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To the Graduate Council:

I am submitting herewith a thesis written by Thomas Emmett Maddox entitled "Temperature preference of chicks." I have examined the final electronic copy of this thesis for form and content and recommend that it be accepted in partial fulfillment of the requirements for the degree of Master of Science, with a major in Biosystems Engineering.

D.O. Baxter, Major Professor

We have read this thesis and recommend its acceptance:

John J. McDow, H.V. Shirley

Accepted for the Council:
Carolyn R. Hodges

Vice Provost and Dean of the Graduate School

(Original signatures are on file with official student records.)

December 1, 1965

To the Graduate Council:

I am submitting herewith a thesis written by Thomas Emmett Maddox entitled "Temperature Preference of Chicks." I recommend that it be accepted for nine quarter hours of credit in partial fulfillment of the requirements for the degree of Master of Science, with a major in Agricultural Engineering.

D. O. Baxter
Major Professor

We have read this thesis and
recommend its acceptance:

John J. McDow

H. V. Shirley

Accepted for the Council:

Hilton A. Smith
Dean of the Graduate School

TEMPERATURE PREFERENCE OF CHICKS

A Thesis
Presented to
the Graduate Council of
The University of Tennessee

In Partial Fulfillment
of the Requirements for the Degree
Master of Science

by
Thomas Emmett Maddox
December 1965

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CHAPTER I

THE PROBLEM

I. INTRODUCTION

Agriculture is the oldest and the largest industry of civilization, and no other industry is so basic to the general welfare of mankind. The origin of agriculture was very primitive, and even today in many regions of the world it still exists in a primitive condition. However, in the more advanced nations agriculture has developed into a complex science with a corresponding efficiency of considerable magnitude. Since the majority of its products are so essential to the progress of man, society as a whole is concerned with the welfare and advancement of the agricultural industry.

The earliest recorded history shows man as being able to produce only meager amounts of food and fiber, and this limited production required the services of a vast majority of the population. The twentieth century has brought many scientific and technological advances to the agricultural industry. Today, in many regions of the world, man's food and fiber supply is produced by a relatively small per cent of the population. Many of the present-day commercial farms are both production and processing units. Where men and animals once supplied the greatest portion of the farm power, mechanical and electrical power and equipment have almost replaced them.

The more exciting modern developments such as the automobile, radio, and the airplane have overshadowed much of the great progress which has been made in various areas of agriculture. Perhaps one of the most dramatic developments in agriculture in the United States has been the poultry enterprise. This industry has evolved from a once small on-the-farm sideline into a multi-million dollar commercial operation. During the past ten years, on-the-farm chick production has decreased about 50 per cent while commercial broiler production has increased approximately 220 per cent, from 950 million birds to 2.1 billion birds per year (40). This fantastic increase in commercial broiler production has by necessity stimulated other areas of the poultry industry. During this same period of increased broiler production, there was a corresponding increase in the hatchery production of broiler-type baby chicks, the total production of eggs increased, and there was a definite trend from an on-the-farm enterprise toward a highly commercialized industry. During 1963 the poultry industry realized a gross income of well over three billion dollars from marketing on-the-farm produced birds, commercial broilers, and eggs (40).

The present and future demands for poultry products is of paramount concern to the poultry industry. In the United States the per capita consumption of poultry meat increased from 22.8 pounds in 1954 to 31.2 pounds in 1964, and during this same period the amount of poultry meat exported increased about 650 per cent (40). If the population of the world continues to increase, then the demand for poultry products will probably increase accordingly, and the poultry industry will continue to provide a substantial monetary credit to the agricultural economy.

With the cost of poultry production increasing and the price for poultry products decreasing, it is imperative that the grower produce poultry products efficiently if a profit is to be realized. The efficiency of poultry production and the quality of growth attained by the individual bird usually depends upon its inherited ability to grow, its food supply, and such environmental factors as temperature, air supply, humidity, light, and protection from parasites and enemies (12).

After the chick leaves the incubator, the grower is responsible for its efficient performance. Most of the embryological development of a chick takes place outside the maternal body, and during this period the egg is surrounded by an ambient temperature of approximately 99°F. and a relative humidity of about 60 per cent. At the time of hatching the young chick is normally placed in an environment with an ambient temperature of 96° to 97°F. and a relative humidity of 73 per cent (11). After several hours the bird is transferred from this hot, humid environment into a hot, but relatively dry environment in a house that is constructed, probably not in accordance with the needs of the chick but rather in keeping with the needs of the grower.

The first few weeks after the young chick has been transferred into this hot and relatively dry environment may be the most difficult and critical period in the management of the bird. The grower can find considerable information concerning the nutritional needs of young chicks, but relatively little basic information concerning the effects of environment on chicks during the first few weeks of life (21). It is during this critical period, known as the brooding period, that the performance of the bird is almost completely dependent upon the knowledge and skill of the grower.

The brooding practices which are recognized as essentially sound today are not based on a definite knowledge of the effects of environment on chicks of successive ages, but are largely the result of empirical methods of investigations. Successful brooding is still largely an art, but information is gradually being accumulated by poultrymen and agricultural engineers which may eventually put commercial brooding on a scientific basis.

When compared to research which has been conducted in nutritional requirements for young chicks, relatively little research has been conducted in trying to determine the optimum environmental conditions which provide for the efficient performance of chicks during the growing period. In tests which have been conducted in which chicks were exposed to various environmental conditions, it appeared that these conditions may have either adverse or favorable results. Barott and Pringle (6) reported that the level of humidity in the brooder house had no direct effect on chicks from one day of age to thirty-two days of age. In 1958 Seigel and Coles (37) reported the results of investigations which supported Barott and Pringle. More recently tests (39) have been conducted which indicate that low humidity has neither an adverse or beneficial effect, but that high humidity did adversely effect the chicks. The adverse effect of high humidity became more noticeable when coupled with high temperature.

Various studies have been made in regard to ventilation of poultry housing. Promersberger and Bryant (35) studied the effects of three different types of ventilating systems and found none of the systems produced any significant difference in feed consumption, gain in body weight, and mortality. However, a study at the University of Connecticut (14) revealed that the rate of ventilation did effect feed conversion efficiency. An air flow rate of three-fourths cubic feet per minute per bird had a significantly greater effect on the feed conversion efficiency than did an air flow rate of two cubic feet per minute per bird.

Several investigators have shown where the ventilation rate effects both the spread of poultry diseases and the diseases effect on chick performance. Prince _et al._ (33) reported tests involving Newcastle virus and the P.P.L.O. organisms. Newcastle virus, the smaller of the two organisms, spread to an uninoculated group of chicks exposed to a ventilation rate of 1416 cubic centimeters per second, but did not spread to the uninoculated chicks at a ventilation rate of 236 cubic centimeters per second. With the same two air flow rates, it was, in general, found that the P.P.L.O. disease spread to the uninoculated chicks regardless of the rate of ventilation. Prince _et al._ (31) reported tests in which both healthy and bronchitis infected chicks were exposed to varying ventilation rates. Although the weight gain of the infected birds was somewhat lower than the weight gain of the healthy birds, it was concluded that the rate of ventilation on the performance of the birds was not significant.

As has been discussed in the preceding investigations, temperature was usually linked with the various environmental factors which caused adverse performance of chicks. Poultrymen are not in agreement as to what the optimum brooding temperature should be, nor as to what the total effect temperature has on young chicks. Neither is there sufficient experimental evidence to definitely determine what this temperature should be. However, Barott and Pringle (4) concluded from their investigations that temperature was the predominate influence in brooding for the efficient growth of young birds.

It would be difficult to establish temperature ranges for all breeds of chicks for all varieties of environmental conditions which might exist. Less heat is probably required for active, vigorous chicks than for birds of less vitality. The temperature should normally be reduced as the chick grows older. This temperature reduction should be as rapidly as is compatible with their comfort, health, and growth performance. If the internal ambient temperature of the house is satisfactory, brooding heat may be taken away altogether as soon as the birds are well feathered.

Probably one of the first considerations of the temperature-chick relationship is that the chick should be comfortable. Ideal temperature conditions probably exist when there is a range in brooding temperatures available to the young chick. United States Department of Agriculture Farmer's Bulletin 1538 gives 100°F. as a maximum and 60°F. to 65°F. as a minimum temperature for brooding.

An experienced poultryman usually depends upon the behavior of the baby chick as a guide for regulating the brooding temperature. A chick that is exposed to prolonged periods of chilling may be susceptible to stunting of growth, outbreaks of diarrhea and pneumonia, and an increased sensitiveness to disease. Exposing birds to an excessive amount of heat for a prolonged period of time may cause slow growth, poor feathering, outbreaks of cannibalism, and an increase in the mortality rate. Therefore, a decrease of production efficiency results from either too little or too much brooding heat.

