weather. The mean indoor and outdoor temperatures and relative humidities are of doubtful value in designing poultry ventilating systems.

Heat and moisture production of poultry are not fixed values; they are influenced by activity, rate of lay, diet, and temperature. However, it is believed that approximate values, obtained by research and reasonable estimates, are adequate for practical design. The suggested data for use in moisture removal problems are presented in Table III. Sensible heat production is given in Table IV and included on the nomograph in Figure X.

Graphical solutions of the heat balance and moisture balance equations were developed. An effort was made to avoid the limitations of previous graphical solutions; such as, fixed relative humidities, set relationships of indoor and outdoor temperature, fixed heat production of birds, or a given amount of insulation. Thus, a practical range of these values was determined and used in the nomographic solutions presented in this work. It is believed that the inclusive values used on the nomographic charts will apply to all sections of the country except the warm southern region where insulated houses are not generally recommended for the winter season.

The nomograph for moisture removal may be used to determine the moisture removed from the house provided estimates of the indoor and outdoor relative humidities and temperatures, and the ventilating rate are available. In this analysis, these values were estimated for the critical cold periods when the minimum ventilating rate is used. For other design periods, estimates have not yet been made.

The nomograph for ventilating rates may be used when the design temperature difference is known since the other necessary data are already on the nomograph or must be calculated in the field. From this nomograph the ventilating rates necessary to control the temperature and the amount of insulation needed may be determined.

Although precision has not been attained in the determination of design data, it is believed that the general values determined are sufficiently accurate to warrant their use for practical design of ventilating systems for laying houses. When the design data are more definitely established, the method and nomographs will still apply to the actual design work.

SUGGESTIONS FOR FUTURE RESEARCH

Moisture expired by poultry or otherwise evaporated in the poultry house during the coldest design periods needs to be investigated. Total moisture to be removed from poultry houses also needs to be determined.

Sensible heat production of chickens for the coldest design periods is needed. The amount of heat obtained from the ground and generated in the litter, and data on heat retained in buildings would be helpful in designing for the coldest periods.

Heat gain in poultry houses from solar radiation is needed for design in warm winter weather.

Evaporation of moisture from litter should be studied.

A method of estimating indoor and outdoor temperatures and relative humidities for determining the moisture removed during ordinary winter weather needs to be developed.

The outdoor minimum design temperature should be rechecked as additional weather data becomes available.

Tests need to be conducted on how effectively the temperature and relative humidity are controlled in houses with ventilating systems as suggested in this work.

Additional work is needed on ventilation for the fall and spring seasons. Would it be feasible to install an automatic device to open the windows during warm periods?

Work needs to be done on the problem of summer cooling. This is an urgent problem in the south.

Ventilation for broiler houses needs to be investigated.

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VITA

Blaine Frank Parker was born in Gaston County, North Carolina on June 12, 1924. He attended North Brook High School in Lincoln County and was graduated in May, 1942. While attending high school he helped with the work on a cotton farm. He was a member of the F.F.A., 4-H, and the high school debating team, and President of his senior class. From June 1942, to February, 1943, he attended Brevard Jr. College at Brevard, North Carolina. The next three years were spent in the Army Air Forces as an aerial gunnery instructor.

In March, 1946 he entered Virginia Polytechnic Institute and enrolled in Agricultural Engineering. As a student he was a member of Alpha Zeta, Phi Kappa Phi, Omicron Delta Kappa, and the A.S.A.E. and held several offices in these organizations. During the summer of 1947, he worked as an Agricultural Engineering Aide for the U.S.D.A. and one year was spent in a co-op training program with the T.V.A. before receiving a B.S. degree in March, 1950. After graduation, two quarters were spent at Peabody College in Nashville, Tennessee studying Education and other subjects.

In September, 1950 he returned to V.P.I. as an instructor in the Agricultural Engineering Department and began part-time work in the graduate school.

