To the Graduate Council:

I am submitting herewith a thesis written by Nazar J. Alias entitled "Minimum Energy Requirements for Optimum Egg Production in Caged Layer Houses." I recommend that it be accepted in partial fulfillment of the requirements for the degree of Master of Science, with a major in Agricultural Engineering.

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MINIMUM ENERGY REQUIREMENTS FOR OPTIMUM EGG PRODUCTION IN CAGED LAYER HOUSES

A Thesis

Presented for the

Master of Science

Degree

The University of Tennessee, Knoxville

Nazar J. Alias

June 1977

1323961

ACKNOWLEDGMENTS

The author wishes to express his sincere appreciation and thanks to Dr. L. R. Wilhelm, for his supervision and encouragement during this study. The support of Dr. R. L. Tugwell, Dr. J. I. Sewell, and Mr. D. O. Baxter, who served as committee members, is also appreciated.

The author wishes to express his deep appreciation and acknowledgement to the Iraqi Government for granting a full scholarship to study for the Ph.D. degree in the United States.

Thanks are due the author's mother for her great help, patience, and prayers from the time he started high school. He also wishes to express his deepest thanks and love to all other members of his family and his wife's family, especially to Father Sharbail Alias, for his prayers and faithfulness.

Finally, the author wishes to express his thanks and love to his wife, Shatha.

ABSTRACT

Studying the environmental control requirements in poultry laying houses is very important when economy and energy conservation are considered. The objectives of this study were: (1) to investigate the possibility of reducing energy consumption in poultry laying houses, (2) to determine the effect of supplementary heat on winter egg production, and (3) to study the effect of temperature and relative humidity on egg production.

An experiment was conducted for six months to study those factors. Special statistical analysis for data was followed. Results of this study indicated that there is no significant effect of daily average temperatures within the range 45-65° F on egg production, and also that the relative humidity, within the range normally encountered, has no significant effect on egg production. A comparison was made between the egg production from two sections of a poultry laying house, one of which was provided with supplementary heat. This comparison indicated that heating may have an adverse effect on egg production.

One day lag of temperatures and relative humidities showed a better correlation with egg production than that of the same day.

TABLE OF CONTENTS

CHAPTER		PAGE
I.	INTRODUCTION	1
II.	REVIEW OF LITERATURE	3
	Ventilation Requirement and Ventilation System Design.	3
	Insulation Requirement for Laying Houses	15
	Temperature and Humidity Effect on Egg Production.	19
	Supplementary Heat	29
	Summary of Literature.	31
III.	BUILDING DESIGN, INSULATION VALUE, AND VENTILATION SYSTEM.	33
	Building Design.	33
	Insulation Value	37
	U-value for walls.	37
	U-value for roofs and ceiling.	42
	U-value for the floor.	42
	Overall U-value of the building.	42
	Exposure factor.	45
	Ventilation System	45
IV.	PROCEDURE.	47
	Equipment and Instrumentation.	47
	Experimental Design.	52
	Installation of thermocouples.	52
	Walls.	52
	Ceiling and roofs.	52

CHAPTER PAGE

Attic. 55
Ventilators. 55
Inside and outside air temperature 55
Cage temperature 55
Black globe. 55
Environmental conditions for the experiment. 55
Light timing and control 56
Data Collection. 56
Hygrothermograph data. 56
Data from the temperature recorder 58
Wind speed data. 58
Energy consumption data. 58
Daily egg production 58
Analysis of Data 59
V. RESULTS AND DISCUSSION 61
Effect of Supplementary Heat on Egg Production 61
Power Consumption. 61
Effect of Age on Egg Production. 62
Temperature and Humidity Effect on Egg Production. 63
VI. SUMMARY AND CONCLUSIONS. 69
LITERATURE CITED 72
APPENDIXES 77
APPENDIX A. STATISTICAL DATA TABLES 78
APPENDIX B. STATISTICAL ANALYSIS OF DATA. 83
VITA 88

LIST OF TABLES

TABLE		PAGE
1.	Average Monthly Egg Production from Ventilated House Versus Unventilated House	7
2.	Insulation Requirement for Poultry Laying Houses According to the Temperature During January	18
3.	Egg Production per Hen from Heated and Unheated Pens for New Hampshires and White Leghorns	30
4.	Conductances and Resistances of Building and Insulating Materials	40
5.	Summary of U-values for Wall Sections of the Building	41
6.	Summary of the U-values of Roofs and Ceiling	43
7.	Summary of UA-values of the Building Components	44
8.	Correlation Coefficients and Equations of Temperatures of the Same Day, One Day, and Two Days Before Production Versus Egg Production	66
9.	Correlation Coefficients and Equations of Relative Humidities of the Same Day, One Day, and Two Days Before Production Versus Egg Production	68
10.	Egg Production Data for the Heated and the Unheated Sections from November 4 to December 15, 1976	79
11.	Actual, Predicted, and Residual Values of the Daily Percentage Production for the Period October 25 to November 22, 1976	80
12.	Mean Daily Temperature and Humidity Data from the Unheated Section	81

LIST OF FIGURES

FIGURE		PAGE
1.	A Cross-Section in the Building Showing Poles and the Structure Framing (not to scale).	34
2.	Cross-Sections in the West and East Walls (not to scale). . .	35
3.	Side View of the Building	36
4.	The Arrangement of Cages, Feed Troughs and Feed Containers Inside the Building	38
5.	The Waste Removal System Showing the Cables' Connections to the Scrapers and Motor.	39
6.	The Temperature Recorder and the Paper Tape Punch	48
7.	Two of the Wet Bulb Temperature Measuring Devices	51
8.	The Electric Heater Installed in the South Section of the Building.	53
9.	A Map Showing Location of Thermocouples Inside and Outside the Building.	54
10.	The Plastic Partition Used to Divide the Building into Two Halves with an Opening at the Center	57
11.	A Graph Representing the Relationship Between Production and Age for the Period October 25 to November 22.	64

CHAPTER I

INTRODUCTION

One of the main problems facing the industrial nations of the world is the current high energy consumption. Due to the decreasing availability of certain energy supplies and the increasing demand for energy, the cost of energy has drastically increased since 1973. Energy required for heating and ventilating farm buildings constitutes an important segment of the industrial nation's energy use. The cost of this energy also affects the value of agricultural and animal products.

Very little work has been done to study the effect of supplementary heat on egg production. Numerous articles seemed to throw doubt on the desirability of heating, particularly if the temperature could be kept above freezing. However, heating poultry houses may accomplish the two purposes of maintaining relatively higher temperature inside the house and to control the relative humidity when the sensible heat is insufficient to remove the extra moisture from the building.

A portion of the energy consumed in laying houses goes into ventilating the houses. Proper performance and timing of the ventilation system may reduce the energy consumed. Ventilating laying houses accomplishes one or more of the following.

1. Provides the desired amount of air change and exhausts harmful gases.

2. Maintains temperatures in the house within desired limits during hot weather.
3. Maintains relative humidity in the house within desired limits.

The work dealing with ventilation and ventilation systems requires a good understanding of the psychrometric properties of air. In general, the heat produced by birds can be used to remove a substantial amount of moisture from the poultry house. Poor insulation of laying houses increases heat transfer through walls and ceiling, and consequently increases the energy required for heating and ventilating poultry houses.

Factors other than ventilation and insulation also affect the environment of poultry laying houses. Some of these factors are: (1) bird density in the building, (2) climatic conditions, (3) lighting requirement, (4) waste system used, and (5) watering and feeding systems used.

The objectives of this study were: (1) to investigate the possibility of reducing energy consumption in poultry laying houses, (2) to determine the effect of supplementary heat on winter egg production, and (3) to study the effect of temperature and relative humidity on egg production.

CHAPTER II

REVIEW OF LITERATURE

I. VENTILATION REQUIREMENT AND VENTILATION SYSTEM DESIGN

A review of the literature shows that ventilation is one of the oldest problems facing the poultry industry. This was clearly shown by Giese (1926) who published a summary of experiments, under the title, "A Method of Research as Applied to a Project on the Air Requirements of Poultry." A part of the article is shown below.

> Mayow, as early as the seventeenth century gave us our fundamental conception of an assumed toxic effect of carbon dioxide. . . . Mayow states: If a small animal and a lighted candle be shut up in the same vessel, the entrance into which of air from without be prevented, you will see in a short time the candle go out; nor will the animal survive its funeral torch. . . . Nor is it to be supposed that the animal in such a case is suffocated by the smoke of the candle, since if the flame be supplied by the burning spirits of wind, no smoke is produced and yet the animal dies.
>
> The New York Commission on ventilation in its report gave a quite detailed summary of the various views held from time to time as to the cause of the harmful effects of a lack of ventilation. After duly considering these and after extensive tests of school room ventilation, they have concluded that temperature, air movement and relative humidity are the most important factors in the ventilation of public buildings.

Armsby (1903) stated that the amount of carbon dioxide produced by animals was approximately proportional to their heat production. Thus the rate of ventilation should also be approximately proportional to their heat production in order to maintain any desired standard of purity of air in a building. These results as a whole indicate that

there is a very definite optimum range of values for air purity and oxygen required by poultry for their best health and comfort, and that there is probably a definite optimum relation between these two ventilation factors.

MacKenzi and Russell (1904) reported that the amount of inspired and respired air, and the amount of carbon dioxide in respired air and in the air of poultry houses of different construction, showed that chickens breathe about 1.2 cubic feet of air per hour. The proportion of carbon dioxide which poultry can withstand was about nine parts in 10,000 (by volume) of air. From this it was calculated that each bird required at least 40 cubic feet of air per hour if this limit of carbon dioxide was not to be exceeded. The air requirement of a medium bird weighing about 4.5 pounds seemed to be much the same as that of a larger bird weighing 7.5 pounds.

Hutter et al. (1933) surveyed the research on poultry house ventilation. Their report included results of work in Maine, New York (Cornell), Nebraska, and Washington.

In Maine, in 1897, a heated house 16 feet wide by 150 feet long was built. This house was never satisfactory for laying hens and was abandoned for the curtain front. Early in this century this station began the practice of rolling down a heavy curtain in front of the roosts at night during the winter, keeping the roosting house quite tight and warm. This practice seemed to result in unfavorable conditions and the house was abandoned in 1911. Raymond (1916) reported the following results:

> The winter of 1910-1911 was a severe one. On several occasions the temperature dropped to 30° F below zero. Yet during this winter the mortality was exceptionally low and egg production exceptionally high. The roost curtain will not again be used at this station.

At the Cornell University, Department of Poultry, Botsford and Lawless conducted a test during the winter of 1923-24 on the effects of varying amounts of open front in six pens on the health and production of 180 Leghorn hens. Three conclusions were drawn from this test. First, that combs and wattles of the birds do not freeze at temperatures above 10° F. Second, that the wide-open houses were by far the driest while the closed houses were very damp at all times. Third, that damp litter may not be as harmful as has been supposed, but that it may sometimes indicate unfavorable air conditions.

In the winter of 1926-27, Carver and Smith of Washington State Agricultural College at Pullman, conducted a test on poultry-house ventilation. Two 24 x 24 foot units were each stocked with 200 White Leghorn hens. The units were both equipped with three sliding curtains in the front. The curtain frames were covered with celo-glass and counter balanced by sash-weights so that they could be raised to any desired level in the openings. Two wooden air-outtake flues were installed in each unit. The lower part of these flues was two and one-half feet above the floor and equipped with a slide which could regulate the amount of opening. A hinged door was also provided just under the straw-loft to open in the summer. The walls were double and 10 to 12 inches of straw was used in the loft. Results indicated that no colds

were encountered during winter and that mortality was only 2.5%. The egg production was averaging from 55 to 51% from October to April 1.

In the fall of 1929, the Department of Agricultural Engineering of the University of Nebraska completed a seven year test on the relation of winter environmental conditions in poultry houses to egg production. In this test eight 20' x 20' pens were compared at various times with varying conditions maintained in them. Some houses were heated, others insulated, others had commercial ventilator flues and others had fans to stir or exhaust the air from the pen. The conclusions drawn from this experiment were as follows.

A commercial ventilator was installed in one of the heated houses. A second heated house, identical to the first with the exception that it did not have a commercial ventilator, was used for comparison. The only provision made for ventilation in the second house was muslin-covered transoms and windows. Another comparison was made between two unheated houses, one of them having a commercial ventilator while the other did not. The total egg production per hen for the seasons 1927-28 and 1928-29 by month from both the heated and the unheated houses is shown in Table 1. An electric fan for stirring the air was operated in one of the heated houses for three seasons and produced no results warranting its installation.

An exhaust fan, which removed large quantities of air from one of the heated united during three seasons of the experiment, produced no results warranting its installation.

Table 1. Average Monthly Egg Production from Ventilated House Versus Unventilated House

Month	Heated Houses		Unheated Houses	
	With Commercial Ventilator	With No Commercial Ventilator	With Commercial Ventilator	With No Commercial Ventilator
November	14.6	15.5	16.8	12.7
December	14.8	18.0	13.1	13.3
January	28.1	28.7	22.1	19.9
February	27.8	26.1	23.6	24.1
March	35.8	34.7	36.4	35.9

Source: J. C. Hutter, F. L. Fairbanks, and H. E. Botsford. (1933) Ventilation of Poultry Houses for Laying and Breeding Hens. Cornell Experiment Station. Bulletin 558.