Depending upon the type of poultry enterprise in which the poultryman is engaged, it will be necessary to replace a portion of the flock at various intervals. This means that brooding is a major cost in the poultry business. This cost should be kept as low as possible while still securing an end product of the highest quality, and one that will ensure a profitable return.

The agricultural engineer's concern with providing optimum environmental conditions is of primary importance to the poultry industry. The engineer should be able to design structures and equipment that will provide environmental conditions for the most efficient chick performance with the greatest economy. In order to do this on a scientific basis, the engineer must oonduct research which will provide much of the basic data for design purposes.

For example, the total heat produced by a twenty-day-old bird is 18.6 Btu. per pound of live weight at 76°F. (24). Ota and McNally (29) have shown that poultry housing in Southern States have an average over-all coefficient of heat transmission, U value, of 1.28 Btu. per hour per square feet per degree F. Because of an indeterminate amount of air leakage, no firm estimate has been made of the total heat losses. If an air-impervious film were used, the U value might be lowered to approximately 0.5 Btu. per hour per square feet per degree F., and the radiant heat loss from the birds to uninsulated walls and roof would be greatly reduced. If a reduction in the U value were possible, then probably only a minimum amount of heat would be required to supplement bird heat during the early states of chick growth.

It may be concluded from the preceding discussion that to a great extent brooding practices are primarily an art at the present, but there is a definite need to place brooding practices on a more scientific basis. Of all the brooding factors to be considered, temperature appears to be the most important. Temperature alone, temperature coupled with various ventilation rates, temperature and different percentages of relative humidity, and temperature and diseases may have critical effects on the young bird during the growing period. The lack of basic data on the optimum environmental conditions for poultry production is probably the greatest handicap in the engineering design of facilities and equipment for this enterprise. Likewise, providing housing and equipment which produce and maintain less than optimum conditions lowers the efficiency of production in the poultry industry. It is imperative for all concerned that further research be conducted to obtain basic data for a more efficient poultry industry.

II. OBJECTIVES OF INVESTIGATION

The objectives of this investigation were:

1. To determine the temperature preferences of chicks when exposed to a heat gradient composed of radiant and sensible heat.

2. To determine if chicks have temperature preferences that are related to age when exposed to a heat gradient composed of radiant and sensible heat.

3. To determine if chicks have temperature preferences that are related to sex when exposed to a heat gradient composed of radiant and sensible heat.

III. REVIEW OF LITERATURE

This project was conducted as a cooperative project between the Agricultural Engineering Department and the Poultry Department of the Agricultural Experiment Station, University of Tennessee, Knoxville. The material reported in this thesis was an investigation conducted as part of a broader project entitled *A Study of Behavioral, Physiological, and Performance Response of Young Chicks to Environmental Factors.* The work reported herein was restricted to investigations of the response of chicks to environmental temperatures.

As early as 1924 Barott and Pringle (4) conducted experiments on the effect of temperature on chicks from one day old to maturity. These investigations revealed that the minimum metabolic rate for chicks one day through fourteen days of age occurs at 95°F. As the bird got older the minimum metabolic rate occurred at progressively lower temperatures. When the chick reached one year of age the minimum metabolic rate occurred at 70°F. In 1934 growth rate studies were conducted by Klieber and Dougherty (20) on chicks from six to fifteen days of age and within a temperature range from 69.8° to 104.0°F. Growth rates were compared and found to be maximum at the lower temperature. Later experiments by Winchester and Klieber (45) found that food consumption was inversely related to environmental temperatures between the limits of 18° to 38°C.

As a means of supplementing the heat produced by the birds, Nicholas and Callenback (27) utilized electric brooders. These brooders, using either coiled resistance wires or strip heaters as heating elements, applied the heat efficiently to a limited area under the hover which produced a comfort zone for the young chicks. Among the first efforts in applying heat from a heat lamp was by Yung and Mussehl (46) in 1940. In 1943 Kennard and Chamberlin (19) furthered the ideas of Yung and Mussehl by developing a hover type brooder which used heat lamps as a source of heat energy.

As previously mentioned, there is an obvious lack of agreement among poultrymen as to what constitutes the proper energy and temperature requirements for chicks during the brooding period. Some investigators believe that relatively high ambient temperatures are necessary during the brooding period while others have had success with low temperatures. Barott and Pringle (5) have suggested that the optimum ambient temperature for a chick of one day old is 95°F. and should be reduced uniformly to 80°F. at eighteen days of age. Yet Seeger and Oliver (36) reported that a group of chicks were brooded satisfactorily for two weeks in a cold room with an ambient temperature of 12°F. below zero using an infrared heat lamp as a source of heat.

In 1950 Baker and Bywaters (3) at the Virginia Agricultural Experiment Station conducted extensive research in the brooding of chicks with infrared lamps. These investigations included observations of feathering, weight gains, and condition of the exposed skin. There were no significant differences in either body weight or feathering when compared to chicks brooded with other systems. Since the birds were given freedom of movement, none developed skin problems due to overexposure to infrared radiation. It was observed that when the room ambient temperature was 60°F. and the maximum temperature under a heat lamp was 120°F., the chicks generally arranged themselves in a circular shaped pattern with the high temperature area being vacant. Several times during the experiment room temperature fell below 35°F., but no adverse effect on the birds was evident.

During the late 1940's and early 1950's, Barott and Pringle (4, 5, 6) conducted environmental investigations using chicks from one to thirty-two days of age. In these investigations chicks were exposed to varying temperatures. Upon completion of the tests it was concluded that the young birds performed best by starting with an ambient temperature of 94°-95°F. the first day and uniformly reducing the temperature to 66°F. by the thirty-second day.

Bywaters (11) found that baby chicks need more heat when below the temperature of 94°-95°F., which Barott and Pringle thought to be the optimum temperature. Bywaters also found that this additional heat was supplied by increased metabolic activity. This increase in metabolism continues with a reduction of ambient temperature until the chicks are no longer able to produce enough heat to maintain body temperature. At this point the bird dies from paralysis of the breathing apparatus. Bywaters further stated that chicks from one day old to two weeks of age were unable to survive an ambient temperature below 70°F. for a twenty-four hour period, and chicks of five to eight weeks of age under similar exposure died at ambient temperatures below 50°F.

Wilson (44) exposed young pullets to an ambient temperature range from 70°-105°F. As the ambient temperature rose above 80°F. the body temperature of the bird rose slightly, but when the ambient temperature rose above 90°F., the body temperature rose very sharply. None of the birds could tolerate an ambient temperature of 105°F. when exposed to this high temperature for periods of seven hours.

Experiments were conducted by Prince and Wheeler (32) on chicks of four to eight weeks of age to determine the effects of different constant temperatures on feed consumption, weight gain, and feed efficiency. Temperatures of 45°, 55°, 65°, and 75°F. were used in these tests. There were no significant differences in weight gain and mortality caused by the different temperatures. However, the lowest temperature caused greater feed consumption and produced better feed efficiency than the higher temperatures. The investigations of Ota and Garver (28) in 1958 seemed to support the work of Prince and Wheeler. Ota and Garver found that the feed consumption of young chicks of one to fifty-six days of age was not as great at 29.3°C. as it was at an ambient temperature of 18.2°C.

In 1961 Baxter and Shirley (8) conducted tests in which temperatures and relative humidities occurring in a solar, windowless, and a conventional type house were recorded and the response of broilers was measured in terms of growth and feed efficiency. Fifty male and fifty female birds from one day old through eight weeks of age were exposed to varying environmental conditions during seven seasonal trials. From these trials it was concluded that the poorer growth rates of the birds occurred in the solar house, which had the higher mean temperature. The better growth rates were obtained in the conventional house, which had the lower mean temperature as well as a wider range in temperatures.

In an experiment involving chicks from four to eight weeks and six to ten weeks of age, Adams _et_ _al_. (1) found the rate of feed consumption decreased in a linear relationship for environmental temperatures between 7.1°C. and 23.8°C. It appeared that this range of temperatures had no significant effect on the weight gained by the birds.

Some of the more recent research continues to reveal interesting and important factors concerning the brooding temperature. Haberman (15) has shown that the brooding temperature may have an effect on the growth and sexual maturity of the young chick. Birds which were raised at 68°F. weighed more at twenty-two weeks of age and went into egg production earlier than those raised in an ambient temperature of 95°F.

Huston (34) of the University of Georgia Agricultural Experiment Station has found that chicks can be brooded at lower temperatures than those generally recommended, provided the ambient temperature is high enough to permit birds to spend sufficient time at waterers and feeders to satisfy their food and water requirements. According to Huston, the performance of birds which were begun at an ambient temperature of 95°F. and reduced five degrees per week did not exceed the performance of birds which were started at 85°F. and reduced five degrees per week. With an ambient temperature of 46°F., the birds did not spend sufficient time eating or drinking during the first week. After the first week, the 46°F. temperature did not hinder their eating or drinking habits as long as the chicks could reach a brooder which provided adequate heat.