Blaine F. Parker

APPENDIX

TABLE VI

ANALYSIS OF LOW OUTDOOR TEMPERATURES
AT BLACKSBURG, VIRGINIA
FROM
NOVEMBER 1, 1940 TO APRIL 1, 1952

Date	Comments	Amt. of Time Under Various Temp. in Hrs.			Minimum Temperature	Number of Failures
		10 °F	5 °F	0 °F		
12-4-40		8			8	
1-6-41		6	-		3	
2-10-41		2			10	
1-6-42	No record	-	-		4	
1-7-42	No record	-	-		9	
1-8-42	No record	-	-	-	-2	1
1-9-42	No record	-	-	-	-3	1
1-10-42	No record	-			10	
1-11-42		16	12	-	0	1
2-3-42		8			8	
12-2-42	Chart shows 11 °F min.				9	
12-13-42		6			8	
12-21-42		10	7	-	-4	1
12-22-42		6	3		4	
1-20-43		4			8	
2-14-43		7			6	
2-15-43		10			6	
3-4-43	No record	-			6	
3-7-43		7			7	
12-16-43	Chart shows 8 °F min.	4	-		3	
12-24-43	Blank under 5 °F	6	-		4	
12-15-44	Chart shows 8 °F min.	3	-		3	
1-31-45 & 2-1-45		13			5	
2-2-45		2			8	
1-23-46		7			5	
12-3-46		4			8	
1-22-47		6			8	
2-4-47 & 2-5-47		25	4		3	
2-8-47 & 2-9-47		27	14		4	1
1-18-48		-			5	
1-14-48	No record	-	-		3	1/2
1-18-48	No record	-			5	
1-24-48		7			8	
1-25-48		7			9	
1-28-48		5			6	
12-26-48		14	4		1	1/2
12-27-48		9	7		2	1
11-25-50		14	-		4	
2-3-51		7			5	
2-7-51		7			8	
12-16-51	Blank under 10 °F	11 est.	7 est.		0	1
1-29-52		2			9	
1-30-52		10			7	
Total Failures--						8

TABLE VII

ANALYSIS OF WATER REMOVED FROM CORNELL

EXPERIMENTAL HOUSE "A" - FEB. 28 - MAR. 7, 1950 AIR FLOW : 300 cfm

OUTDOORS Rel. Hum. (%) 6-Hr. Avg.	OUTDOORS Rel. Hum. (%) Daily Avg.	OUTDOORS Temp. (°F) 6-Hr. Avg.	OUTDOORS Temp. (°F) Daily Avg.	INDOORS Rel. Hum. (%) 6-Hr. Avg.	INDOORS Rel. Hum. (%) Daily Avg.	INDOORS Temp. (°F) 6-Hr. Avg.	INDOORS Temp. (°F) Daily Avg.	Water Removed in lbs/Day Based on: 6-Hr. Avg.	Water Removed in lbs/Day Based on: Daily Avg.
89		27		81		40		55	
91		21		78		35		42	
95		24		82		35		36	
79		23		81		36		56	
	88		24		80		36	47	42
71		22		77		37		64	
74		21		77		33		46	
75		14		77		28		39	
61		18		73		35		66	
	70		19		76		33	54	54
46		26		64		43		86	
67		19		70		34		50	
87		19		77		32		36	
78		26		81		37		53	
	69		22.5		73		36	56	54
59		27		70		42		74	
77		18		76		33		48	
82		18		80		30		39	
58		29		79		40		78	
	69		23		76		36	60	58
63		35		72		44		61	
70		35		70		43		42	
78		37		72		44		30	
63		44		67		50		46	
	69		38		70		45	45	39
58		53		58		57		28	
86		42		70		53		84	
94		38		77		48		34	
97		33		78		46		48	
	84		41.5		71		51	48	37
86		37		79		47		48	
83		27		77		47		65	
73		19		75		36		63	
54		14		65		37		72	
	74		24		74		40.5	62	71
TOTALS								372	355
AVERAGE OF TOTALS								53	51
WEEKLY AVERAGES	75		27		74		40		47