Hutter et al. (1933) studied ventilation in a shed-roof type house. It was known as the Cornell Open-Front House. Two 20 x 20 foot pens were constructed as one long building with an 8 x 20 foot observation and feed room between them. They had both front and rear rafter ventilators and an open front covered, when necessary, with muslin curtains. Results indicated that the egg production in both pens was very good throughout the test. They also observed that the rate of air movement through either pen, when closed on cold days, was strongly influenced by the rate of air movement outdoors and the direction of the wind. It was necessary to close the curtains in the front of the house when outdoors temperatures dropped below 15° F or during strong winds or storms.

Fairbanks and Goodman (1935) wrote an article on the different types of ventilation for cold and warm poultry houses. They suggested the use of an electric fan for ventilation to insure more continuous movement of air and to dry litter.

A difference of opinion exists on the necessity of air intakes for electric fan ventilation. Their installation is recommended by Fairbanks and Goodman (1926), and Miller et al. (1945), while Bugbee (1941) observed that air comes in through natural leaks in such a way that is is quite evenly distributed. Fairbanks and Goodman (1926) do not recommend thermostats for use with fans because (1) it is important to run the fans continuously and (2) if the house is properly built, and if the air is removed from near the floor, there is no occasion to stop the fan because of low temperature.

Kable (1946) studied different systems of electric ventilation for poultry houses. He concluded that: (1) sufficient information is available to warrant the installation of electric ventilation system in poultry houses; (2) ventilation is only one factor in poultry management. It must be considered in connection with building insulation, feeding, labor requirements and other management problems; (3) it should be borne in mind that electric ventilation is justified only if it does a better job or does it cheaper or more reliably than other systems of ventilations; and (4) research work on the effect of ventilation on hens should be extended.

Hienton and McCalmont (1947) conducted an experiment on the method of forced ventilation for poultry houses. They mentioned that: (1) installation of an electric ventilator is simpler than that of the gravity system in that no outtake flue is constructed; and (2) the need for ventilation of poultry houses is now considered primarily to be for minimizing moisture condensation on the walls and ceiling, to keep the litter dry, and to remove foul odors.

Oliver (1950) mentioned that it is impossible to ventilate an uninsulated house adequately and still maintain above freezing temperatures in the house at the same time. He also recommended that fan ventilation is adequate to keep the house dry when the average mean temperature during the winter months is 20° F or higher with relative humidity of 70% or less; and that, where the relative humidity is above 80% or the mean temperature is much below 20° F, supplemental heat must be added at least a portion of the winter to maintain dry litter

conditions. Oliver conducted his experiment on a 20 x 20 foot well-insulated house, containing 133 Leghorns. He concluded that: (1) all the water entering the house must be removed daily (about one-half pint per hen); (2) heat must be conserved by adequate insulation if above-freezing temperature is to be maintained in the house; and (3) a poorly insulated or uninsulated house can be ventilated by increased air flow, but with an inside temperature maintained only a few degrees above that outside.

Paker (1953) constructed two nomographs representing solutions for the required ventilation in poultry laying houses. The first nomograph was constructed to determine the ventilation rate required for moisture control. The first nomograph represented the following equation:

Moisture-Balance Equation

$$W_a = W_e/(w_i - w_a) \qquad (1)$$

where

W_a = air flow, pounds per minute

W_e = moisture to be removed from the house, pounds per minute

w_i = moisture contained in the indoor air, pound water per pound of dry air

w_o = moisture contained in outdoor air, pound water per pound of dry air.

The second nomograph, represented by equation (2), was used to determine the ventilation rate required to control inside temperature of laying houses:

Heat-Balance Equation

$$Nq_s = (\Delta t)(A\ U_{av} + 60\ V\ c) \qquad (2)$$

where

N = number of chickens

q_s = sensible heat available, Btu/hr hen

Δt = difference between indoor and outdoor temperatures, °F

A = total exposed area, square feet

U_{av} = average heat transmission coefficient for the exposed area, Btu/hr ft^2 °F

V = air flow, cubic feet per minute

c = specific heat of air, Btu/ft^2 °F

The two nomographs were suggested by Paker for use in the rapid design of poultry laying house ventilation systems.

In an experiment on the response of chickens to temperature and ventilation, Prince et al. (1961) reported that lowering the ventilation rate from 2 to 3/4 cfm per bird significantly decreased feed consumption by 0.126 pounds per bird. This experiment was con-conducted on White Plymouth Rock male chicks subjected to environmental temperatures of 45° F, 65° F and 75° F and ventilation rates of 3/4 and 2 cfm per bird. Three replications which required six trials were completed in four environmental cabinets. The experimental

period extended from four to eight weeks of age and 20 chicks were used in each cabinet.

Hinkle and Good (1970) compared three types of ventilation control systems by using computer simulation. The first system simulated used one fan with a variable speed control. The voltage to the fan motor, and consequently the air flow rate, was varied using a variable transformer controlled by a thermostat. A 500 to 2000 cfm fan output was selected. The second system was one fan, with a time clock control. In this system a constant volume fan of 4000 cfm was used. The fan was operated for a specified period of time, e.g., three minutes, and off for the remainder of a 10 minute period. A thermostat was used to stop the fan if the temperature dropped below a set minimum. The third simulated system was two fans with a thermostat control. One of the fans was 1500 cfm output and the other was 500 cfm output. Each of the fans was controlled separately by a thermostat. Preliminary results indicated that the ventilation systems would not remove much of the moisture. Thus, a 20,000 Btu/hr heater was included which would turn on when the relative humidity reached 90% and off if the relative humidity became less than 85%. Three graphs were drawn by the computer. Each graph represented the variation of the indoor and outdoor temperature, the indoor and outdoor relative humidity and the airflow rate with time for the 24 hour period of the analysis. Hinkle and Good mentioned that if weather information were available for an average day during a month, this would allow any of the systems to be tuned to the average.

The American Society of Agricultural Engineers has published data (D270.4) (1975) on the "Design of Ventilation Systems for Poultry and Livestock Shelters." Section 3.3.1 of this data included two general equations ((3) and (4) below) for ventilation rates required to control the humidity and temperature inside a building. These two equations are similar to those used by Paker (1953) to develop his two nomographs.

Moisture-Balance Equation

$$M = \frac{\bar{v}}{60} \left(\frac{Q_1}{1044\ (\Delta w)} \right) \qquad (3)$$

where

M = ventilation rate, cfm per animal unit

$\bar{v}$ = specific volume at inside temperature, cu. ft/lb dry air

Q_1 = latent heat production, Btu/hr animal unit

1044 = latent heat of vaporization at body temperature, Btu/lb water

Δw = difference between inside and outside moisture content of air, pound of water per pound of dry air.

Temperature-Control Equation

$$M = \frac{\bar{v}}{14.4\ (\Delta T)} (Q_s - EF\ (\Delta T)) \qquad (4)$$

where

ΔT = difference between inside and outside temperature, °F

Q_s = sensible heat production, Btu/hr animal unit

EF = exposure factor.

Winter ventilation rates can be estimated by using Figures 45 and 47 from the ASAE Data. Summer ventilation rates can be calculated by using equations (3) and (4) above, the values of Q_s and Q_l for laying hens can be found by using Figure 44 from the ASAE Data.

Reece (1976) presented an overview of some of the basics in designing a livestock structure ventilation system. He recommended the use of equation (5) as a general equation for determining the ventilation rate required for temperature control when the inside temperature is lower than the outside temperature.

$$0.24\ M\ (t_i - t_o) = N\ (Q_s - Q_b) + Q_a \qquad (5)$$

where

M = mass flow rate of ventilation air, lb/hr

t_i, t_o = inside and outside air temperatures, °F respectively

N = number of livestock

Q_s = sensible heat production per head of livestock, Btu/head hr

Q_b = heat transfer through walls and ceiling as determined by $Q_b A = U\ (t_i - t_o)$, where A is total area, ft^2, and U is overall heat transfer coefficient, Btu/ft^2 hr °F

Q_a = quantity of supplementary heat, if added, Btu/hr.

Reece classified ventilation systems into: (1) positive pressure systems and (2) negative pressure systems. In the first, the fans are placed in the air supply to the structure, and the building operates at slightly above atmospheric pressure. He listed two advantages and two disadvantages for this type of system. The advantages are:

(1) fan and motors operate in clean air, so they are more efficient and require less maintenance; and (2) air leaks in the building have very little effect on air distribution.

The disadvantages are: (1) the pressure in the house forces moisture-laden air through leaks in the insulation; and (2) construction is more costly because of the additional air ducting required to locate the fans in the air inlet and distribution system.

In the second system the fans are placed to exhaust air from the structure. In this type system the pressure inside the building is lower than the atmospheric pressure.

Reece recommended that the supplementary heat control during the growout phase of production should be integrated with the ventilation control system to prevent energy waste.

II. INSULATION REQUIREMENT FOR LAYING HOUSES

The main function of insulation is to decrease heat flow to and from the building. During the cold months of the year, insulation reduces heat loss, thus reducing heating costs. In summer, insulation helps in maintaining cooler inside temperatures.

Smith (1930) studied the effect of insulation on winter egg production. He compared egg production from two houses. One of them was uninsulated and the other had walls packed with mineral wool, storm doors, and windows. The uninsulated house was always low in production in January and February. Smith concluded that insulation had a beneficial effect on winter egg production.

At the Cornell Experiment Station, studies were conducted by Hutter et al. (1933) using two pens. Pen 1 was constructed according to the conventional Cornell plans for a laying house; and Pen 2, or the insulated pen, had the interior of the house entirely ceiled by a 7/16-inch layer of insulating board made of pressed sugar-cane pulp (Celotex) nailed to the inside of the studs on all four walls and to the underside of the rafters. The results indicated that egg production of birds in Pen 2 (insulated) was significantly greater than Pen 1.

Lee et al. (1937), after two years work on applying heat in an insulated laying house, concluded that annual egg production is lowered by the use of supplementary heat in an insulated laying house. They questioned if that would be true in an uninsulated laying house; and they recommended insulation rather than artificial heat, since insulation costs less than heating over a period of years. They explained the reduction in egg production due to heating as the effect of forcing birds to lay at an unnatural season by heating the house.

Gutteridge et al. (1944) carried out their experiment on three kinds of pens to study the effect of artificial heat, insulation, and other factors on egg production. Pens (1) were uninsulated as a control. Pens (2) were semi-insulated with 1/2-inch insulation board under a straw loft for a ceiling, 3/4-inch V joint over 1/2-inch insulation board on studding under windows for the front wall. Pens (3) were the same as the semi-insulated pens except: front wall, one-third glass and two-thirds wood (3/4-inch V joint over 1/2-inch insulation board). Gutteridge et al, after four years of work concluded

that increasing the environmental temperature of laying pullets by the use of artificial heat and insulation had no significant effect upon egg production.

Ashby et al. (1945) classified insulation requirement for poultry laying houses according to the climatic condition into four zones. Table 2 shows the recommended insulation values for the walls and ceiling according to the temperature during January.

Ashby et al. also noted that a vapor barrier was needed on the warm side of fibrous or fill-insulating materials to prevent the water vapor in poultry-house air from condensing in the insulation. Shiny, heavily asphalted, or aluminum-flake paint, or aluminum foil were examples recommended by them to be used as a vapor barrier. They further recommended that the spaces packed with fill insulation should breathe to the cold (outer or upper) side to assist in drying out moisture that might penetrate through the barrier.

White and Schwantes (1947) conducted an experiment on six laying houses by using different methods of insulation in each house. In house A, they used an insulation board sheathing on walls, ceiling, and roof. House B was the same as house type A with single blanket insulation added to walls and straw in the loft. Houses C and D were the same as A with double blanket insulation added to walls only. House E was the same as A with double blanket added to the walls and ceiling. House F was similar to house A without vapor barriers, with open stud spaces, and with low front and rear walls.

Table 2. Insulation Requirement for Poultry Laying Houses According to the Temperature During January

Zone No.	Temp. in Jan. °F	Inside Design Temp. °F	Extreme Design Temp. °F	R-value for Walls	R-value for Ceilings
1					
a. Very cold	< 10	32	15	10 or 8	12 or 15
b. Cold	10 - 20			6 or 5	8 or 12
2	20 - 40	40	20	5 or 3	6 or 10
3	40 - 50	45	25	1.5	4
4	> 50	50	32		

Source: W. Ashby, T. A. H. Miller, G. L. Edick, and A. R. Lee, (1945) Functional Requirements in Designing Laying Houses for Poultry. U.S.D. of Agriculture. Circular 738.

White and Schwantes concluded from their experiments that construction types A, B, E, and F were satisfactorily warm and dry, and weeping occurs on walls in colder weather in types A and B, and that house D was not satisfactory because of condensation on the ceiling.