CHAPTER II

DESCRIPTION OF EXPERIMENTAL PROCEDURE

I. INFRARED RADIATION

When a body is heated, infrared energy is produced because of the vibrational and rotational phenomena associated with the molecules at the surface of the heated body. Heat is generally associated with infrared energy since this energy is converted into sensible heat when it is absorbed by a body.

Infrared energy is radiated through space or through a material medium in the form of waves. The theory of physics has pointed out that infrared energy and other forms of electromagnetic waves are similar, and regardless of the method by which they are generated, they differ only in frequency of wave length. The infrared region, 7,600 A. to 4,000,000 A., is a band of invisible energy lying between the shorter waves of the visible spectrum and the longer radio waves.

All objects which have a temperature above absolute zero emit radiant energy, and in many cases most of this energy is emitted in the infrared region of the electromagnetic spectrum. The amount of radiant energy emitted from a source depends on the absolute temperature and the nature of the exposed surface of the source. The perfect emitter of infrared radiation is the so-called black-body. Although a perfect black-body does not exist, there are many surfaces which approach black-body conditions.

The relationship between the amount of energy emitted by a blackbody and its absolute temperature is given by the Stefan-Boltzman law,

$$E = kT^4$$

where E is the radiant energy emitted per unit of time; k is the Stefan-Boltzman constant; and T is temperature (42). The wave length of the emitted energy is also a function of the temperature of the source. This effect is described by Wien's Displacement Law which expresses the wave length of the peak radiation as being inversely proportional to the absolute temperature of the source.

Infrared energy is radiated through space without the need of a conducting or convecting medium. Since this energy is an electromagnetic wave, it travels through space with the velocity of light and with lower velocities in other mediums. The energy emitted from a source will be transmitted, reflected, or absorbed upon striking a body contingent upon the surface characteristics of the receiving body. The intensity of radiation reaching receiving bodies varies inversely with the square of their distances from the source.

In the transfer of radiant energy absorption is as important as emission of energy. When electromagnetic waves of any wave length fall upon any surface, part of the energy is reflected and part is accepted, the accepted energy is known as absorbed energy. Kirchhoff's Law of Radiation states any body in thermal equilibrium emits as much heat radiation as it receives at any given wave length and temperature. Therefore, the principles of emission of infrared energy are also valid when referring to bodies which absorb the same type of energy.

Although infrared energy does not require a material medium in which to travel, the medium through which it may travel effects the energy received by a body. When heat energy is radiated through the atmosphere, a portion of the energy is absorbed. Most of the infrared energy absorbed is due to the water vapor and carbon dioxide content of the atmosphere. Water vapor absorbs infrared radiation of wave lengths from 7,600 A. to 8,500 A. and from 12,000 A. to 25,000 A., while carbon dioxide has absorption bands from 12,500 A. to 16,000 A.

One known effect of infrared radiation on men and animals is that of heating, but the full effect of this energy is still unknown. For a particular wave length the penetrating properties of this energy are determined by the characteristics of the body receiving the energy. It has been found that the shorter wave infrared energy, 7,600 A. to 38,000 A., is usually more readily absorbed and has greater penetration than the longer waves. In general, the absorption of infrared energy decreases as the temperature of the receiving body increases.

II. PRODUCTION OF INFRARED RADIATION

The conventional tungsten-filament lamp generates some infrared energy although the primary purpose of this lamp is the production of visible light. The filament temperature is high, approximately 5,000°F., so that the emission of energy is mainly in the visible spectrum.

If a conventional lamp were used as a source of infrared energy, it would be inefficient since most of the generated energy would be wasted in the form of visible radiation. However, this lamp can become an efficient generator of infrared energy by decreasing the filament temperature. When the filament temperature is reduced, less light is produced, and the wave length of peak radiation shifts toward the infrared waves.

When the tungsten-filament lamp is designed as an infrared lamp, its filament operates at approximately 4,000°F. This lamp has an efficiency of only six to eight lumens per watt as compared to 18 to 24 lumens per watt for a lamp designed for the production of visible energy. From seventy-five to eighty-five per cent of the power input to the filament of a heat lamp is radiated as infrared energy with most of this energy within the range of 7,600 A. to 50,000 A. Wave lengths longer than 50,000 A. are absorbed by the glass bulb and carried away by either convection , conduction, or re-radiation.

III. DETECTION OF INFRARED RADIATION

Infrared radiation from a body can be measured and the temperature calculated from it. An advantage of this method of measurement is that no part of the temperature sensing element is required to be in physical contact with the radiating body.

The purpose of a radiation-temperature measuring device is to convert the radiant energy from the heated body into a sensible indication of temperature. After this conversion the temperature may be measured by thermocouples, resistance thermometers, or even bimetallic strips.

In its most elementary form a thermocouple consists of two dissimilar wires, insulated and joined together to provide the measuring junction. However, the two free ends of the thermocouple must be connected to a millivoltmeter or a potentiometer so that the created electromotive force can be measured and converted to temperature. The thermocouple is an accurate and reliable temperature measuring device.

In regard to comfort conditions for humans, authorities have long recognized that an ordinary mercury thermometer, which registers air temperature alone, is not an accurate criterion of comfort. This thermometer is not sufficiently sensitive to either radiant energy or air movement. It has been generally accepted that ambient temperature, relative humidity, air movement, and radiation are the major factors determining human comfort (38), and as investigators experiment with animals it appears that these same factors have a great influence on their performance (7).

As early as 1887, Aitken (9) used a blackened hollow sphere of thin sheet metal, with a thermometer inserted into the sphere, as an infrared measuring device. During the early years of the twentieth century, Vernon (41), used a hollow sphere as a radiant energy measuring device for heat received by humans from an open-flame fire. Vernon used globes which ranged in diameters from 6.3 centimeters to 22.8 centimeters, with the largest globe indicating the highest temperature, 6.8°C., and the smallest globe only slightly lower, 6.3°C.

The final globe thermometer constructed by Vernon was made from a hollow six-inch diameter copper sphere, such as those used for ball valves, coated with black paint, and containing an ordinary thermometer bulb inserted into the center of the sphere. The globe temperature depended solely on the environmental conditions of the surroundings. The infrared energy from the source impinged upon the blackened surface of the globe and raised the globe temperature somewhat above the ambient temperature recorded by the bulb thermometer.

When the globe thermometer is in equilibrium with its environment, the effects of radiation and convection will balance each other. Since the area projected by the globe is the same in all directions, the mean radiation is not influenced by the direction from which the energy reaches the globe. However, the rate of air flow does effect the recorded globe temperature. As the velocity of air increased, more heat is removed by convection and the resulting temperature will be somewhat reduced.

The temperature recorded by the Vernon globe thermometer is referred to as the radiation-convection temperature because it is an indication of the combined effects of radiation, ambient temperature, and air flow. Vernon indicated that the globe temperature was a good index of comfort, even when the relative proportions of radiant heat and convected heat vary considerably.

IV. EXPERIMENTAL PROCEDURE

Discussion of objectives. As previously stated the purpose of this study was to determine the temperature preference of young chicks and to relate these to age and to sex.

Previous research workers, as well as growers, have observed that chicks will assemble at particular locations when they are exposed to temperature conditions which provide a heat gradient. However, so far as it was able to be determined, none of the previous investigators have related the grouping of birds to the temperature gradient, to the successive age of the bird, or to the sex of the bird.

Discussion of approach. In order to accomplish the goals of this project it was necessary to provide an appropriate research facility. The essential items of this facility were that a system be provided which would establish a suitable temperature gradient and at the same time allow the birds complete freedom of movement within the gradient. Also, the necessary instrumentation and equipment had to be provided to record the relevant data.

The review of literature did not reveal any test facilities that were either adequate or acceptable for this experiment. Therefore, test facilities which would accomplish the stated objectives of this investigation had to be designed and developed.

Various approaches and designs which would establish a temperature gradient were considered. Some of these could utilize convective heat to establish a gradient while others could utilize infrared sources to establish the gradient. It was finally decided that a gradient using an infrared source was more adaptable to the conditions and facilities available for conducting this project.

Description of test facilities. For this experiment it was decided that the required temperature gradient could be effectively established by using infrared heat bulbs in a cooled environmental chamber. This chamber was provided by remodeling and adapting an existing windowless poultry house to fulfill the requirements of this project. This house was located on the Cherokee Farm of the University of Tennessee Agricultural Experiment Station, Knoxville.