TABLE VIII

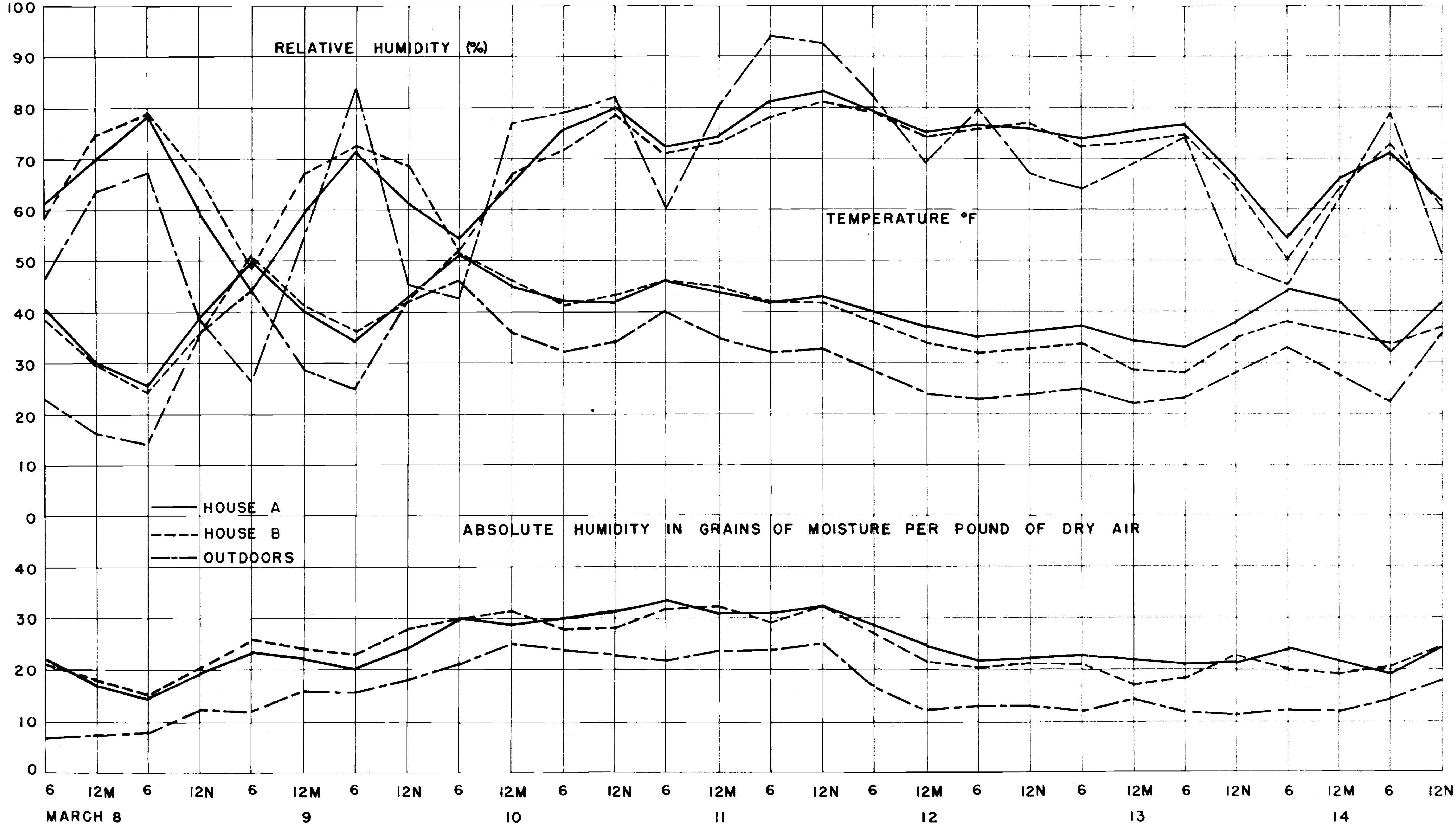
ANALYSIS OF WATER REMOVED FROM CORNELL

EXPERIMENTAL HOUSE "A" - MARCH 7-14, 1949

AIR FLOW: 520 cfm

OUTDOORS Rel. Hum. (%) 6-Hr. Avg.	OUTDOORS Rel. Hum. (%) Daily Avg.	OUTDOORS Temp. (°F) 6-Hr. Avg.	OUTDOORS Temp. (°F) Daily Avg.	INDOORS Rel. Hum. (%) 6-Hr. Avg.	INDOORS Rel. Hum. (%) Daily Avg.	INDOORS Temp. (°F) 6-Hr. Avg.	INDOORS Temp. (°F) Daily Avg.	Water Removed in lbs/Day Based on 6-Hr. Avg.	Water Removed in lbs/Day Based on Daily Avg.
47		22		61		41		127	
63		16		70		30		75	
67		14		78		26		73	
39		36		69		39		110	
	54		22		69.5		34	96.3	106
27		44		44		50		104	
54		28		60		40		89	
83		25		71		33		31	
46		42		61		43		66	
	52.5		35		62		41.5	72.5	76
43		46		54		51		90	
77		36		65		45		41	
79		33		75		42		80	
82		34		80		42		71	
	70		37		68.5		45	70.5	67
61		40		73		46		105	
80		35		74		44		66	
94		32		81		42		72	
92		32		83		43		68	
	82		35		78		44	82.7	73
82		28		79		40		92	
69		24		75		37		110	
79		23		76		35		78	
67		24		75		36		98	
	74		25		76		37	94.5	88
64		25		74		37		102	
69		22		75		35		94	
74		23		77		33		78	
59		28		67		38		85	
	66.5		24.5		73		36	89.8	91
56		33		54		44		69	
62		28		66		42		102	
78		23		71		33		53	
51		36		62		42		72	
	62		30		63		40	74.0	72
TOTALS								580.3	573.0
AVERAGE OF TOTALS								82.9	81.9
WEEKLY AVERAGES	66		30		70		40		87