The Poultry Committee of the New Jersey Agricultural Experiment Station (1947) recommended insulation for laying houses because it helps to maintain more nearly uniform temperatures. In their opinion the roof or ceiling of the laying houses should be well-insulated to counteract the heat absorbed by the roof in hot weather and to reduce heat losses during cold weather. Side-wall insulation was also recommended by them in regions where there is intense cold in the winter season, extreme heat in summer, or both. They mentioned that observations and some experimental results indicated that the cost of insulation would soon be recovered through increased egg production.

Recently the Midwest Plan Service (1975) recommended the following insulation values for walls and ceilings.

Walls: R-value of 8-10 (frame wall + 1 inch - 2 inch insulation, or 8 inch light weight concrete block + 2 inch insulation + interior lining). The walls should be peck proof.

Ceilings: R-value of 12 - 15 (lining + 4 inch fill insulation).

III. TEMPERATURE AND HUMIDITY EFFECT ON EGG PRODUCTION

A review of the literature covering the effect of temperature and humidity on egg production indicates extensive study over two centuries.

Stewart and Atwood (1899) studied floored versus unfloored houses for poultry and concluded that the best results were obtained in the warmer, unfloored pens where the fowl remained in a healthy condition. Egg production in the unfloored houses equaled or exceeded production in houses provided with floors.

In the early years of this century Gardiner (1902) indicated that poultry houses may be profitably heated to an average temperature of 45 to 50° F, although little artificial heat was required in a properly constructed house while the sun was shining. He also mentioned that under the average conditions poultry will be healthier when kept in buildings properly heated since they will avoid extremes of heat and cold.

From Canada, Gilbert (1906) studied the effect of heating on egg production by comparing a heated and an unheated house. Egg yield from the warm house for 13 Barred Plymouth Rock hens was averaging 65.75 eggs per month, while the egg yield from the cold house for the same number and the same breed was averaging 76 eggs per month. This conclusion is not in agreement with the conclusion of Gardiner (1902), Stewart (1899), and Hinebauch (1896).

Elford (1915) from Canada indicated that the best results were obtained from houses having low uniform temperatures and dry conditions.

Studies by Lewis and Thompson (1917) showed that the average poultry house should be warmer than the outside normal temperature during the winter and cooler than the outside normal temperature during the summer.

Hutter et al. (1933) in their experiment at the Cornell Agricultural Experiment Station also gave conclusions concerning the temperature and humidity effects on egg production: (1) birds seemed to slow down in their activity, and production lagged when the temperature dropped below 10° F in the pens and remained below for more than three or four hours; (2) drops in winter temperature seemed to cause a drop in the cage production of pullets. The full significance of this cannot be brought out by correlation coefficients; and (3) relative humidity, ranging from 40 to 95% but never remaining above 90% for longer than 24 hours, seemed to have no effect on pen conditions or on the activity of the birds through the test.

The experiment conducted by Moore and Karns (1937) indicated that the temperature variations occurring locally were relatively unimportant, except for extremely cold periods in the winter. Cold periods of several days duration reduced production.

In 1944, at the University of Queensland, Australia, Lee et al. (1945) studied the effect of temperature and humidity and other factors on the birds' health and egg production. Their conclusions about temperature and humidity effects can be summarized as follows: (1) a dry bulb temperature of 80° F marks the point above which slight disturbances of bodily function begin to appear. It is probable that the economic efficiency of the hen commences to decline at the same time; (2) a dry bulb temperature of 100° F cannot be safely withstood for seven hours unless the relative humidity is less than 75%. A dry bulb temperature of 105° F can be safely withstood for only a few hours,

no matter what the relative humidity is. As the temperature increases, the tolerance time falls off rapidly; and (3) if shade temperatures above 105° F are likely to be experienced for more than one hour during the day, the well-being of the hens will be markedly upset and death is likely to occur.

Ragab and Assem (1953) conducted their experiment to study the seasonal variation of egg production in different geographic locations. They concluded that high environmental temperature is one of the major cause of decline in egg production during summer.

Wilson et al. (1957) studied the influence of environment on the production characteristics of chickens. To study the effect of decreasing air temperatures on production characteristics, they lowered the temperature 10° F every three weeks, starting from 95° F to a minimum of 25° F. Two control groups of pullets were used. One group kept at a constant temperature of 65° F, the other group kept in an unheated room where the temperature decreases seasonally from a weekly average of 77° F to 50° F. They mentioned that within the range of 48° F, egg production was not reduced by variations in temperature, and that daily fluctuation in temperature was not harmful to egg production in the group kept in the unheated room. They also concluded from their experiment that high ambient temperature and high relative humidity may affect the health of the birds.

Many researchers indicated that 55° F is the optimum temperature for efficient egg production. Long et al. (1958) conducted an experiment to study this factor, and to determine the effect of different temperatures over a long test period with large numbers of hens.

Eight different pens of 100 White Leghorn hens were kept under different environmental temperatures. The different environmental treatments were: (1) floor pen with no temperature control; (2) cage pen with no temperature control; (3) mechanically ventilated floor pen with no temperature control; (4) mechanically ventilated floor pen with temperature control; (5) floor pen with constant 40° F temperature; (6) floor pen with constant 55° F temperature; (7) cage pen with constant 55° F temperature; and (8) floor pen with constant 70° F temperature. Results from the first six months test period indicated that the highest egg production was 113.36 eggs/hen from the birds in the 55° F floor pen. The next highest egg production was 112.85 eggs/hen from the birds housed at 70° F in the floor pen. The third pen in production was the cage pen with 55° F where the production was 111.90 eggs/hen. For the remaining pens, the egg production was as follows:

from the floor pen with no temperature control, 90.84 eggs/hen;

from the pen with constant 40° F temperature, 77.33 eggs/hen;

from the mechanically ventilated pen with no temperature control, 93.34 eggs/hens;

from the mechanically ventilated pen with temperature control, 108.33 eggs/hen;

from the cage pen with no temperature control, 108.18 eggs/hen.

Temperature control in the mechanically ventilated pen showed higher production. This result does not agree with Fairbanks and Goodman (1926) who recommended not to use a thermostat to control the operation of the ventilators.

Two experiments to study the effect of high temperatures and humidity on egg production were conducted by Squibb (1959) and by Squibb et al. (1959). In the first experiment, the birds were housed in wire cages 12 x 18 x 18 inch in size in five distinct climatic areas having temperatures ranging from 32 to 113° F with variable humidities. Results from this experiment indicated that there were no significant differences in egg production, egg size, and mortality between areas or between groups within areas, and that New Hampshire chicks may tolerate high environmental temperatures and humidities through a wide diurnal pattern. In the second experiment, a flock of 56 White Leghorn hens, nine months of age, was divided randomly into two groups consisting of 15 and 41 birds respectively. The 15 hen group was placed in an all-wire 3 x 3 foot cage and housed in a clear plastic, air-supported structure. The larger group was kept in a standard poultry house. Maximum ambient temperatures during the first and third weeks in the air-supported structure reached levels which have been lethal under field conditions, and rose to 96 and 98° F during the other two periods. Results from this experiment as from the first experiment showed that there were no significant differences in egg production between the birds subjected to the high ambient temperatures and the other group that kept in the standard poultry house (control house).

Muller (1961) studied the effect of constant and variable environmental temperature and humidity on egg production, feed intake, and mortality in pullets. For this purpose, three rooms, each

9' x 19' x 9' high were used in the experiment. Different constant temperatures and relative humidities were tried in the three rooms. A fourth room was designed to cycle temperature within the limits of 50 to 110° F and relative humidity within 30 to 90%. Results from this experiment indicated that a constant temperature of 90° F increased mortality and decreased egg production and feed intake as compared with pullets kept under a constant temperature of 55° F. Results also indicated that pullets kept in an environment where temperature cycled from 55° F to 90° F and back to 55° F every 24 hours produced more eggs than pullets kept at a constant temperature of 55° F. The egg production of pullets kept in the uncontrolled environment was higher than the egg production of the pullets kept at a constant temperature of 55° F.

Payne (1966a) showed that a fluctuating environment in which the birds were kept first under 86° F for fifteen hours and then under a temperature of 65° F for fifteen hours and then under a temperature of 65° F for nine hours was very efficient in egg production.

Payne (1966b) studied the effect of different environmental temperatures upon production. Four environments were maintained in this experiment: (1) a constant temperature of 84° F day and night, (2) a constant temperature of 62° F day and night, (3) a fluctuating temperature of 86° F during light time and 63° F during dark time, and (4) a fluctuating temperature of 68° during light time and 86° F during dark time. The following is a summary of

results: (1) birds housed at constant temperatures of 62° F and 86° F laid equal total egg masses, equivalent to 260 eggs of (2.0 ounce) weight in one laying year; (2) birds housed at a constant temperature of 84° F produced more (but smaller) eggs than the birds housed at a constant temperature of 62° F; (3) birds housed in a fluctuating environment produced a significant increase in total egg mass of approximately 4% compared to the birds housed at a constant environment; and (4) the same number of eggs were produced from birds housed in the two fluctuating temperature cases.

For the purpose of studying the practical aspects of environmental temperature for laying hens, Payne (1966c) conducted an experiment on four strains of birds. The birds were placed, three per battery cage, into each of eight environmentally controlled rooms. Each room contained 72 pullets (18 of each of the four strains). Two rooms were maintained at a constant temperature of 83° F. The other rooms were used as three pairs of fluctuating environments. One pair of rooms was maintained at 41° F by means of high ventilation rate. Ventilation was reduced only when the outside temperature fell below the freezing point. The other four rooms were maintained at a temperature of 59° F by using thermostatically controlled ventilators. Cooling equipment was used to lower the temperature in two of the four rooms to 47° F for three hour period each day. Results from this experiment, for the first six months, showed (1) a superior egg production from each of the fluctuating environments as compared with production

from the rooms maintained at a constant temperature of 83° F, (2) egg production was decreasing in the cool, highly ventilated, environment.

The most significant work with respect to the rate of ventilation for maintaining proper temperature and relative humidity in poultry houses is that of Ota (1966). He applied a new technique for the physical control of environment for growing and laying hens. His technique was to use the conserved heat in the house. He mentioned that the use of conserved heat in the poultry house to control temperature and moisture removal requires an understanding of the psychrometric properties of air and proper management of the ventilation system, and that, during mild winter weather, if the poultry house air is at 50° F with 60% relative humidity each one pound of air will remove 0.0015 pounds of water. Under actual conditions, the indoor humidity will reach that of the outdoor very quickly if a high ventilation is continued. This is an expensive way to remove moisture from poultry houses; however, if the ventilation rate were adjusted such that the indoor temperature was raised a few degrees above the outdoor, large amounts of moisture could be removed from the house without any waste of energy. Ota (1966) mentioned some points which are worth noting: (1) one should note the relationship of ventilation rate to indoor temperatures as the weather changed, thus, by trial and error, he will be able to control temperature and removal of moisture; and (2) temperature inside the poultry house is seldom uniform. Effective ventilation

is indicated when the temperature at the bird level is within 4 to 5° F of each other. If greater temperature spreads are noted, corrective measures are necessary, such as adjusting air inlets for better air distribution, sealing cracks around doors and windows to minimize air leakage, and even adding insulation to surfaces where moisture condenses.

Ota (1968) gave a brief summary for temperature and humidity control factors as follows: (1) in summer, birds lose more heat by inspiring dry air than by high air movement around their bodies. Also, they produce heat at a sharply accelerated rate at low temperatures. Chickens can withstand temperatures as low as 20° F if air velocity is kept low. High speed air distribution in densely populated houses may be harmful even at 55 to 60° F; (2) chickens acclimatize to hot and cold weather. Diurnal temperature fluctuations in summer between 50 to 60° F appear to have no influence on egg production; (3) chickens radiate an appreciable portion of their total sensible heat. Aluminum colored surfaces minimize radiant heat loss to the building. This is an advantage in winter but a disadvantage in summer; (4) constant air temperatures near 50 to 60° F in winter show good egg production. In summer, any temperature lower than 90° F may be satisfactory with the lowest possible humidity; and (5) daily trends in egg production may help to control the temperature and moisture removal. To assess the values of insulation and ventilation, compare egg data from production houses.

IV. SUPPLEMENTARY HEAT

Controlling the environmental conditions, especially air conditioning, in poultry laying houses is one of the engineering problems related to egg production. The problem could be solved if certain factors concerning the requirements of birds were known. Supplementary heat during the cold months of winter, when the temperature drops below freezing, seems to improve the environmental conditions of the laying house and to increase egg production.

Bruckner (1936) studied this problem and concluded that the use of heat to maintain a mean temperature of 50° F in laying houses during winter increased egg production, and that a temperature of 50° F or higher decreased food consumption. He suggested that temperatures between 35 and 50° F are more preferred if the poultry house is to be artificially heated. He also concluded that in a poultry house artificially heated to a mean temperature of 60° F, the health, body weight, and egg size of the birds will be adversely affected.