The structure was eighteen feet wide by forty-six feet long. The front of the house was eight and one-half feet high, and the roof had a pitch of one-twelfth. The exterior face of the building was three-fourths inch tongued-and-grooved wood sheathing, and the interior wall surface was three-sixteenths inch cement-asbestos board. The floor of this structure was a concrete slab four inches thick.

Commercial "Fiberglass" blanket insulation, three and one-half inches thick, was placed in the stud spacings between the interior and exterior wall surfaces, and in the rafter spacings between the roof decking and asbestos-cement board. The roof blankets were encased with aluminum foil, and the sidewall blankets were encased with heavy brown paper.

Figure 1 shows the interior of this poultry house remodeled to provide an instrument room, an environmental chamber, and a compressor room. These rooms were divided by a stud partition which was covered with poultry mesh and one-inch commercial "Styrafoam" insulation boards. In the wall between the instrument room and the chamber, a thirty-six inch by thirty-six inch glass observation window was installed so

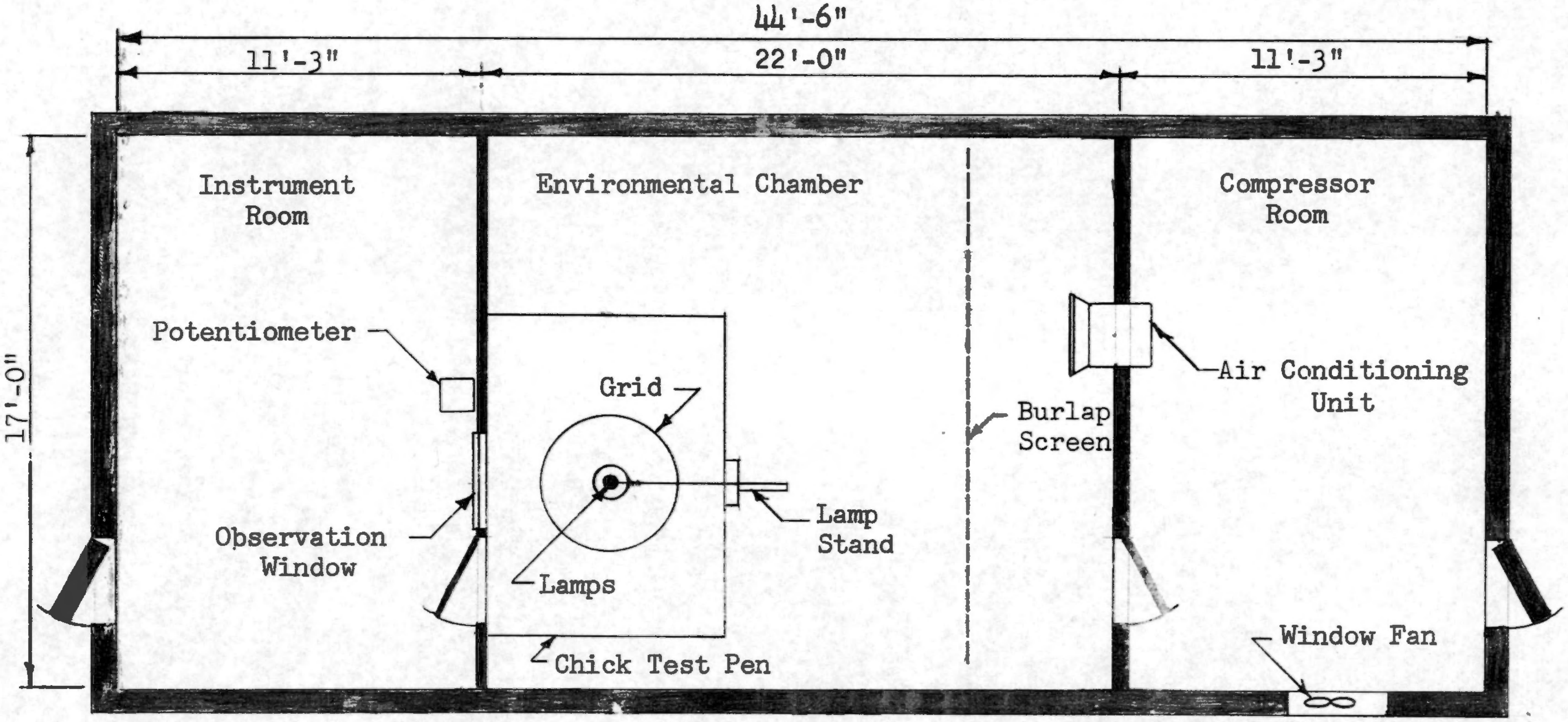

Figure 1. Plan view of experimental facility.

physical observations of the environmental chamber could be made.

A 23,000 Btu. per hour Carrier air conditioning unit was installed in the wall between the environmental chamber and the compressor room. Within narrow limits this unit controlled both the ambient temperature and relative humidity of the environmental chamber. To reduce the effects of a cool air draft across the test pen, a four feet by thirteen feet burlap screen was placed five feet in front of and perpendicular to the flow of air from the discharge grill of the cooling unit.

Within the environmental chamber the movement of the birds was limited to a test pen in which the heat gradient was established. This cubicle, as shown in Figure 1, page 23, was constructed of one-fourth inch plywood and was 96 inches wide by 125 inches long by 24 inches high. In addition to limiting bird movement within the environmental chamber, this fence helped to further reduce the effects of draft across the test pen.

Heat gradient. The heat gradient was produced by three General Electric, type R-40, 375 watts, industrial heat lamps. This type of lamp has a built-in reflector which provides a fixed focus for even distribution and high concentration of energy in the form of a beam of approximately 120 degrees total spread.

The lamps were placed over the test pen by mounting a junction box and a lamp holder at the end of three separate steel pipes. Each pipe was one-half inch in diameter and four feet long. Figure 2 illustrates how the opposite end of the pipes were mounted on a wooden

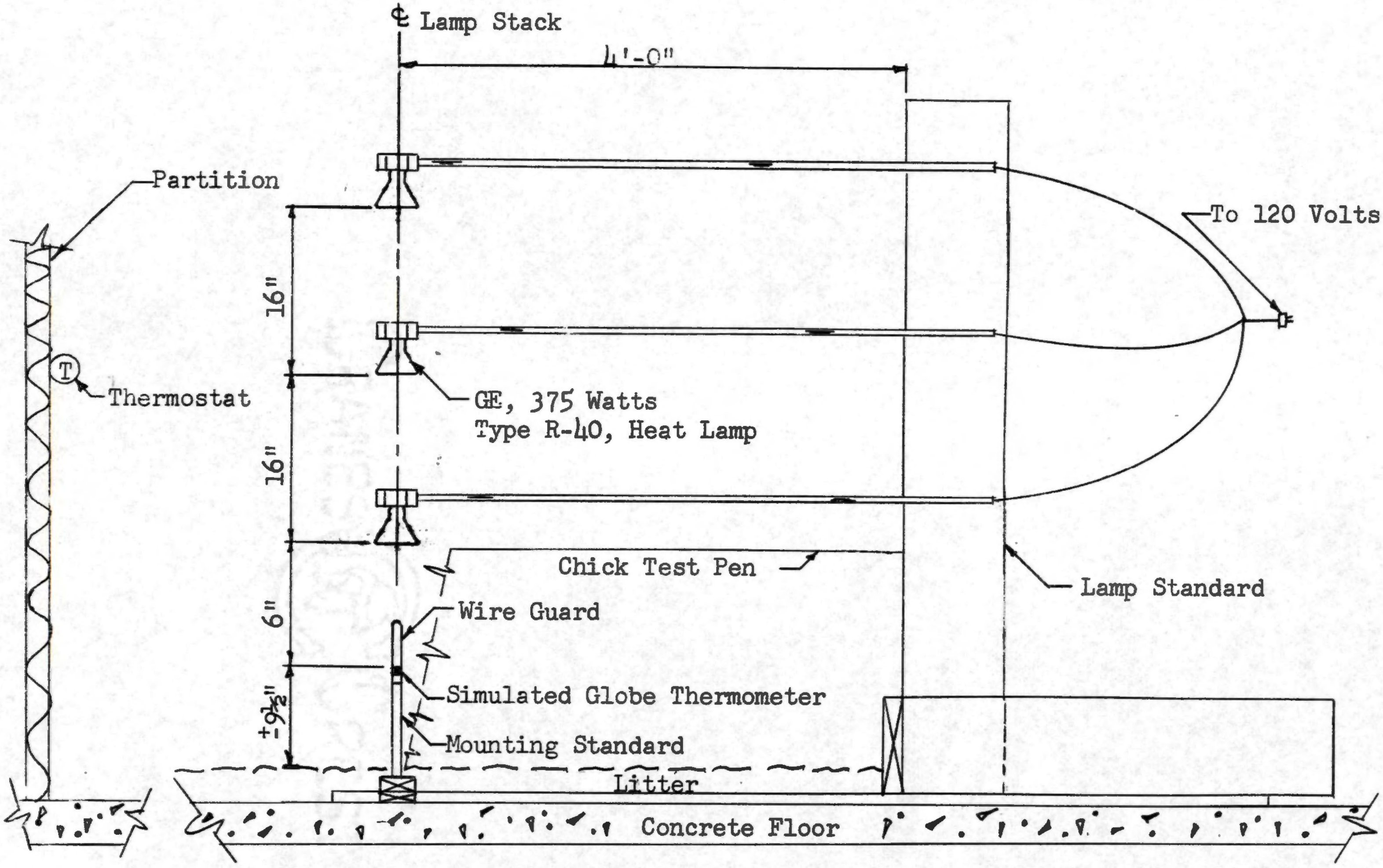

Figure 2. Elevation of chick test pen.