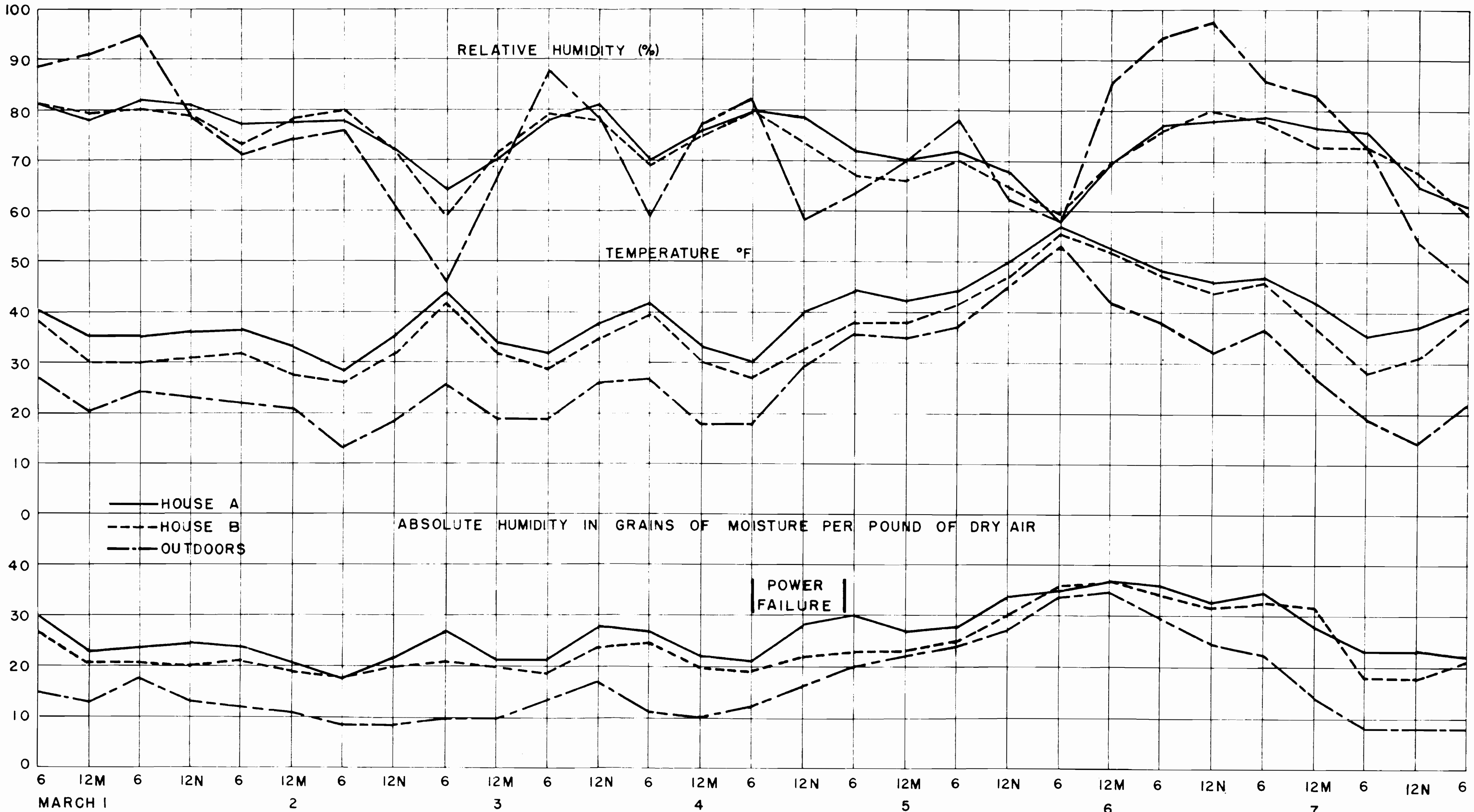
TEMPERATURE, RELATIVE HUMIDITY AND ABSOLUTE HUMIDITY, OUTDOORS, IN POULTRY HOUSE A WITH AN EXHAUST RATE OF 520 c.f.m. AND RECIRCULATION RATE OF 680 c.f.m., AND IN POULTRY HOUSE B, SIX-HOUR AVERAGES DURING THE PERIOD MARCH 7 TO 14, 1949[a]