Lee et al. (1937) studied the effect of supplementary heat on egg production. The experiment was conducted using eight artificially ventilated and insulated 24 x 24 foot pens. Artificial heat was supplied in four pens for the period from November 26, 1935 to March 24, 1936. Average temperatures of 38 to 45° F were kept in the heated pen. The average temperature of the unheated pens was 29.7° F for January, 33.8° F for February and 48.7° F for March. Table 3 shows the egg production per bird from four of the eight pens for the first year. Results from the first year obviously show that the annual egg

Table 3. Egg Production per Hen from Heated and Unheated Pens for New Hampshires and White Leghorns

Month	Unheated Pen New Hampshires	Heated Pen New Hampshires	Unheated Pen White Leghorns	Heated Pen White Leghorns
1935				
September	3.60	9.78	0.18	0.06
October	12.27	12.57	5.52	5.10
November	13.17	10.83	9.68	10.67
December	11.83	9.61	8.66	13.07
1936				
January	6.78	10.28	12.09	13.92
February	5.54	7.34	14.15	14.27
March	12.08	8.09	19.41	17.38
April	17.22	12.01	21.06	13.65
May	17.00	12.62	19.83	12.70
June	14.56	11.80	18.64	13.88
July	11.35	9.61	14.82	11.70
August	11.86	9.26	13.57	10.68
September	5.40	4.19	6.04	5.35
Total Production for One Year	142.66	127.99	163.63	142.43

Heating Period

Source: C. E. Lee, S. W. Hamilton, C. L. Henry, and M. F. Callanan. (1937) The Effect of Supplementary Heat on Egg Production, Feed Consumption, Amount of Litter Required, and Net Flock Income. Paultry Science 16:267-273.

production both in New Hampshires and in White Leghorns is lowered by applying supplementary artificial heat. Lee et al. (1937) mentioned that the net return per bird was not significantly different in the heated and unheated pens with New Hampshires, and that the net return per bird seemed to be significantly different, in favor of the unheated pens, with the White Leghorns.

Results from the second year experiment conducted by Lee et al. (1939) indicated that supplementary heat also lowered annual production, and that heating poultry houses slightly decreased feed consumption. This experiment was conducted on S.C.W. Leghorns and Rhode Island Reds.

V. SUMMARY OF LITERATURE

The lack of agreement in the results of experiments conducted by hundreds of people working in this area was apparently due to failure to consider all environmental factors affecting egg production.

Smith (1930), Hutter et al. (1933), Lee et al. (1937), the poultry committee of the New Jersey Agricultural Experiment Station (1974), Ota (1966), and Ota (1968), from their observations and experimental results, recommended good insulation for poultry laying houses for the purpose of decreasing heat flow to the building in the summer and to decrease the heat lost from the building in the winter. Thus better environmental conditions throughout the year can be maintained with minimum cost.

Experiments conducted by Hinebauch (1896), Gardiner (1902), Hutter et al. (1933), Lee et al. (1945), Wilson et al. (1957), Long

et al. (1958), Muller (1961), and Payne (1966b) indicated that an average daily temperature within the range of 35 to 70° F improves egg production and has no adverse effect on feed consumption and mortality of chickens. As the average daily temperature became higher than 70° F the egg production and feed consumption decreased, while mortality increased. Daily average temperatures lower than 35° F indicated an increase in feed consumption and mortality and a decrease in egg production.

CHAPTER III

BUILDING DESIGN, INSULATION VALUE, AND VENTILATION SYSTEM

I. BUILDING DESIGN

The experiment was conducted on house number (10) at the Poultry Farm of the University of Tennessee, Agricultural Experiment Station, Knoxville, Tennessee. The house had outside dimensions of 32 x 160 feet. A cross-section through the building is shown in Figure 1. Columns and trusses were 10 feet apart. Columns were 3.5 x 3.5 inches, constructed on a concrete foundation. The building had 32 windows. The east wall contained 16 windows of 8' 6" x 5' 3" size uniformly spaced, and installed five inches above the ground level. The other 16 windows of the west wall were installed 1' 10" above the ground with a size of 8' 2" x 3' 11". Total window area was 1,225 ft^2. Upper and lower parts of the windows were adjustable to be opened and closed when necessary. The windows were made of 1.5 inch thick wood frame and a wire net. Cross-sections through the east and west walls are shown in Figure 2. Windows were constructed on eight inch concrete block walls and separated by 16 inch square concrete block columns. Figure 3 shows a side view of the building. A maximum of 3,360 chickens could be housed in the building. Two birds were housed in each 8 x 18 x 18 inch wire cage. Thus 1,680 cages were provided to house the 3,360 bird flock. Cages were arranged in eight lines and supported by steel wires to the ceiling. Each line consisted

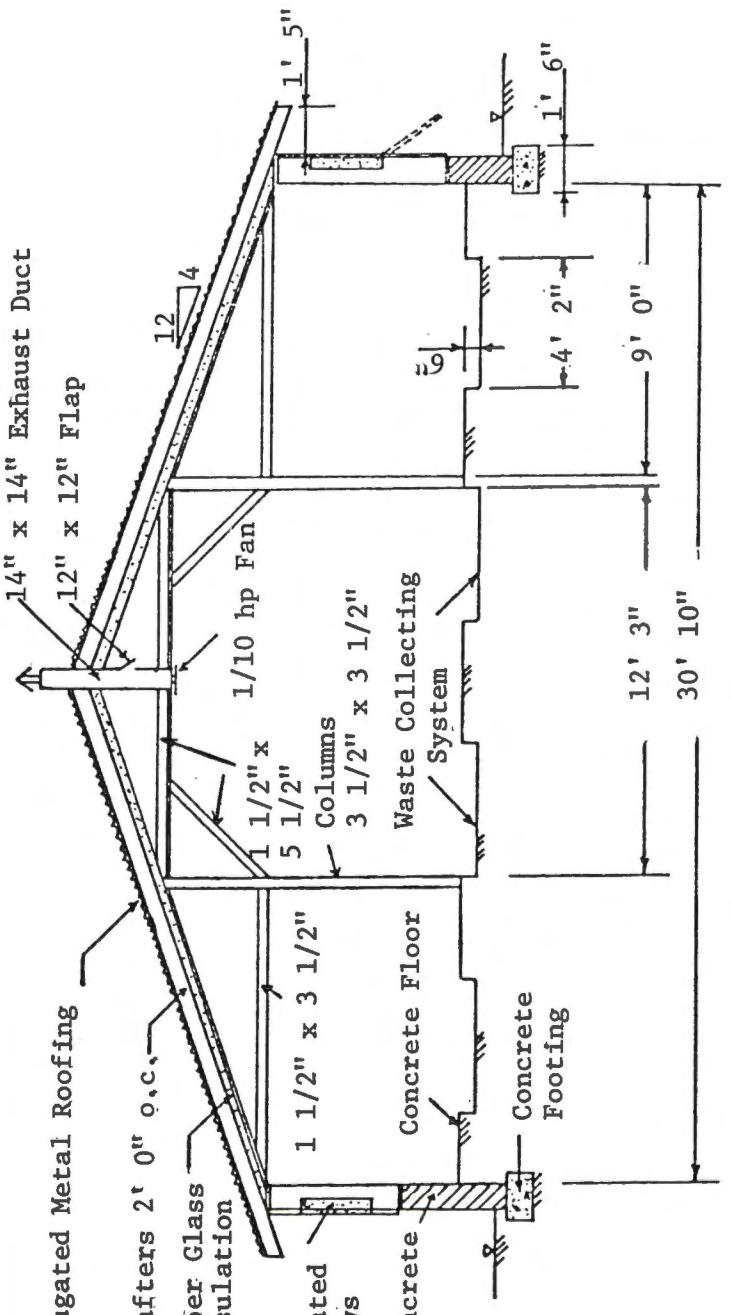


Figure 1. A Cross-Section in the Building Showing Poles and the Structure Framing (not to scale).

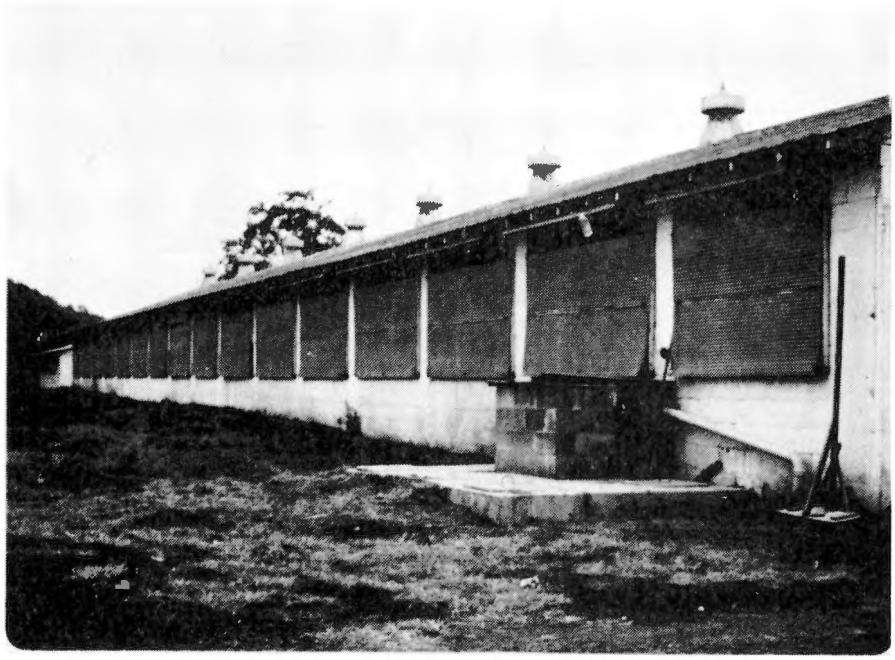


Figure 3. Side View of the Building.

of 210 cages extending lengthwise along the building. Water was provided by a trough passing through the center line of each two cage rows. Feed was supplied to chickens in a metal trough on the side of cages. Figure 4 shows the arrangement of cages and feed troughs. Waste was collected in four concrete ditches 4' 2" wide and six inches deep located below the cages in the longitudinal direction of the building. Pit scrapers were installed inside each ditch. The scrapers were mounted on a steel cable and operated by an electrical motor. As shown in Figure 5, the operation of the motor was arranged to move two of the scrapers towards the front of the building and the other two scrapers in the reverse direction. Scrapers that moved to the front collected the waste into a cross channel. From the cross channel waste was collected into two reservoirs constructed outside the building. A one horsepower motor was used to drive the system. The time required to remove waste from ditches was about five hours each three weeks.

II. INSULATION VALUE

A. U-value for Walls

Fiber glass was used to insulate the windows, north and south walls, and the ceiling. Adjustable parts of the windows were insulated with one inch thickness of expanded polyurethane.

U-values of the different wall sections were determined using the resistance for component materials given in Table 4. These values were calculated based on an estimated wind speed of 7.5 miles per hour outside the building. The overall U-values for walls are given in Table 5.

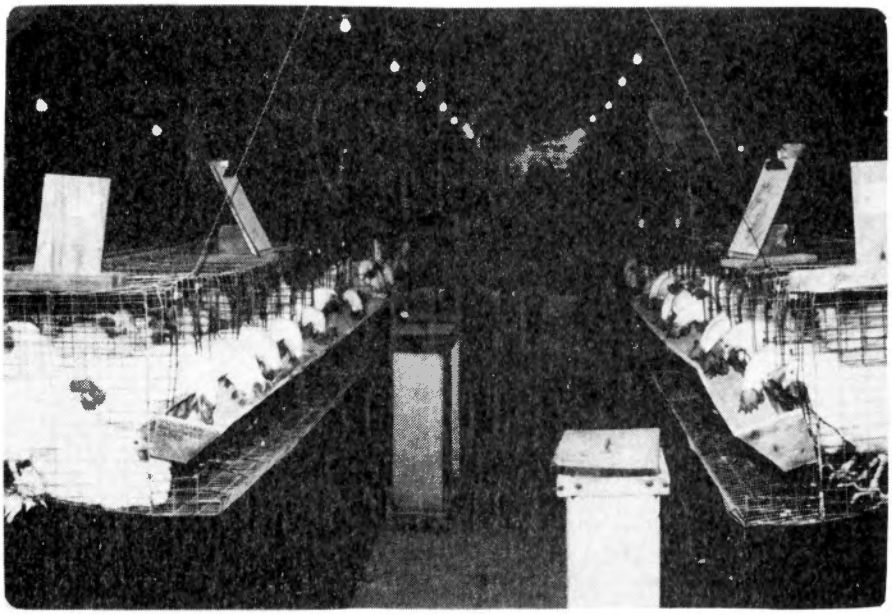


Figure 4. The Arrangement of Cages, Feed Troughs and Feed Containers Inside the Building.