standard which permitted the bulbs to be positioned in a vertical line with each bulb sixteen inches above the other. The lower bulb was positioned approximately sixteen inches above the litter. The pipes were attached to the wooden standard with standard "U" bolts which allowed the lamps to be positioned at various horizontal positions over the test pen. The lamp arrangement established a temperature gradient broad enough so that the chicks had a clearly defined choice of temperatures over a relatively large floor area.

Comfort. In calorimetric studies on the human body, DuBois (13) defined the range of ambient temperature at which the body has to make no increase in activity in order to maintain its heat balance as the zone of thermal neutrality. This zone appears to closely approach what is generally referred to as the comfort zone.

The maintenance of the proper body temperature depends upon heat equilibrium between the body surface and its surroundings. Several fundamental thermodynamic processes affecting the body heat balance are described by the equation

$$M = \pm S \pm E \pm R \pm C$$

where M is the rate of metabolism; S is the rate of heat storage, depending upon whether heat is being stored or depleted owing to a rise or fall in body temperature; E is the rate of evaporation (when the dew point of external air is below the body surface temperature E is positive); R is the rate of radiative heat loss or gain; and C is the rate of convective heat loss or gain. R and C are positive when body surface temperature is above that of air and walls, and negative when it is below.

The rate at which these heat balancing processes take place depend upon the conditions surrounding the body. For instance, when the ambient temperature is below the blood temperature, heat losses occur by radiation, convection, and some by evaporation. However, when the ambient temperature rises above the blood temperature, the process of heat removal is by evaporation only.

The comfort of a human is greatly affected by the factors of the heat balance equation. This equation states that the metabolic heat produced by a living body is balanced against the heat gained or lost from its surroundings. This physiological ability of a man or animal to balance heat gain against heat loss in order to maintain a constant internal body temperature is called homeothermy. This homeothermic ability of the human body is known to be effective for a relatively wide range of external conditions. Within this range of homeothermy lies the comfort zone or zone of thermoneutrality which is the area of minimum heat production by the human body. Heat production of the body is fairly constant in this zone and is the result of normal metabolism.

If a human is given a choice of environmental conditions, normally those conditions which produce maximum comfort will be selected. In effect the human body senses the environmental conditions which balances its metabolic heat production against the integrated effect of all the external physical factors which affect comfort. Since a combination of external factors affect comfort it is apparent that a limited variety of external conditions can exist which will produce comfort. The American Society of Heating and Air Conditioning Engineers have conducted considerable research on the various combinations of factors which produce comfort conditions for humans (16).

The conditions for comfort of animals are not clearly defined, but they are generally thought to be similar to those of humans. The heat balancing process is not unique to the human body. Any living body tends to come to the temperature of its surroundings by the same basic thermodynamic processes as the human body, but the methods by which this is accomplished varies in different forms of life. For example, the heat losses by evaporation for man and some animals, particularly the horse, is accomplished by both perspiration and action of the lungs. However, most domestic animals, dogs, cattle, and poultry, remove heat by evaporation through the lungs only. The heat is expelled from the lungs by respiration.

It is not known to what degree animal comfort and performance are correlated. In the case of chicks it is not definitely known what the comfort of birds is in relation to the environmental factors which would influence comfort. However, it is known that a young chick must rely on a sufficient supplement of external heat in order to control its body temperature because its heat regulating mechanisms are not completely developed.

This study was an attempt to better define the comfort conditions of young chicks as related to black globe temperatures. In this investigation the remaining factors which contribute to bird comfort, ambient temperature, relative humidity, and rate of air flow, were held as constant as possible with the available facilities.

Instrumentation. Since the Vernon globe thermometer is an indicator of the combined effects of radiation, ambient temperature, and air flow, several agricultural engineers have used this instrument or modifications thereof to study the combined effects of environmental conditions on animals. In 1949 Kelly, Bond, and Lorenzen (18) used a globe thermometer in tests which compared the amount of radiation received by livestock under various types of shades. These investigators slightly modified the Vernon globe by replacing the bulb thermometer with a thermocouple. Preliminary to the shade studies, Kelly, Bond, and Lorenzen compared the size of different globes to the recorded temperature of each globe. It was found that the six inch diameter globe offered sufficient accuracy and adaptability for their study.

The total heat load on animals was measured by Bond, Kelly, and Ittner (10) using a black globe thermometer. In this study six inch globe thermometers were used to compare thermal conditions of two shades as they affected the relative comfort of animals under them. Raber and Hutchinson (17) suggested using blackened spheres as a reference surface in simplified calculations of the radiant heat load received by animals.

A modification of the globe thermometer (3) was developed by the Virginia Agricultural Experiment Station to obtain relative heat patterns from a heat lamp brooding system. In these experiments the brooder temperatures were measured by inserting thermocouples into the center of perforated black and perforated white ping-pong balls. Nicholas (26) defined the heat zones under a heat lamp brooding system by obtaining the ambient air temperature immediately adjacent to the litter.

In an effort to maintain a desirable environment under an infrared brooder, White and Taylor (43) developed a radiation-sensitive infrared brooder control. The basic elements of this control were a four-inch diameter globe painted flat black and an internal heating element. The globe was placed under the infrared lamp just above the litter where it was used to simulate the comfort conditions of baby chicks.

The preceding discussion illustrates various experiments in which previous investigators have used the black globe thermometer. Where an environment is composed of or affected by the combined effects of radiant heat, ambient temperature, and air velocity, the black globe thermometer seems to be the best indicator of the resultant temperature. In many respects it has become the standard device for such temperature measurements, especially when they are associated with animal comfort. Since this is true, the black globe thermometer was used as a standard for calibration of the thermal sensing elements developed for this study.

V. METHODS OF RECORDING MEASUREMENTS

Development of thermal sensing element. Since the heat gradient established by the infrared brooding system used in this project was approximately six feet in diameter, it was impractical to use six-inch diameter globes. A smaller device was required if the young chicks were to be given the maximum freedom of movement.

In an attempt to develop a smaller thermal sensing element which would duplicate a six-inch diameter globe thermometer reading, several devices were developed and compared to globe temperatures. A view of some of the experimental sensing elements are shown in Figure 17 of the Appendix. The initial device was constructed on an one-fourth inch diameter blackened lead ball with a thermocouple imbedded in its center. This lead ball thermocouple, a standard six-inch diameter globe thermometer, as described by Kelly, Bond, and Lorenzen (18), and a bare thermocouple shielded with aluminum foil were exposed to a variety of atmospheric conditions. Table I is a comparison of the recorded temperatures of each of these devices, and shows that the lead ball temperatures more closely approached those of the ambient temperature.

Next a series of square plates were made from aluminum, copper, and galvanized metal. These plates were of various dimensions and thickness. A thermocouple was soldered to the center of each plate. These plates were painted with two coats of flat black paint and compared with globe temperatures when all the elements were exposed to sunlight. After several tests under various conditions of sunlight and other environmental factors, it was apparent that the one-inch square, 26 gauge sheet metal plate gave temperatures quite similar to those of the globe thermometer. The magnitude of the temperature of this sheet metal plate was a few degrees lower than that of the globe. Its response

TABLE I

COMPARISON OF AMBIENT, LEAD BALL, AND BLACK GLOBE TEMPERATURES, °F.

Ambient Air	Lead Ball	Six-inch Black Globe
74	81	100
73	82	98
71	79	98
78	87	104
78	84	105
73	82	104
78	85	105
75	85	106
77	84	103
78	84	104
77	87	109
79	89	106
80	87	107
80	87	109

NOTE: Test conducted May 4, 1964, 9:20-10:30 A.M.

to radiant heat was quicker than the globe, since there is a lag of several minutes for heat equilibrium to be re-established after a change in globe temperature. After several initial tests it was decided that this one-inch blackened metal plate was sufficiently accurate to satisfy the requirements of this project. Use of small metal plates as sensors of infrared energy has been confirmed by other investigators (30) who have used similar devices for sensing infrared radiation in other types of research.