[a] BATES (6)

FIGURE VII

TEMPERATURE, RELATIVE HUMIDITY AND ABSOLUTE HUMIDITY, OUTDOORS, IN POULTRY HOUSE A WITH AN EXHAUST RATE OF 300 c.f.m. AND RECIRCULATION RATE OF 625 c.f.m., AND IN POULTRY HOUSE B, SIX-HOUR AVERAGES DURING THE PERIOD FEBRUARY 28 TO MARCH 7, 1950[a]



[a]BATES (6)

FIGURE VIII

NOMOGRAPH FOR DETERMINING MOISTURE REMOVED

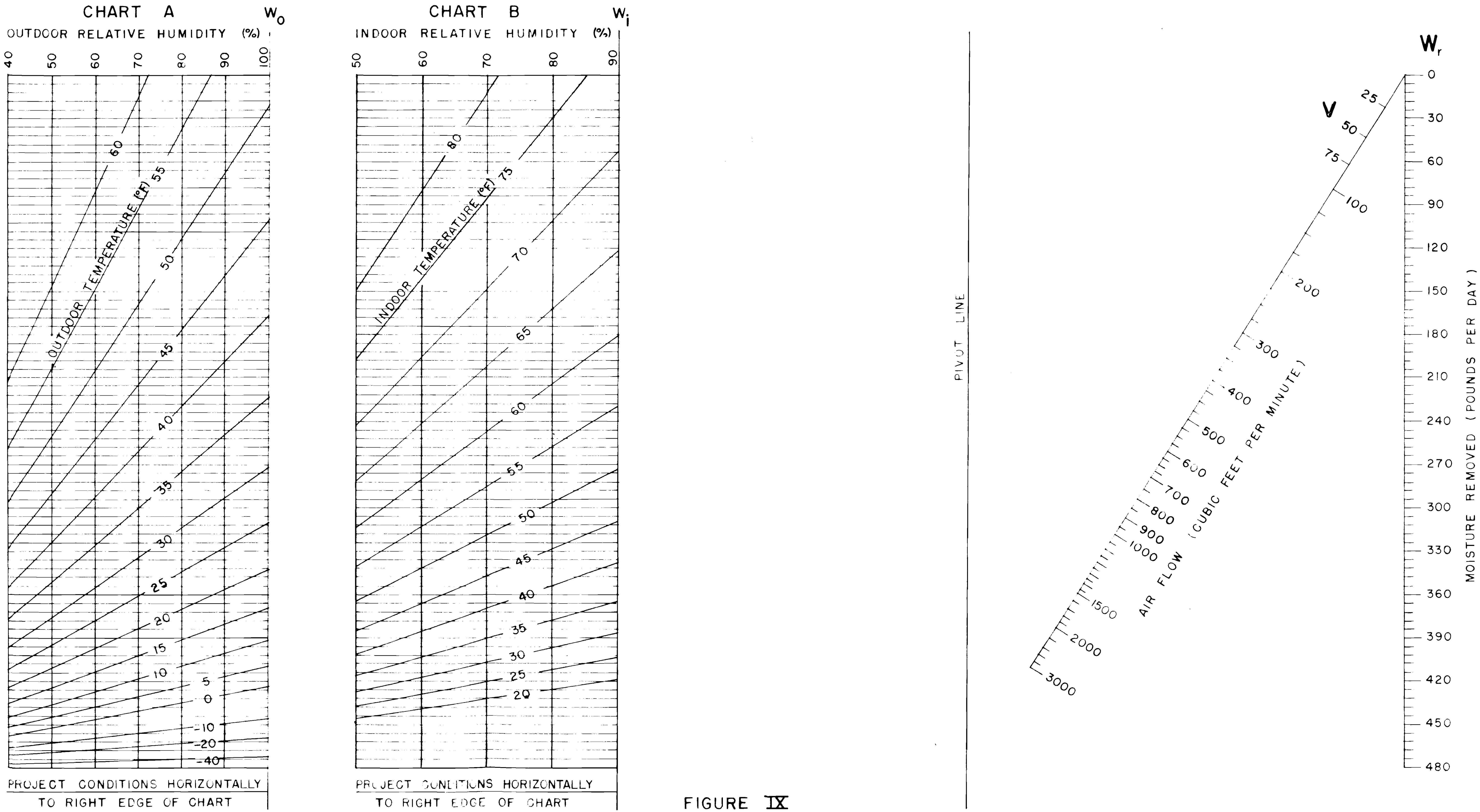


FIGURE IX

NOMOGRAPH FOR DETERMINING WINTER VENTILATING RATES

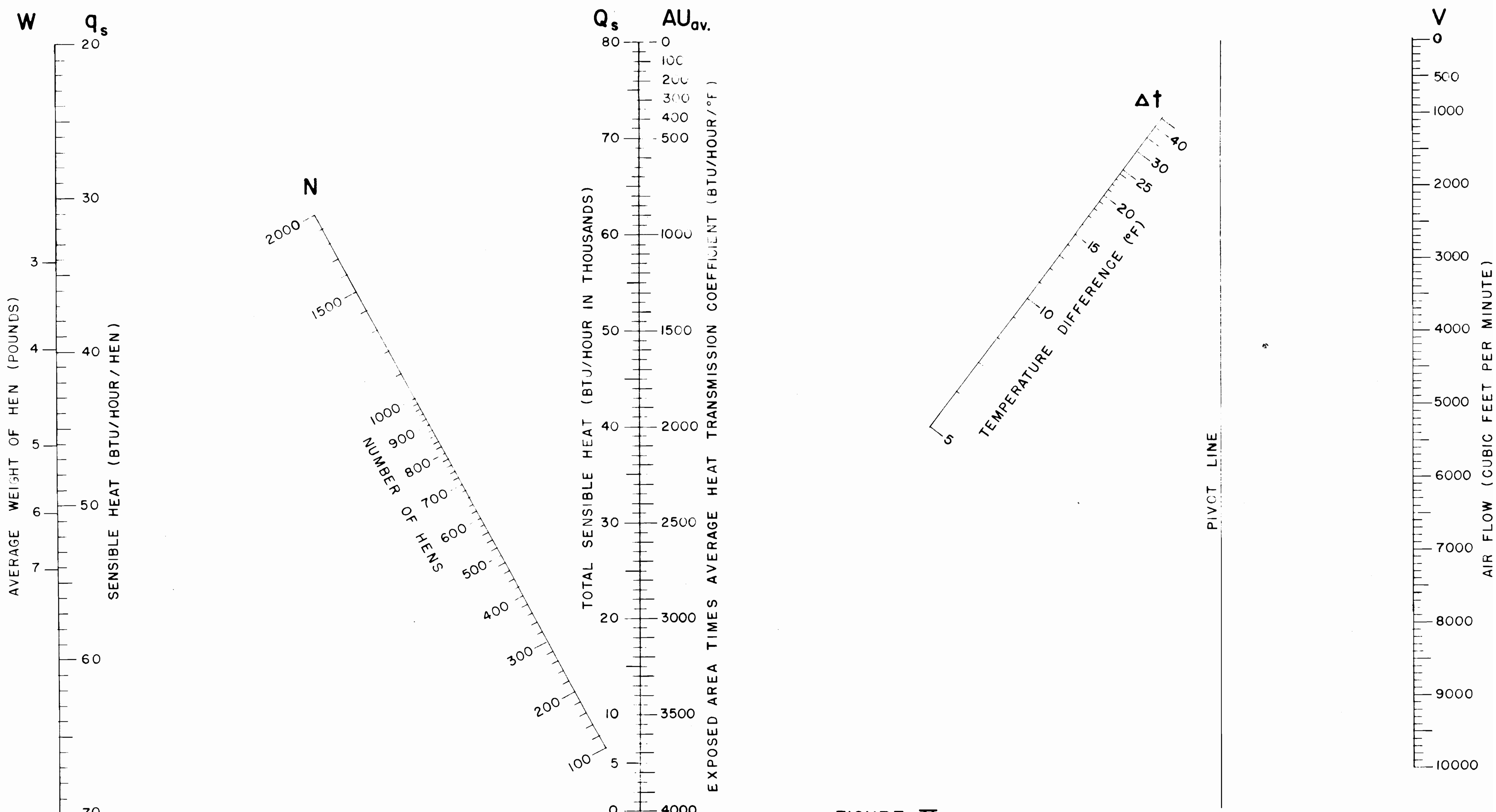


FIGURE X