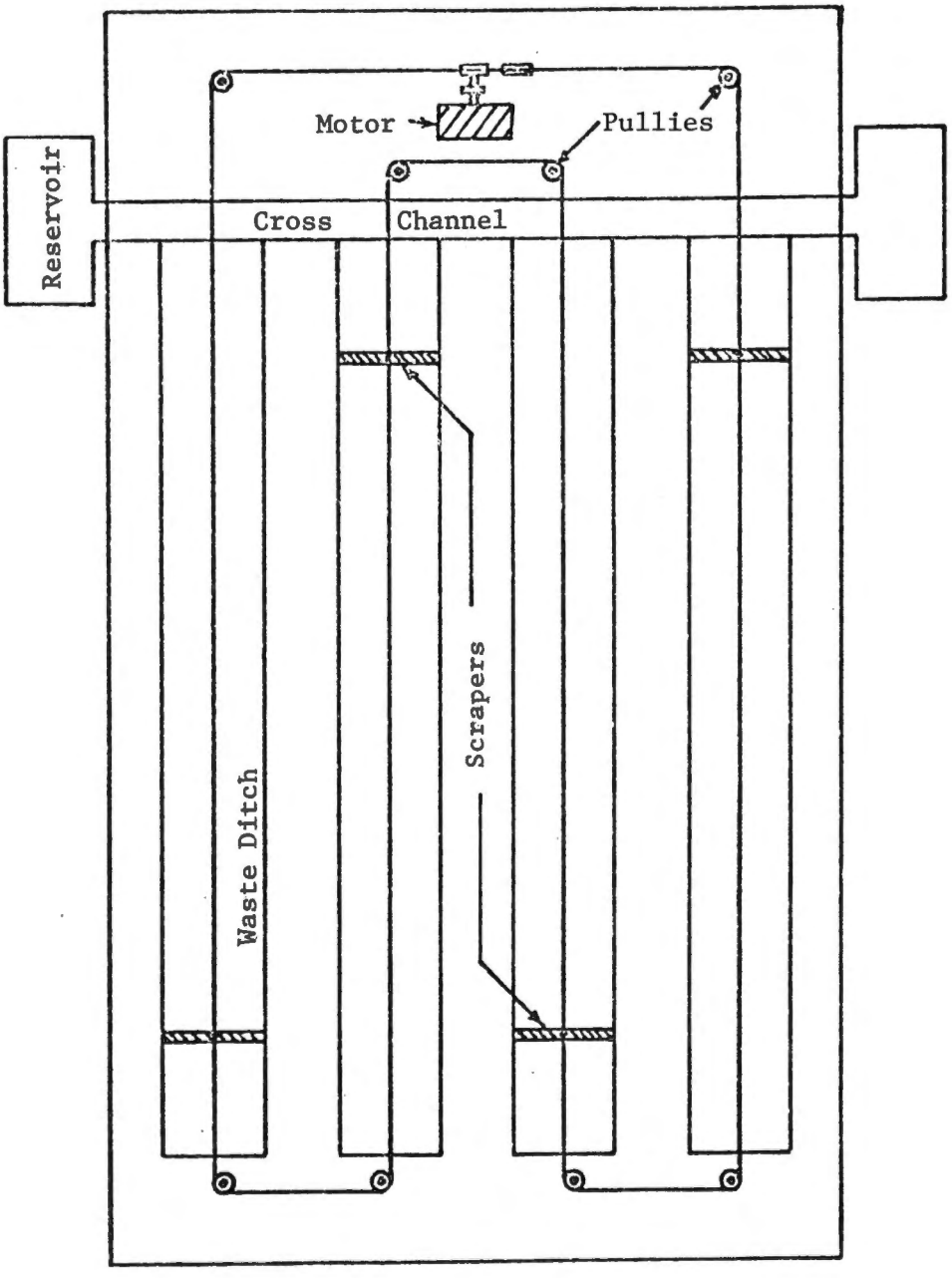


Figure 5. The Waste Removal System Showing the Cables' Connections to the Scrapers and Motor.

Table 4. Conductances and Resistances of Building and Insulating Materials

Material	Thickness inch	Conductance (c) Btu/hr ft^2 °F	Resistance R = 1/c
Concrete blocks, three oval core cinder aggregate	8	0.580	1.72
Square columns of concrete blocks three oval core cinder aggregate	16	0.290	3.44
Expanded polyurethane	1	0.160	6.25
Loosefill (mineral fiber)	5 1/2	0.061	16.40
Fiber glass	3 1/2	0.091	11.00
Wood frame	8	0.100	10.00
Plywood (doors material)	1/2	1.613	0.62
Plywood board	1/4	3.226	0.31
Air space in the attic of one foot thickness which is equivalent to one and one-half inch air space	--	--	1.14
Surface conductances and resistances for air:			
a. Moving air 7.5 mph wind		4.0	0.25
b. Still air (inside building)		1.46	0.68

Table 5. Summary of U-values for Wall Sections of the Building

Wall	Wall Section	Estimated Area-A ft^2	U-value	UA
East	8 inch block wall	72.78	0.37735	27.46
	16 inch block columns	117.06	0.22883	26.79
	Window frame 8 inches thick	55.18	0.09150	5.05
	Fixed part of windows	319.00	0.05669	18.08
	Adjustable parts of windows	412.50	0.13351	55.07
West	8 inch block wall	250.00	0.37735	96.22
	16 inch block columns	123.14	0.22883	28.18
	Window frame 8 inches thick	48.17	0.09150	4.41
	Fixed part of windows	274.45	0.05669	15.56
	Adjustable parts of windows	216.40	0.13351	28.89
	One door	28.00	0.64520	18.07
North	Concrete walls with 2 inch fiber glass insulation	200.81	0.09124	18.32
	One door	28.00	0.64520	18.07
South	Concrete walls with 2 inch fiber glass insulation	200.81	0.09124	18.32
	One door	28.00	0.64520	18.07
	Total	2349.30		396.56

B. U-value for Roofs and Ceiling

Insulation used for the south section of roofs and ceiling was originally one inch thickness expanded polyurethane. During summer this insulation was replaced by 3 1/2 inch thickness fiber glass having a resistance value of 11.0. Table 6 is a summary of the computed U-values for roofs and ceiling.

C. U-value for the Floor

No exact value of the coefficient of heat transmission was found. However, a U-value of 0.10 Btu/hr ft^2 °F for concrete floors on ground is frequently used. The area of the floor was 4,880 ft^2.

D. Overall U-value of the Building

All results from Table 5 and Table 6 are summarized in Table 7. From this table and equation (6) the overall U-values before and after the modification of roofs were determined to be equal to 0.1153 and 0.1045 Btu/hr ft^2 °F respectively.

$$\text{Overall U-value} = \frac{\Sigma(A_i U_i)}{A} \qquad (6)$$

where

U_i = overall coefficient of heat transfer for a particular structural component, Btu/hr ft^2 °F

A_i = area of the specific building component, ft^2

A = total surface area of the building, ft^2.

Table 6. Summary of the U-values of Roofs and Ceiling

Section of the Roof or Ceiling	Estimated Area A-ft^2	U-value	UA
Before Modification			
North section			
east and west roofs	1518.72	0.08170	124.08
ceiling	1015.12	0.07474	75.87
South section			
east and west roofs	1518.72	0.13927	211.51
ceiling	1015.12	0.12019	122.00
After Modification			
east and west roofs	3037.44	0.08170	348.16
ceiling	2030.24	0.07474	151.74
Total			
Before modification	5067.68		533.46
After modification	5067.68		399.90

Table 7. Summary of UA-values of the Building Components

Building Component	Area Ft^2	U-value	UA
Walls	2349.30	1.68790	396.56
Floor	4880.00	0.10000	488.00
Roofs and Ceiling			
Before modification	5067.68	0.10526	533.46
After modification	5067.68	0.07891	399.90
Total			
Before modification	12296.98		1418.02
After modification	12296.98		1284.46

E. Exposure Factor

The exposure factor of the building can be defined as the conductive heat loss from an animal shelter expressed in units of Btu/hr °F animal or

$$E.\ F. = \frac{\Sigma(A_i U_i)}{N}$$

where N = number of animal units housed. The exposure factor of the building before modification was found to be equal to 0.471 Btu/hr °F animal (the number of birds housed was 3,009). After modification, the number of birds was averaging 3,326, and the exposure factor for the new conditions was 0.386 Btu/hr °F animal. The ASAE data D270.4 (1975) recommended an exposure factor of 0.2 - 0.5 to be satisfactory for poultry laying houses.

III. VENTILATION SYSTEM

The building was supplied with eight intermittently operated ceiling exhaust fans equally spaced along the center line of the building. The north and south halves of the building were each supplied with a thermostat. The two thermostats could be set to obtain several rates of ventilation depending upon the temperature inside the house. Each fan was powered by a 1/10 horsepower motor. Fourteen inch square ducts were constructed through the ceiling with a 12 x 12 inch flap which could be opened for attic ventilation during the summer. These flaps could be opened and closed as necessary.

To determine the maximum capacity of the ventilators, a velocity transducer with a sensor was used to measure the velocity of air in

cross sections of two of the ducts. Graphs of the air velocity through both ducts were drawn, and the average air velocity in the ducts was found to be 13.6 fps. The capacity of each fan was thus determined. The overall air flow was equal to 8885 cfm. Based on the maximum number of birds that could be housed in the building (3,360 birds), the air flow rate was calculated to be approximately 2.65 cfm/bird if the fans were operated continuously. Because fans were operated for only four minutes every 10 minutes, the actual air flow was about 1.0 cfm/bird.

CHAPTER IV

PROCEDURE

I. EQUIPMENT AND INSTRUMENTATION

A thermocouple recorder with 60 point capacity was used in the study. Fifty-two copper constantan thermocouples were distributed in different locations of the building to cover all the necessary measurements of dry and wet bulb temperatures. The recorder could be set to measure temperatures at time intervals from one to 60 minutes. Along with temperatures, the time of the day and the thermocouple number were also recorded. Since the recorder enclosure was sealed for dust protection, high temperatures during summer affected its operation and caused erroneous temperature measurements. A ventilation fan was installed to cool the recorder and eliminate the high temperature problem. A paper tape punch was used to record the data on paper tapes during the last month of the experiment. From the tapes the data could be transferred to a computer. Figure 6 shows the temperature recorder and the paper tape punch.

Other instruments used were: two hygrothermographs, a wind speed measuring device, a black globe thermometer,. wet bulb temperature measuring devices, two kilowatt-hour meters, and a 4000 watt heater.

One of the hygrothermographs was used to measure the temperature and relative humidity inside the building. The other one was used to measure the outside temperature and relative humidity. The

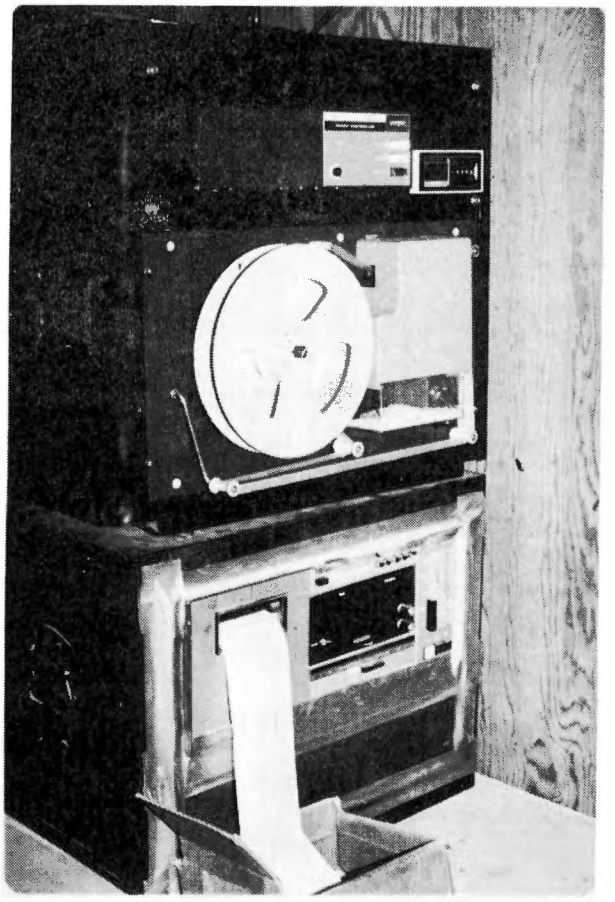


Figure 6. The Temperature Recorder and the Paper Tape Punch.

hygrothermographs consisted of a recording chart mounted on a drum. The drum was operated by a mechanical drive. Data for one week could be recorded on one chart starting from 12:00 noon Monday and ended at 11:00 a.m. of the next Monday. It was necessary to change the chart, wind the chart drive, and check the ink in the recorder pins every week.

The wind speed measuring device was a three cup anemometer. The cups rotated due to the effect of wind. A vertical shaft was connected at the top to the three cups and to a gear arrangement at the bottom. The gears were arranged to rotate a counter to indicate the linear movement of the wind. The average wind speed during any given day could be found by dividing the difference in the counter reading by the time during which the change happened. One disadvantage of this mechanism was that a very low wind speed would not rotate the anemometer due to the friction in the mechanism.

One of the thermocouples was connected to a black globe and a continuous record of the black globe temperature was taken for the purpose of determining the daily radiant heat load.

Wet bulb temperature can be measured if a good air movement is provided over a wetted wick. Arrangements were made to measure wet bulb temperatures of exhaust air. Air movement was provided by the exhaust fans. The wetting device consisted of a plastic water filled bottle with a plastic tube of about 3/8 inch diameter installed in a hole near the top. A wick was inserted through the tube extending from both ends. The water rose through the tube by the capillary action. Thermocouples were installed to the top part of the wick.

The water level in the plastic bottles was checked periodically and water was added to keep its level above the bottom of the wick. Thus, a constant wet surface was provided. Figure 7 shows two of the wet bulb temperature devices near one of the exhaust fans.