Before the plates were actually used for collecting data, they were given a series of calibration checks against the black globe thermometer. Also, it was found that the performance of the plate temperature as related to globe temperatures was improved considerably by covering the plate with a one-inch square piece of single strength glass.

Since most of the infrared energy generated by the heat lamps is within the wave length range of 7,600 A. to 50,000 A., the glass did not affect the radiation which was to be measured. The glass plate reduced the fluctuations of plate temperatures, and raised the plate temperature so that it more closely duplicated the globe temperatures. The glass cover had an additional advantage for this investigation since it provided an easily cleaned surface for protecting the black plates from dust and other foreign matter.

With this plate covered with glass, a series of calibration tests were conducted. The results of these tests are given in Tables IX, X, XI, and XII of the Appendix. A plot of Table IX is shown in Figure 3

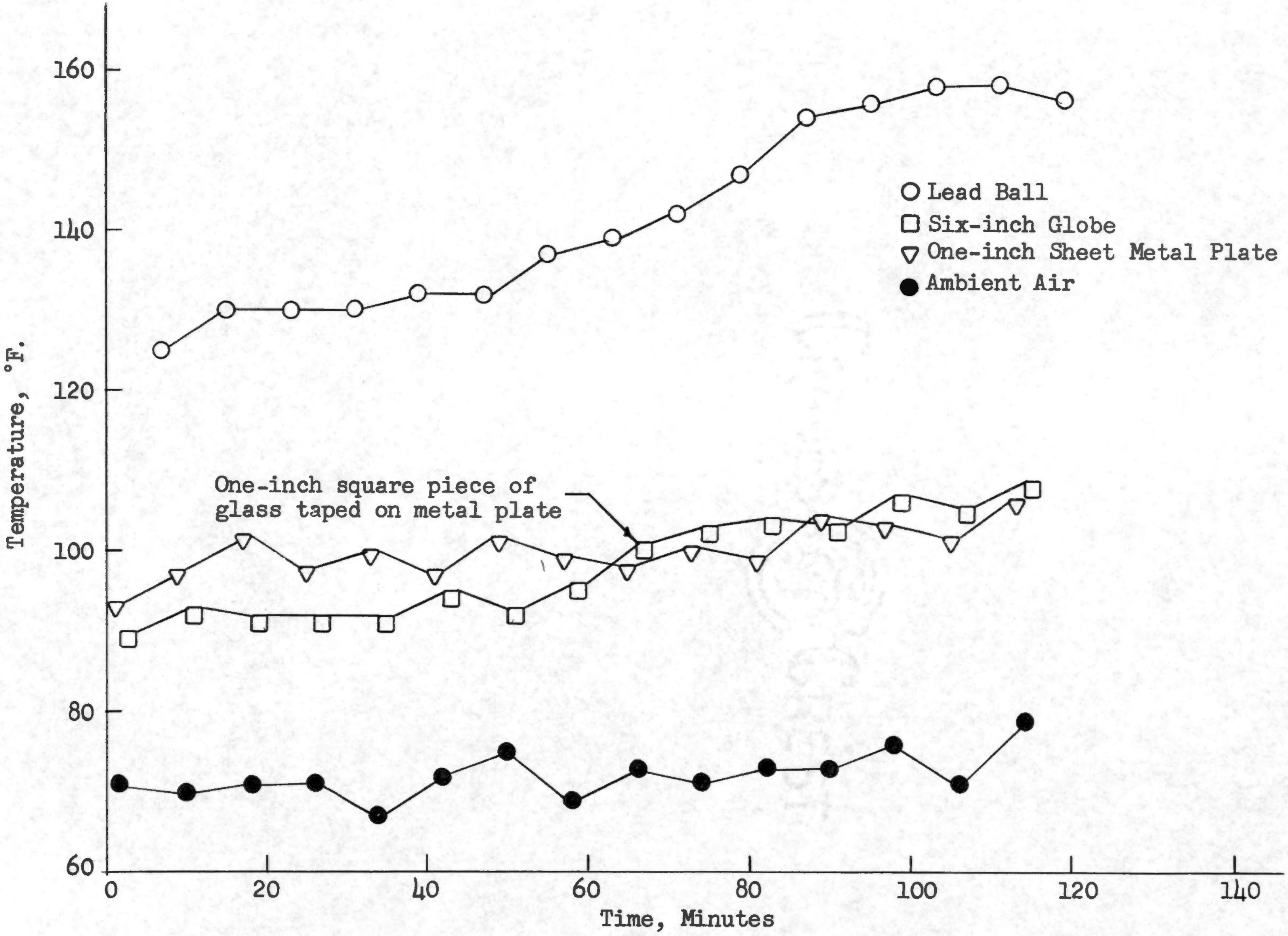

Figure 3. Relationship between ambient, black globe, sheet metal, and lead ball temperatures, °F.

and illustrates the close relationship between the plate temperature and globe temperature.

Table II gives a comparison of the average plate temperature and the average globe temperature as obtained in the preceding tests. From this data it was determined that the plate temperature was an average of 2.5°F. less than the globe temperature. Before a statistical analysis was made of the recorded data, this temperature correction factor was added to each mean comfort temperature.

Employment of thermal sensing elements. Once the sensing elements for radiant heat had been developed, a method of arranging them under the heat lamps was devised. The thermal plates were mounted on a one-inch square wooden standard as shown in Figure 4. The top of each standard was sloped in such a manner that the incident radiation from the middle lamp would impinge the blackened plates in a normal direction. A portion of the wooden mounting standard, immediately beneath the thermal plate, was removed so the plates were essentially suspended in air and heat could be removed by convection. The height of the plates was approximately nine and one-half inches above the litter and remained fixed throughout the investigation. This height was necessary to prevent the body of the chick from interrupting the radiation of the infrared energy from the lamps to the thermal plates.

The blackened plates were placed in a horizontal plane six inches below the lowest heat lamp and centered on the centerline of the heat lamp stack. The mounting standards held the sensing elements in the

TABLE II

MEAN TEMPERATURE DIFFERENCES OF ONE-INCH SHEET METAL PLATE AND SIX-INCH BLACK GLOBE, °F.

	Trial			
	1	2	3	4
Mean, six-inch globe temperature	99.87	127.33	111.60	111.89
Mean, one-inch sheet metal temperature	98.00	123.93	109.20	109.44
Difference	1.87	3.40	2.40	2.45

Mean temperature difference for four trials = 2.5°F.

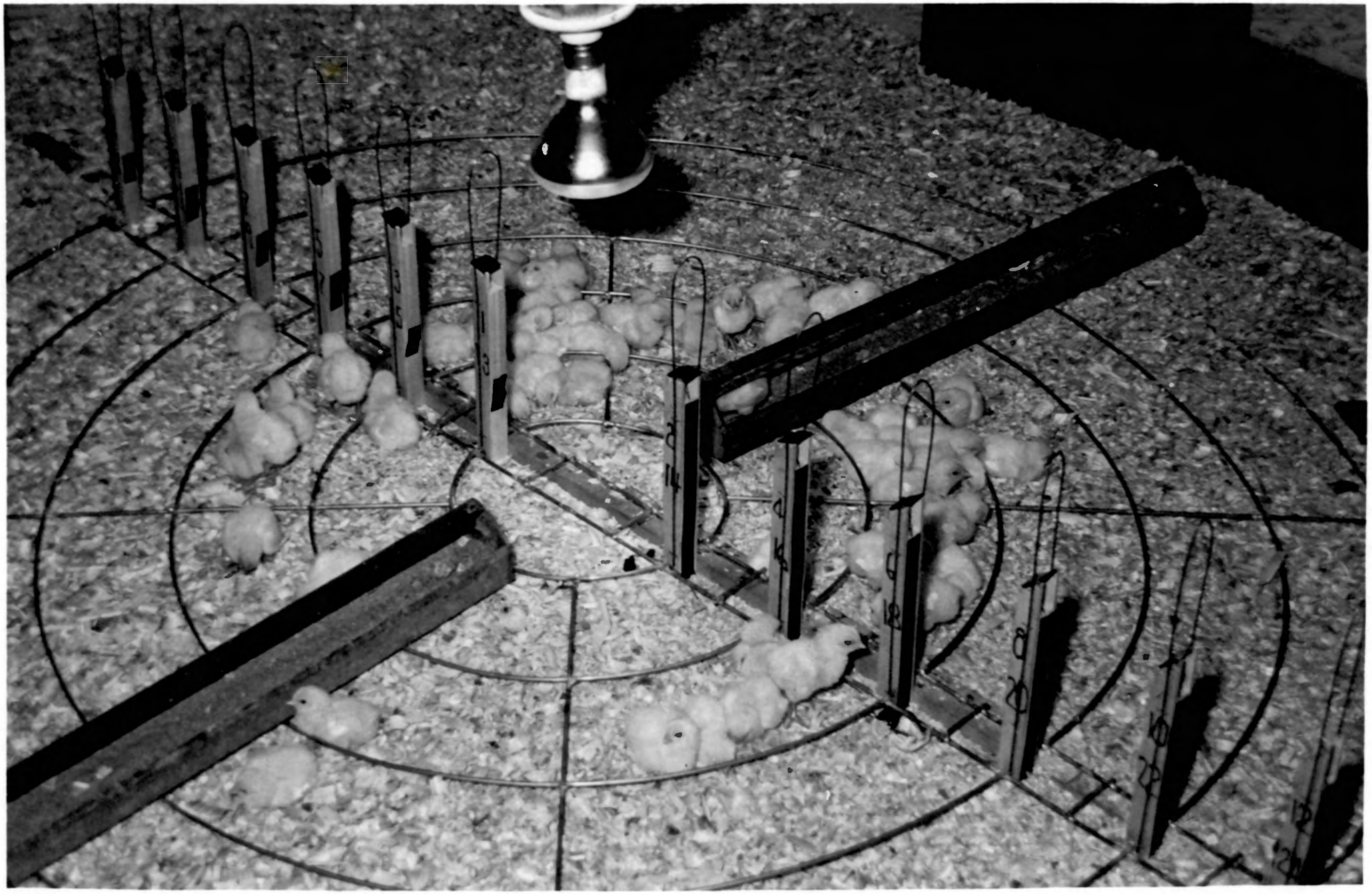

Figure 4. View of chick test pen.

horizontal plane and spaced them at six-inch intervals extending thirty-six inches radially from the lamp stack centerline. An anchor arm positioned the black plate standard assembly at the proper location beneath the lamp assembly.

Lying on the litter and centered on the thermal sensing elements and lamp stack centerline was a wire grid. This grid was composed of six concentric rings forming six-inch wide zones which corresponded to the circular pattern of the temperature gradient. Each zone was identified so an observer could make a physical observation of the birds in each zone.

Since thermocouples were attached to the back of the sensor plates, an electronic recording potentiometer was used to record each of the detected temperatures. A Daystrom-Weston twenty-four point potentiometer was used to record the temperature at twelve individual points under the heat lamps. The thermocouples were wired to the potentiometer panel board so that the temperature of corresponding plates on opposite sides of the temperature gradient would be recorded at one minute intervals. The recording cycle of the twelve plates would be repeated every twelve minutes.

The recording potentiometer was placed in the instrument room, and lead wires were run from there to the respective location of the thermocouple sensing elements. The lead wires were sixteen gauge copper-constantan Continental wire insulated with thermoplastic. The thermocouple attached beneath the blackened plates was made of Minneapolis-Honeywell twenty-four gauge copper-constantan wire insulated with a thermoplastic cover.

Calibration checks. Before the thermocouples were attached to the back of the blackened sheet metal plates, they were calibrated for accuracy. Lorenzen (25) cited a method of thermocouple calibration by exposing the thermocouple tip to a known temperature in the range in which the thermocouple would be used. Each thermocouple used in this investigation was calibrated against the temperature of melting ice and also the temperature of boiling water. Only those thermocouples which recorded these fixed temperatures were used.

After the thermocouples were attached to the metal plates and placed in the environmental chamber, they were periodically calibrated. For calibration within the chamber, all the heat sources were removed, and the ambient temperature within the chamber was allowed to stabilize. When this chamber condition was reached, the recording potentiometer recorded the thermal plate temperatures, and these values were compared to the room ambient temperature. Each time the thermocouples were calibrated in this manner, all the detected temperatures were within plus or minus one degree of the ambient temperature of the chamber.

Since the black plate standard assembly was positioned parallel to the observation window throughout the length of the investigation, tests were conducted to insure that the lamps provided a uniform temperature gradient. The standard assembly was rotated about the lamp stack centerline in forty-five degrees increments, and the average temperatures equidistant from the lamp centerline were plus or minus one and one-half degrees from those recorded with the standard assembly in the normal position.

Since the black plates were permanently positioned nine and one-half inches above the litter, tests were conducted to determine the difference in temperature at various heights above the litter from those recorded by the standard plates. A portable sensing element similar to the permanent elements was used to record temperatures midway between two of the permanent elements and at heights of nine and one-half inches, six inches, and two and one-half inches above the litter. With the portable element placed nine inches from the lamp stack centerline and at heights of nine and one-half, six, and two and one-half inches above the litter, the recorded temperatures were 94.1°F., 96.4°F., and 91.6°F., respectively. Near the outer edge of the gradient, thirty-three inches from the lamp stack centerline, the temperatures recorded at the same heights were 60.2°F., 60.5°F., and 61.1°F., respectively. An analysis of all tests revealed that the mean temperature differences between the portable element at nine and one-half inches above the litter and the portable element at heights of six and two and one-half inches above the litter were 0.74°F. and 0.63°F., respectively.

The environmental chamber's ambient temperature and relative humidity were continuously recorded by a Friez-Hygro-Thermograph. This instrument was suspended inside the chamber five feet above the litter so it could be viewed from the instrument room. The hygro-thermograph was periodically calibrated against a sling psychrometer and a psychrometeric chart.

Collection of data. The temperatures of the thermal sensing elements were recorded by the recording potentiometer on strip charts designed for use with this instrument. The number of the sensing element under the heat lamps was imprinted on the chart so it could be easily identified.

Each zone of the wire grid was identified by an alphabetic character so an observer could make a physical count of the number of chicks that were resting or moving in the respective temperature zones. This information was recorded on the data sheet as shown in Figure 18 of the Appendix.

The ambient temperature and relative humidity of the environmental chamber were continuously recorded on the hygro-thermograph chart by a stylus. From this chart the environmental condition of the chamber could be determined for any period of time.

For convenience of analysis, the data were extracted from the potentiometer charts, chick count sheets, and hygro-thermograph charts. This data was tabulated on forms designed for this investigation.

VI. CHICKS AND MANAGEMENT OF ENVIRONMENTAL CHAMBER

The Poultry Department of the Agricultural Experiment Station of the University of Tennessee furnished the chicks to be used in this investigation. The experiments consisted of two tests of five weeks duration each. At the beginning of each of the two test periods, the Poultry Department placed twenty male and twenty female, one-day-old Vantress x Arbor Acre White Rock chicks in the test pen. Each sex was marked with distinguishing mark so it could be identified throughout the length of each trial.

The Poultry Department staff was responsible for the feeding and management of the young birds. The management of the chicks included supplying feed and water, cleaning the test pen at the end of each trial, supplying fresh litter for the test pen, and other routine services. The birds were managed in a manner similar to a normal broiler operation.

The Department of Agricultural Engineering assumed the responsibility for the mechanical equipment and instrumentation required for this experiment.

CHAPTER III

PRESENTATION AND DISCUSSION OF DATA

I. EXPERIMENTAL DATA

During the experiment observations were made twice each day, and the chicks resting within each zone of the heat gradient were recorded on a daily temperature preference chart. One observation was generally made during the morning and the second during the late afternoon. Table XIII of the Appendix shows a sample chart and the method of recording each observation.

In both trial 1 and trial 2, weekly summaries for the total group of birds and for each sex were computed, and the mean temperature of the stations along the heat gradient were calculated. This information was summarized on a weekly summary chart as shown in Table XIV of the Appendix.

The chicks resting in the respective zones of the heat gradient were assumed to have selected a position of maximum comfort, and only these birds were counted as having exhibited a temperature preference. The ambient temperature of the environmental chamber was generally low enough to force the young birds to remain within the area of the heat gradient as shown in Figure 4, page 37. When the ambient temperature of the chamber rose sufficiently, the birds found a comfortable temperature outside the effects of the gradient. Birds resting in this area were assumed to be within the outer zone of the gradient because the black plate temperature and the ambient temperature were the same value in this area. Chicks which were moving inside the gradient or outside the gradient were assumed to be either seeking a more comfortable position or seeking food or water which was located outside the heat gradient during trial 1 and trial 2.

The temperatures detected by the black plates duplicated those which a standard globe thermometer would record, and these were used as an index of chick comfort. From the daily temperature preference charts a mean temperature was calculated, and this value was assumed to be the temperature preference of the resting birds for that specific observation. As explained in the previous chapter, the correction factor of 2.5°F. was added to each mean temperature so the final temperature more closely approached the temperature of a standard globe thermometer. For the remainder of this thesis, all temperatures have the correction factor added, and these temperatures will be referred to as the equivalent globe temperature or E.G.T.