Two kilowatt-hour meters were used. One of them measured power consumption for lights, exhaust fans, and the motor used to operate the waste cleaning system. The other was provided to measure the power consumption of the heater. Using these kilowatt-hour meters, the power consumption of each of the lights, exhaust fans, motor, and the heater could be determined separately by shutting off the electricity from all the other equipment and measuring the electricity supplied only to the device being tested. Power consumption was determined from the formula

$$P = K_h \times N \tag{7}$$

where

P = power, kilowatt-hour

K_h = the meter constant = 3.6 for the kilowatt-hour meters used

N = number of revolutions per hour of the kilowatt-hour meter disc.

The total power consumption over any period of time could be found by determining the difference in readings at the beginning and end of the period.

The 4000 watt heater was used to raise the temperature of the south section a few degrees above that of the north section. It was an electrical resistance unit with a circulating fan to force air over

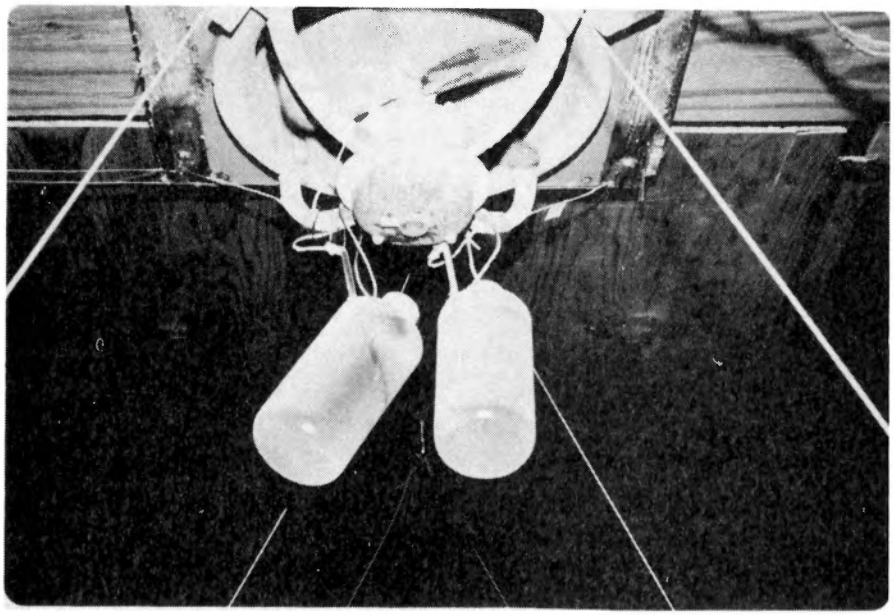


Figure 7. Two of the Wet Bulb Temperature Measuring Devices

the resistance wires. The heater could be adjusted to operate on low and high stages. Figure 8 shows the heater installed in the south section of the building.

II. EXPERIMENTAL DESIGN

A. Installation of Thermocouples

Thermocouples were distributed in the building to meet the need for temperature measurements at different locations. Figure 9 is a map showing the different locations of thermocouples inside and outside the building. Those measurements were as follows.

1. Walls.

a. East Wall: two thermocouples were installed to measure the outside temperature of the east wall and another two thermocouples for measuring the inside temperature of the wall.

b. West Wall: the same arrangement was made for measuring the inside and outside temperatures of the west wall.

c. North Wall: one thermocouple was installed to measure the outside temperature of the wall and one for the inside temperature of the wall.

d. South Wall: same process was used as on the north wall.

2. Ceiling and roofs. Two thermocouples were installed to measure the temperature of the upper surface of the roof, and another two were installed for measuring the temperature of the inside (lower) surface of the ceiling.

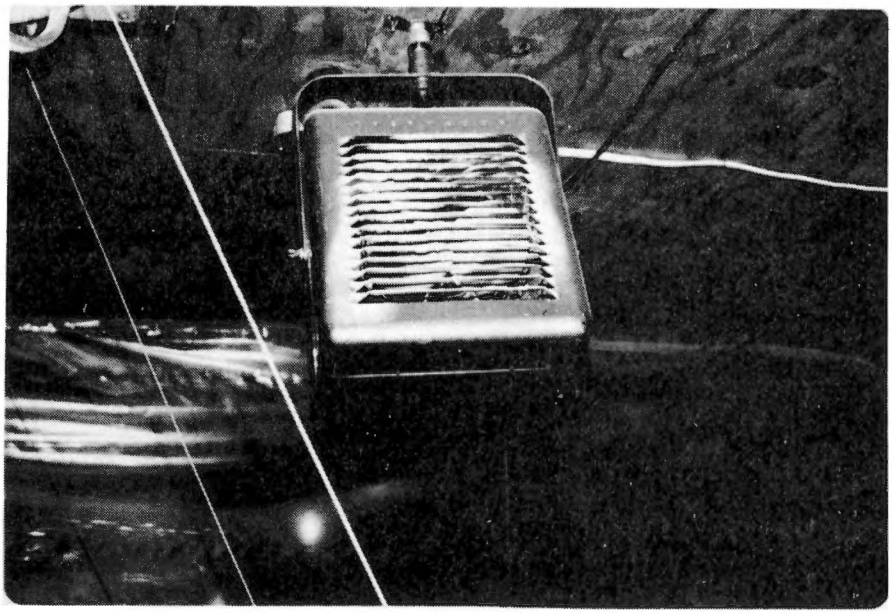


Figure 8. The Electric Heater Installed in the South Section of the Building.

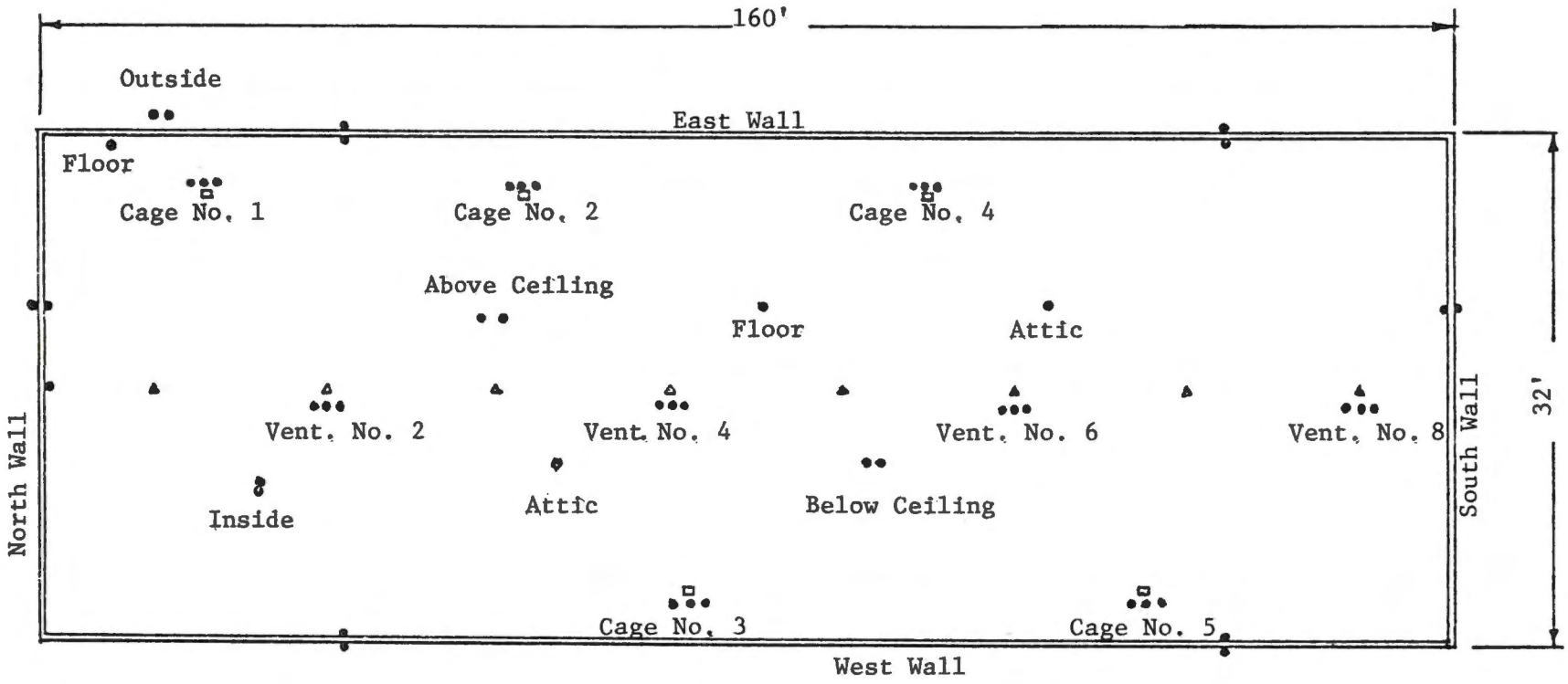


Figure 9. A Map Showing Location of Thermocouples Inside and Outside the Building.

△- Ventilator.

□- Cage.

●- Thermocouples

3. Attic. Two thermocouples were installed in the attic. These thermocouples were inserted to the center of the attic so that the measurements would be representative.

4. Ventilators. Wet and dry bulb temperatures were measured by installing two thermocouples for measuring the wet bulb temperature and one for measuring the dry bulb temperature at four of the eight ventilators, two located at the north section of the building, and two in the south section. During the period of supplemental heating in the south section, three of the thermocouples which had been used to measure the wet and dry bulb temperatures were used to measure the inside temperature of the south section.

5. Inside and outside air temperature. Two thermocouples were used to measure wet bulb temperature of air inside and outside the building and another two were installed to measure the inside and outside dry bulb temperatures of air.

6. Cage temperature. Three thermocouples were installed for measuring temperatures above, below, and in the cage for five cages distributed in different locations within the building.

7. Black globe. One thermocouple was used to measure the black globe temperature.

B. Environmental Conditions for the Experiment

The experiment was conducted under two conditions: (1) summer season when the inside air temperature reached slightly above 80° F

during June, July, and August; (2) winter season when the inside air temperature reached below 30° F during October, November, and December. In the second stage of the experiment (winter season), the building was divided into two sections (north and south sections), and a new fiber glass insulation material replaced the old insulation in the south half of the building ceiling. A plastic partition was constructed at the center of the building so that half of the birds were kept in each section. The plastic partition was constructed to prevent heat from flowing from one section to the other and to keep a difference in temperature of 5° F or slightly above between the heated south end and the unheated north end. Figure 10 shows the plastic partition used. The heater in the south end was installed below the ceiling and tilted to an angle of about 10° with the vertical, so that it would not create an air current directly on the nearby cages.

C. Light Timing and Control

Light was supplied by sixty-four 40-watt bulbs equally spaced and distributed in the building. An automatic control was provided to adjust for the time required for light by birds. It was set to operate for 15 hours between 5:30 a.m. to 8:30 p.m. every day.

III. DATA COLLECTION

A. Hygrothermograph Data

Continuous data for the inside and outside temperatures and relative humidities of air were taken by installing two hygrothermographs, one inside the building and the other outside the building.

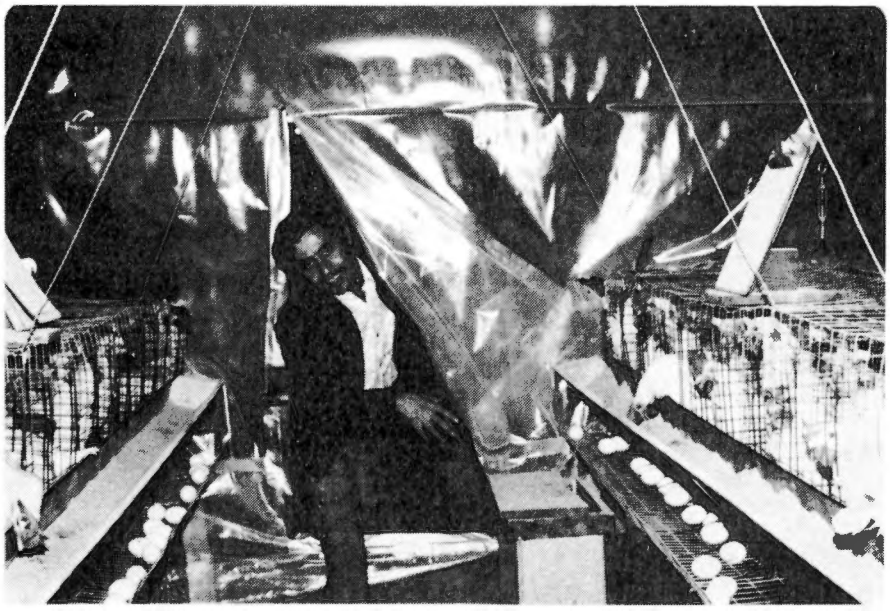


Figure 10. The Plastic Partition Used to Divide the Building into Two Halves with an Opening at the Center.

The data were transferred to tables showing temperature and relative humidity each hour during the day. The tables were used to determine the other properties of air including wet bulb temperature, dew point, and the temperature humidity index (THI).

B. Data from the Temperature Recorder

The recorder was used to print temperatures from the 52 locations of the thermocouples at one hour intervals. Due to power failures, recorder malfunctions, and unathorized tampering, no continuous data were taken during the summer months. The output of the machine was transferred to computer cards for further analysis.

C. Wind Speed Data

The device used to measure the wind speed does not give instantaneous wind speed, but rather works as a counter for the wind movement in miles. Reading of the counter was taken every day and the average wind speed was determined.

D. Energy Consumption Data

Reading of the two kilowatt-hour meters were taken each day along with the time of the day. Energy consumption for summer and winter seasons were analyzed to study the effect of each segment of power consumption on the total energy consumption of the house.

E. Daily Egg Production

Each section of the house was divided into 56 pens. Daily egg production of each pen was recorded on charts prepared for this purpose.

These charts also included a record of feed consumption and mortality. Every four weeks, charts were collected and replaced by new charts. No data were taken during weekends.

IV. ANALYSIS OF DATA

The age of birds is one of the main factors affecting egg production. This fact necessitates certain procedures to be followed for studying the effect of other variables (temperature, humidity, and the temperature humidity index) on egg production. The procedure followed was to construct a model for the relationship of bird age in days to the percentage of egg production. The Statistical Analysis System was used to construct this model. Residuals of egg production (residual of production = actual production - predicted production from model) were determined. Daily average relative humidities and dew point temperatures were determined by using FORTRAN IV Computer and Subroutines constructed by Wilhelm (1976). A preliminary study for the significance of the effect of temperature, the temperature one day before, the temperature two days before, the relative humidity, the relative humidity one day before, the relative humidity two days before, and the temperature humidity index (THI) on egg production was done by using the STEPWISE procedure constructed by Barr et al. (1976). The temperature humidity index was calculated using Equation (8).

$$THI = 0.4\ (t_{db} + t_{wb}) + 15 \qquad (8)$$

where

t_{db} = dry bulb temperature, °F

t_{wb} = wet bulb temperature, °F.

Simple and multiple regression analysis were used to predict the correlation of the different variables to the residuals of egg production. Appendix B shows the statistical analysis program used to analyze the data.

CHAPTER V

RESULTS AND DISCUSSION

I. EFFECT OF SUPPLEMENTARY HEAT ON EGG PRODUCTION

Heat was added to the south half of the building for six weeks beginning November 4, 1976. An average difference of 5° F between the south and north sections was maintained. More eggs were produced from the unheated section than from the heated section. These results are shown in Table 10 of Appendix A. Percentage egg production from the heated section averaged 71.11, while the percentage egg production in the unheated section averaged 72.33. This difference was equivalent to 579 eggs over the 30 days period. The difference in egg production was significant at the 90% confidence level. The real cause of the reduction in production is not known, however, during this experiment a very bad smell was noticed in the heated section of the building. This was due to ammonia produced from the poultry waste. The higher temperature and limited ventilation increased this problem. This appeared to have a detrimental effect upon the health of the birds.

II. POWER CONSUMPTION

The highest ratio of energy consumption was for heating the south section of the building. It averaged 96.56 kilowatt-hours per day with a total consumption of 4055.6 kilowatt-hours for six weeks of heating.

During the winter experiment, the ventilators were set to operate for four minutes out of 10 minutes when the inside temperature reached 45° F. The power consumption of the eight ventilators averaged 4 Kwh/day during the first week of the experiment. This consumption increased gradually until it reached 13 Kwh/day in the last week of the experiment (December 8 - December 15).

In general the power consumption for ventilation during winter when no heat was provided averaged 9% of the total consumption, and 86% for lighting. The remaining 5% consumption was for the lights outside the building and for the motor operating the waste removal system.

When supplemental heat was added, the power consumption for ventilation and lighting averaged 6% and 26% of the total consumption respectively. Sixty-six percent of the total consumption was for heating the south half of the building. Two percent of the power consumption was for the outer lights and the motor operating the waste removal system.

From these results and the discussion on the necessity of supplemental heating mentioned above, we can see that the best provision that can be made to conserve energy is not to supply heat for poultry laying houses as long as the inside temperature of the building is higher than 32° F.

III. EFFECT OF AGE ON EGG PRODUCTION

A model was constructed to study the effect of age on egg production for the period October 25 to December 15. Data from the different stages of the experiment were analyzed for this purpose. The best model

found to fit the data was of the form

$$\text{Percentage Production} = f(\text{AGE}, \text{AGE}^2, \text{AGE}^3).$$

The equation of this correlation for the above period was

$$\text{Percentage Production} = 5663.2 - 93.339\ (\text{AGE}) + 0.51479\ (\text{AGE})^2 - 9.3769 \times 10^{-4}\ (\text{AGE})^3 \qquad (9)$$

$$(R^2 = 0.81)$$

where

AGE = age of birds, days.

The significance level was 99.99%. Figure 11 is a graph representing this correlation. Actual, predicted, and the residual values of production are tabulated in Table 11 of Appendix A. The optimum percentage production was 86.5 when the age of birds was 200 days. The production suddenly decreased from the maximum due to a respiratory infection affecting some of the birds. This resulted in a very low production for about two weeks started on November 8.

IV. TEMPERATURE AND HUMIDITY EFFECT ON EGG PRODUCTION

During the winter season the daily average temperatures in the unheated section of the building ranged between a minimum of 45° F and a maximum of 66.5° F. The daily average humidities were within the range of 53 to 92%.

No significant effect of temperature on egg production was observed within this range. This was due to the fact that the range

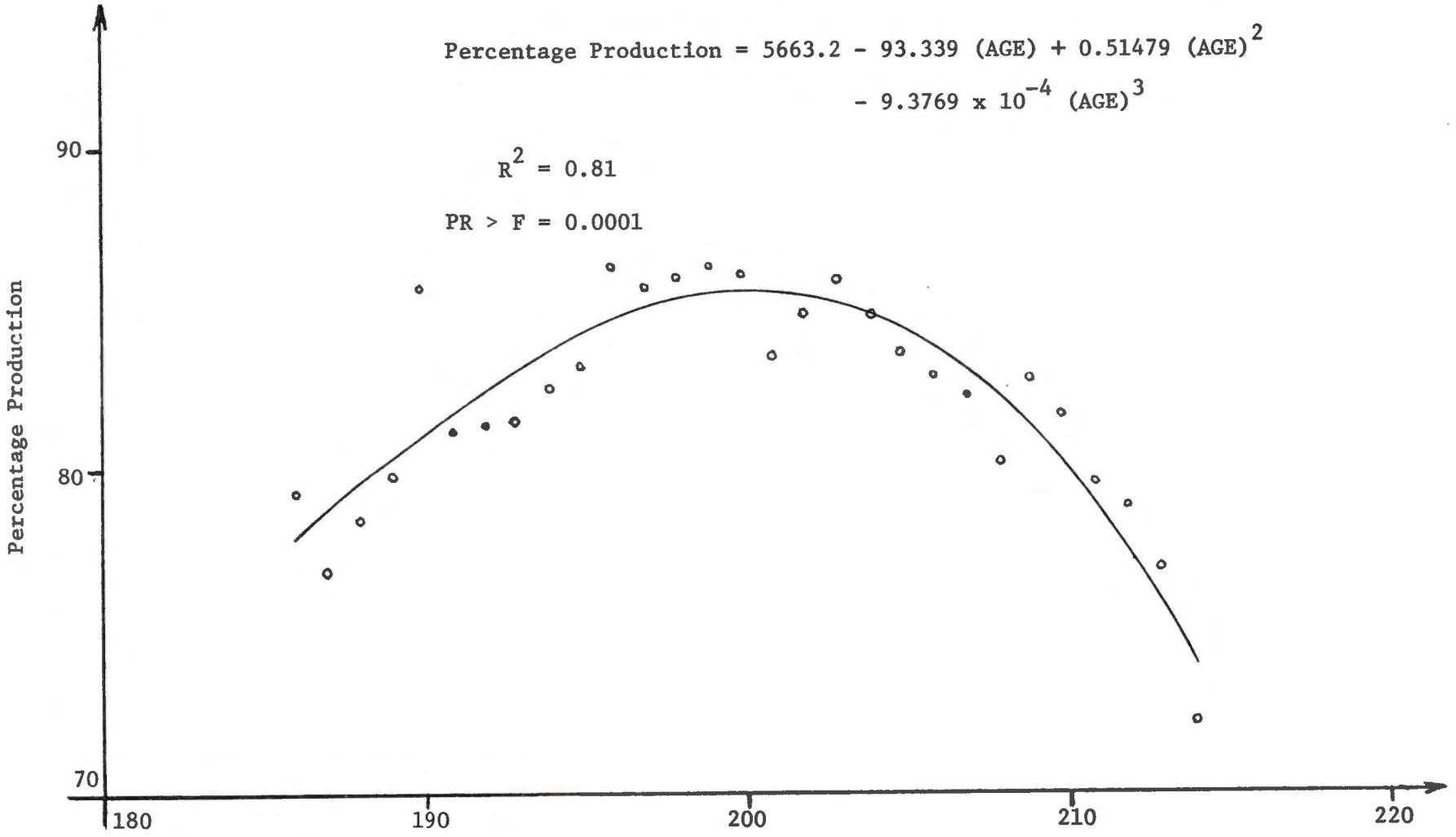


Figure 11. A Graph Representing the Relationship Between Production and Age for the Period October 25 to November 22.

of temperatures under which the experiment was conducted were near the optimum range for maximum egg production. That was clearly shown by Long et al. (1958) and Muller (1961). However, results from this study indicated that high relative humidities may have tended to decrease production. Statistical verification was not possible due to the limited number of days with adverse conditions for production. No correlation was found between the temperature humidity index (THI) and the egg production. Table 12, Appendix A, shows the mean daily temperatures and humidities for a few days of the summer season and the data for the winter part of the experiment. These data were taken from the north section (unheated).

It was felt that temperature and relative humidity on any given day might affect the formation of eggs and thus affect later production. Thus, some analysis were conducted to study the effects of temperatures and relative humidities one and two days prior to the date of interest. Data for the period November 9 to November 22 were used in this analysis. Table 8 shows the regression coefficient (R^2-value) and the significance level for the correlation of temperatures of the same day of production, one day before production, and two days before production respectively, versus the residual of production from equation (9). From this table we can see that there is an improvement in the correlation coefficient and the significance level for the correlation between the temperature one day before production in comparison with the other two results.

The same analyses were conducted to compare between the effect of relative humidities in the same day of production, one day before

Table 8. Correlation Coefficients and Equations of Temperatures of the Same Day, One Day, and Two Days Before Production Versus Egg Production

Treatment	Correlation Equation	R^2-Value	Level of Significance Percent
1. Temperature of the Same Day	$Y^{*} = -6.7855 + 0.1225\ (T)^{**}$	0.374	98
2. Temperature One Day Before	$Y = -8.0742 + 0.1451\ (T_1)^{**}$	0.482	99
3. Temperature Two Days Before	$Y = -4.1964 + 0.0748\ (T_2)^{**}$	0.128	75

*Y = residual of production, percent.

**T, T_1, and T_2 are temperatures of the same day of production, one day, and two days before production respectively.

production, and two days before production on egg production. Table 9 shows the results of this comparison. From this table we can see that the relative humidity one day before production had the highest effect on egg production.

It should be noted, however, that these results cover only the latter half of the winter period. For the first half of the winter period there was no significant improvement when records from previous days were used--no model gave a satisfactory correlation. This may, again, be attributed to the lack of adverse climatic condition during that period.

Table 9. Correlation Coefficients and Equations of Relative Humidities of the Same Day, One Day, and Two Days Before Production Versus Egg Production

Treatment	Correlation Equation	R^2-Value	Level of Significance Percent
1. R. H. of the Same Day	$Y^{*} = 1.113 - 0.016\ (R.H.)^{**}$	0.014	Not Significant
2. R. H. One Day Before	$Y = 4.890 - 0.070\ (R.H.1)^{**}$	0.257	94
3. R. H. Two Days Before	$Y = 0.646 - 0.0093\ (R.H.2)^{**}$	0.005	Not Significant

*Y = residual of production, percent.

**R.H., R.H.1, and R.H.2 are the relative humidities the same day of production, one day and two days before production respectively.

CHAPTER VI

SUMMARY AND CONCLUSIONS

The objectives of this study were: (1) to investigate the possibility of reducing energy consumption in poultry laying houses, (2) to determine the effect of supplementary heat on winter egg production, and (3) to study the effect of temperature and relative humidity on egg production.

The experiment was conducted under two different environmental conditions. The first part was during the summer season (June, July, and August) when the temperature inside the building reached slightly above 80° F. The second part was during September, October, and November when the inside temperature dropped to 30° F at night. The house used had outside dimensions of 32 x 160 feet. The maximum capacity of the house was 3,360 birds. Wire-net cages of 8 x 18 x 18 inches in size were used to house two birds in each cage. Daily egg production and mortality were recorded.

Fifty-two measurements of wet and dry bulb temperatures at different locations of the building were taken every hour. Mean daily temperatures were calculated from those measurements. Using measured wet and dry bulb temperatures, the other properties of air were determined by using a special computer program prepared for this purpose. To study the effect of supplemental heating on egg production, the house was divided into two halves by a plastic partition installed at the center of the building. An electric heater rated at 4000 watts

was used to heat the south half of the building. Using this heater, the temperature of the south section was raised about 5° F above the temperature of the north section. Egg production from both sections were analyzed by comparing daily egg production from each section.

Analysis of egg production data indicated that the age of birds has a great effect on production. Thus, to study the effect of temperature and relative humidity on egg production, a model for the age versus egg production was constructed. Residuals of production from this model were correlated to the daily average temperatures and relative humidities. Temperatures and relative humidities one and two days before were also considered in this analysis.

Based on the results of this study, the following conclusions were reached.

1. Supplemental heating may have an adverse effect on egg production under certain conditions.
2. No supplemental heat is required as long as the temperature inside the building is above 32° F.
3. Within the range 45-65° F, the daily average temperature has no effect on egg production.
4. No significant effect of daily average relative humidities within the range of 50 to 90% were observed when the average daily temperature inside the building was kept within 45-65° F.
5. Temperatures and relative humidities the previous day were possibly more significant with respect to egg production of birds than temperatures and relative humidities of that day.

Further studies are recommended (1) to determine the effect of high and low temperatures and relative humidities on egg production; and (2) to compare the energy consumption and the economy of fluorescent lighting versus the incandescent lighting.

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APPENDIXES

APPENDIX A

STATISTICAL DATA TABLES

Table 10. Egg Production Data for the Heated and the Unheated Sections from November 4 to December 15, 1976

No. of the day of year	Age Days	Heated Section Temperature °F	Heated Section No. of Birds	Heated Section No. of Eggs	Unheated Section Temperature °F	Unheated Section No. of Birds	Unheated Section No. of Eggs
309	196	55.2	1675	1449	51.9	1673	1444
310	197	51.7	1675	1429	53.0	1673	1434
313	200	50.6	1672	1440	--	1672	1442
314	201	58.6	1671	1435	--	1672	1399
315	202	65.7	1671	1411	--	1672	1422
316	203	61.5	1669	1443	--	1672	1443
317	204	51.9	1669	1424	58.0	1670	1417
320	207	50.7	1666	1399	59.4	1669	1373
321	208	54.0	1665	1340	61.8	1668	1338
322	209	56.6	1665	1311	60.4	1667	1382
323	210	60.6	1665	1316	63.1	1667	1365
324	211	62.5	1664	1261	--	1664	1326
327	214	48.6	1660	1179	--	1659	1196
328	215	46.5	1660	1116	--	1658	1243
329	216	52.5	1660	1032	59.0	1658	1290
330	217	56.2	1657	1021	64.3	1655	1084
331	218	61.1	1657	999	68.4	1655	1071
334	221	45.3	1655	970	--	1653	986
335	222	44.1	1654	963	--	1652	960
336	223	47.9	1654	934	51.2	1652	942
337	224	52.9	1652	942	55.9	1651	957
338	225	49.7	1652	980	54.4	1650	920
341	228	52.5	1650	1017	56.8	1649	1026
342	229	55.3	1650	1065	58.4	1648	1008
343	230	48.1	1650	1002	51.3	1648	997
344	231	45.0	1650	1047	--	1647	1015
345	232	47.1	1650	1054	53.2	1645	1063
348	235	51.4	1648	1164	55.1	1644	1174
349	236	47.8	1647	1115	55.1	1643	1136
350	237	52.2	1646	1147	60.0	1642	1131
Total				35,405			35,984
Percentage Production				71.11			72.33

Table 11. Actual, Predicted, and Residual Values of the Daily Percentage Production for the Period October 25 to November 22, 1976

Age	Actual Production (Percent)	Predicted Production (Percent)	Residual of the Actual Production (Percent)
186	79.4	77.9422	1.4578
187	76.9	78.7753	-1.8753
188	78.4	79.5859	-1.1859
189	79.8	80.3683	-0.5683
190	85.7	81.1170	4.5830
191	81.2	81.8263	-0.6263
192	81.4	82.4906	-1.0906
193	81.6	83.1043	-1.5043
194	82.6	83.6617	-1.0617
195	83.3	84.1572	-0.8572
196	86.4	84.5852	1.8148
197	85.8	84.9401	0.8599
198	86.1	85.2162	0.8838
199	86.5	85.4079	1.0921
200	86.2	85.5096	0.6904
201	83.7	85.5157	-1.8157
202	85.0	85.4204	-0.4204
203	86.0	85.2183	0.7817
204	84.9	84.9037	-0.0037
205	83.7	84.4709	-0.7709
206	83.0	83.9143	-0.9143
207	82.3	83.2284	-0.9284
208	80.2	82.4074	-2.2074
209	82.9	81.4457	1.4543
210	81.9	80.3378	1.5622
211	79.7	79.0780	0.6220
212	79.0	77.6606	1.3394
213	77.0	76.0801	0.9199
214	72.1	74.3308	-2.2308

Table 12. Mean Daily Temperature and Humidity Data from the Unheated Section

Age of Birds (days)	Production Percent	Temperature °F	Relative Humidity	THI
Summer Experiment				
438	59.7	79.0	79.0	75.3
450	59.1	72.9	83.0	71.1
451	57.1	73.2	71.0	71.4
452	61.4	76.5	69.0	72.7
470	57.7	81.1	59.0	75.2
474	53.3	80.1	75.0	75.8
478	55.2	75.6	51.0	70.3
480	59.1	80.5	72.0	75.9
485	53.1	75.0	61.0	70.9
488	52.0	82.8	63.0	76.9
Winter Experiment				
186	79.4	65.0	84.0	65.2
187	76.9	57.0	77.0	58.8
188	78.4	52.2	62.0	55.7
189	79.8	49.6	61.0	52.2
190	85.7	52.8	66.0	55.0
193	81.6	57.4	67.0	58.4
194	82.6	57.1	70.0	58.4
195	83.3	59.7	73.0	60.6
196	86.4	55.2	64.0	56.5
197	85.8	51.7	66.0	54.1
200	86.2	50.6	54.3	57.0
201	83.7	58.6	55.0	58.3
202	85.0	65.7	53.0	63.3
203	86.0	61.5	61.0	60.9
204	84.9	51.9	72.0	55.7
207	82.3	50.7	88.0	54.8
208	80.2	54.0	68.0	56.0
209	82.9	56.6	78.0	58.6
210	81.9	60.6	72.0	61.2
211	79.7	62.5	70.0	62.4

Table 12. (continued)

Age of Birds (days)	Production Percentage	Temperature °F	Relative Humidity	THI
214	72.1	48.6	65.6	51.8
215	75.0	46.5	66.3	50.3
216	77.8	52.5	63.0	54.5
217	65.5	56.2	75.0	58.2
218	64.7	61.1	78.0	61.9
221	59.6	45.3	78.9	50.6
222	58.1	44.1	69.6	48.6
223	57.0	47.9	71.0	50.9
224	58.0	52.9	66.0	54.5
225	55.8	49.7	70.0	52.9
228	62.2	52.5	82.0	55.9
229	61.2	55.3	92.0	58.5
230	60.5	48.1	81.0	52.5
231	61.6	45.0	78.0	50.0
232	64.6	47.1	83.0	52.0
235	71.4	51.4	73.0	54.5
236	69.1	47.8	71.0	51.7
237	68.9	52.2	84.0	55.8

APPENDIX B

STATISTICAL ANALYSIS OF DATA

STATISTICAL ANALYSIS OF DATA

```
C    AGE = AGE OF BIRDS, DAYS;
C    PROD = PERCENTAGE EGG PRODUCTION; PROD = (NO. OF EGGS/NO. OF BIRDS)*100;
C    TEMP = MEAN DAILY TEMPERATURE, DEGREE F;
C    HUMD = MEAN DAILY RELATIVE HUMIDITY;
C    THI = TEMPERATURE AND HUMIDITY INDEX; THI=0.4(TEMP+DUE POINT TEMP)+15


C         INPUT;


     DATA CHICK;
INPUT AGE 1-3 PROD 5-8 TEMP 10-13 HUMD 15-18 THI 20-23;

C    LAGGING OF TEMPERATURES;
C    TLAG = TEMP; TLAG1 = ONE DAY LAG OF TEMP; TLAG2 = TWO DAYS LAG OF TEMP;
RETAIN TLAG TLAG1 TLAG2;
TLAG2 =TLAG1;
TLAG1 = TLAG;
TLAG = TEMP;

C    LAGGING OF RELATIVE HUMIDITIES;
C    HLAG = HUMD; HLAG1 = ONE DAY LAG OF HUMD; HLAG2 = TWO DAYS LAG OF HUMD;
RETAIN HLAG HLAG1 HLAG2;
HLAG2 = HLAG1;
HLAG1 = HLAG;
HLAG = HUMD;

C    LAGGING OF THI;
C    ILAG = THI; ILAG1 = ONE DAY LAG OF THI; ILAG2 = TWO DAYS LAG OF THI;
RETAIN ILAG ILAG1 ILAG2;
ILAG2 = ILAG1;
ILAG1 = ILAG;
ILAG = THI;
```

STATISTICAL ANALYSIS OF DATA (CONTINUED)

```
AGE = AGE/200.0;
AGE2 = AGE*AGE;
AGE3 = AGE2*AGE;
AGE4 = AGE2*AGE2;

          CARDS;

PROC PRINT;
VARIABLES AGE PROD TEMP HUMD THI AGE2 AGE3 AGE4 TLAG1 TLAG2 HLAG1 HLAG2 ILAG1
ILAG2;

C    STEPWISE REGRESSION;
PROC STEPWISE DATA=CHICK;
MODEL PROD = AGE AGE2 AGE3 AGE4/MAXR;

C    DETERMINATION OF THE RESIDUAL OF THE MODEL PROD = AGE AG2 AG3;
PROC GLM DATA=CHICK;
MODEL PROD = AGE AGE2 AGE3;
OUTPUT OUT=CHUCK PREDICTED=YPROD RESIDUAL=RESID;

PROC PRINT DATA=CHUCK;
VARIABLES PROD YPROD RESID;

PROC STEPWISE DATA=CHUCK;
MODEL RESID = TEMP TLAG2 TLAG3 HUMD HLAG2 HLAG3 THI ILAG2 ILAG3/MAXR;

PROC GLM DATA=CHUCK;
MODEL RESID = TEMP;

PROC GLM DATA=CHUCK;
MODEL RESID = TLAG2;
```

```
MODEL RESID = TLAG3;
PROC GLM DATA=CHUCK;

PROC GLM DATA=CHUCK;
MODEL RESID = TEMP TLAG2;

PROC GLM DATA=CHUCK;
MODEL RESID = TEMP TLAG2 TLAG3;

PROC GLM DATA=CHUCK;
MODEL RESID = HUMD;

PROC GLM DATA=CHUCK;
MODEL RESID = HLAG2;

PROC GLM DATA=CHUCK;
MODEL RESID = HLAG3;

PROC GLM DATA=CHUCK;
MODEL RESID = HUMD HLAG2;

PROC GLM DATA=CHUCK;
MODEL RESID = HUMD HLAG2 HLAG3;

PROC GLM DATA=CHUCK;
MODEL RESID = TEMP HUMD;

PROC GLM DATA=CHUCK;
MODEL RESID = TLAG2 HLAG2;

PROC GLM DATA=CHUCK;
MODEL RESID = TLAG3 HLAG3;
```

STATISTICAL ANALYSIS OF DATA (CONTINUED)

```
PROC GLM DATA=CHUCK;
MODEL RESID = TEMP HUMD TLAG2 HLAG2;

PROC GLM DATA=CHUCK;
MODEL RESID = TEMP TLAG2 TLAG3 HUMD HLAG2 HLAG3;

PROC GLM DATA=CHUCK;
MODEL RESID = THI;

PROC GLM DATA=CHUCK;
MODEL RESID = ILAG2;

PROC GLM DATA=CHUCK;
MODEL RESID = ILAG3;

PROC GLM DATA=CHUCK;
MODEL RESID = THI ILAG2;

PROC GLM DATA=CHUCK;
MODEL RESID = THI ILAG2 ILAG3;
```

VITA

Nazar J. Alias was born in Mosul, Iraq, on July 27, 1950. He graduated from Al-Mustakbal High School in June 1968. In September of that year, he entered the University of Mosul where he graduated in June of 1972 with a Bachelor of Science degree in Agricultural Engineering. He received the honor of being the first in his department and the third in his college among graduates of that year. During July of 1972 he became a member of the Iraqi Engineers Union. In October of that year he entered the Iraqi Army and served as a soldier for one year and as a Second Lieutenant for six months. In March, 1974 he was employed as an assistant engineer by the College of Engineering, University of Mosul. In 1974 he was granted a full scholarship from the Iraqi Government to study in the United States. The scholarship was given to him to study for the M.S. and Ph.D. degrees in the field of Farm Structures and Environment. He entered the University of Tennessee in the Fall of 1975.

He was married to Shatha K. Toma in August, 1976. He plans to continue his studies to obtain the Doctorate degree in the United States before returning to Iraq.