Table III gives the equivalent globe temperature for the total group for each day of trial 1, and Table IV gives similar data for trial 2. Each table also has the E.G.T. as chosen by each sex. Table V and Table VI have the E.G.T. for the total birds and each sex summarized on a weekly basis.

TABLE III

DAILY EQUIVALENT GLOBE TEMPERATURE PREFERENCES IN TRIAL 1, °F.

Total Group				Males				Females			
Age[a]	E.G.T.[b]	Age	E.G.T.	Age	E.G.T.	Age	E.G.T.	Age	E.G.T.	Age	E.G.T.
1a[c]		19a	73.0	1a		19a	73.0	1a		19a	73.1
p[d]	86.7	p	76.1	p	88.4	p	77.4	p	84.4	p	74.8
2a	84.6	20a	69.8	2a	85.1	20a	69.5	2a	84.2	20a	70.1
p	87.5	p	76.0	p	91.1	p	74.8	p	83.3	p	78.0
3a	86.6	21a	74.8	3a	82.7	21a	73.9	3a	88.9	21a	75.8
p	82.0	p	74.4	p	85.2	p	76.4	p	80.4	p	72.7
4a	*	22a	70.2	4a	*	22a	71.0	4a	*	22a	69.4
p	79.0	p	73.1	p	80.0	p	72.8	p	78.1	p	73.4
5a	76.0	23a	68.2	5a	76.8	23a	69.2	5a	75.1	23a	66.9
p	85.4	p	70.4	p	86.2	p	70.4	p	84.9	p	70.3
6a	73.3	24a	82.1	6a	74.6	24a	70.9	6a	72.0	24a	104.3
p	74.9	p	74.5	p	76.7	p	75.9	p	73.2	p	72.5
7a	72.5	25a	70.7	7a	72.3	25a	68.7	7a	72.7	25a	72.9
p	74.6	p	71.7	p	74.9	p	71.4	p	74.2	p	72.1
8a	77.6	26a	71.3	8a	77.4	26a	70.9	8a	77.9	26a	72.2
p	86.7	p	75.3	p	85.5	p	70.8	p	89.9	p	78.3
9a	78.1	27a	83.3	9a	79.0	27a	82.7	9a	77.3	27a	84.3
p	74.6	p	71.6	p	72.7	p	71.1	p	76.5	p	72.4
10a	77.9	28a	69.5	10a	79.8	28a	70.4	10a	75.6	28a	68.7
p	71.3	p	66.5	p	71.4	p	82.7	p	71.2	p	72.0
11a	88.2	29a	76.8	11a	86.7	29a	66.3	11a	89.4	29a	66.8
p	79.8	p	76.9	p	79.8	p	77.7	p	80.1	p	75.3
12a	84.5	30a	86.9	12a	84.2	30a	81.0	12a	85.1	30a	90.6
p	87.0	p	75.4	p	93.7	p	70.5	p	79.5	p	81.0
13a	71.7	31a	72.3	13a	70.5	31a	76.5	13a	73.1	31a	64.5
p	76.5	p	77.5	p	75.1	p	82.7	p	78.1	p	69.5
14a	74.8	32a	68.1	14a	74.6	32a	68.6	14a	75.2	32a	67.1
p	71.0	p	85.0	p	71.4	p	87.7	p	70.8	p	75.0
15a	71.8	33a	70.1	15a	73.2	33a	70.5	15a	70.1	33a	69.0
p	78.1	p	73.2	p	79.7	p	73.3	p	76.2	p	72.9
16a	82.1	34a	66.8	16a	82.5	34a	67.2	16a	81.2	34a	65.7
p	78.1	p	69.6	p	78.4	p	70.0	p	77.8	p	68.2
17a	75.6	35a	67.8	17a	71.4	35a	68.3	17a	78.1	35a	66.5
p	73.5	p	84.6	p	73.8	p	78.4	p	73.2	p	109.5
18a	80.7	36a	74.1	18a	81.0	36a	74.3	18a	80.0	36a	73.4
p	80.6			p	81.2			p	80.1		

[a] Age in days.

[b] E.G.T. is equivalent globe temperature.

[c] Morning observation is a.

[d] Afternoon observation is p.

*Observation omitted because of unusual conditions.

TABLE IV

DAILY EQUIVALENT GLOBE TEMPERATURE PREFERENCES IN TRIAL 2, °F.

Total Group				Males				Females			
Age[a]	E.G.T.[b]	Age	E.G.T.	Age	E.G.T.	Age	E.G.T.	Age	E.G.T.	Age	E.G.T.
1a[c]		19a	100.5	1a		19a	102.4	1a		19a	97.6
p[d]	88.4	p	73.3	p	87.4	p	73.7	p	89.4	p	72.9
2a	107.3	20a	93.1	2a	117.5	20a	98.6	2a	99.8	20a	87.7
p	83.6	p	69.7	p	83.8	p	69.0	p	83.5	p	70.3
3a	83.0	21a	90.1	3a	85.2	21a	85.1	3a	80.8	21a	95.1
p	86.7	p	86.7	p	85.2	p	89.3	p	88.6	p	82.4
4a	83.5	22a	85.2	4a	86.2	22a	94.1	4a	81.1	22a	74.7
p	87.7	p	84.5	p	87.3	p	92.5	p	88.7	p	78.7
5a	111.3	23a	91.4	5a	111.6	23a	87.6	5a	111.0	23a	95.8
p	76.6	p	90.2	p	75.7	p	87.1	p	77.6	p	94.2
6a	79.6	24a	88.1	6a	79.1	24a	93.2	6a	80.1	24a	83.4
p	85.0	p	70.8	p	85.6	p	71.1	p	84.3	p	70.6
7a	79.0	25a	73.3	7a	80.7	25a	74.0	7a	77.3	25a	72.6
p	97.9	p	78.5	p	97.5	p	72.2	p	98.3	p	85.3
8a	89.9	26a	70.1	8a	86.4	26a	71.7	8a	93.2	26a	68.8
p	81.9	p	71.7	p	81.5	p	70.5	p	82.2	p	72.9
9a	79.2	27a	69.3	9a	78.6	27a	68.3	9a	79.9	27a	70.3
p	85.2	p	82.6	p	84.6	p	84.0	p	85.8	p	81.0
10a	79.4	28a	80.4	10a	80.8	28a	75.9	10a	78.3	28a	83.9
p	82.7	p	85.3	p	81.3	p	83.0	p	83.8	p	87.5
11a	86.3	29a	78.3	11a	90.5	29a	71.2	11a	81.4	29a	83.8
p	79.5	p	71.3	p	80.5	p	72.2	p	78.5	p	70.4
12a	89.5	30a	70.1	12a	86.6	30a	71.2	12a	94.1	30a	69.3
p	72.3	p	86.8	p	70.9	p	99.8	p	73.7	p	73.8
13a	75.1	31a	72.2	13a	75.6	31a	73.9	13a	74.6	31a	70.6
p	78.0	p	69.6	p	76.0	p	68.4	p	80.0	p	70.8
14a	79.1	32a	75.3	14a	81.3	32a	77.2	14a	76.7	32a	73.8
p	97.1	p	76.6	p	95.3	p	79.5	p	99.9	p	74.5
15a	74.7	33a	66.4	15a	72.0	33a	65.5	15a	76.5	33a	67.6
p	75.6	p	66.2	p	75.3	p	65.3	p	75.9	p	67.2
16a	70.8	34a	69.6	16a	71.9	34a	69.1	16a	69.7	34a	70.2
p	78.9	p	68.0	p	78.1	p	67.4	p	80.1	p	68.5
17a	70.1	35a	76.3	17a	69.8	35a	74.8	17a	70.5	35a	77.9
p	77.8	p	68.7	p	78.4	p	68.1	p	77.3	p	69.5
18a	64.1	36a	72.2	18a	64.5	36a	71.2	18a	63.9	36a	73.2
p	83.0			p	80.1			p	86.9		

[a] Age in days.

[b] E.G.T. is equivalent globe temperature.

[c] Morning observation is a.

[d] Afternoon observation is p.

TABLE V

WEEKLY SUMMARY OF EQUIVALENT GLOBE TEMPERATURE PREFERENCES IN TRIAL 1, °F.

Age in Weeks	E.G.T.
Total Group	
1	78.8
2	76.7
3	75.7
4	72.5
5	74.1
Males	
1	78.9
2	77.2
3	76.1
4	72.1
5	73.8
Females	
1	78.3
2	76.0
3	75.2
4	73.0
5	74.8

NOTE: E.G.T. is equivalent globe temperature.

TABLE VI

WEEKLY SUMMARY OF EQUIVALENT GLOBE TEMPERATURE PREFERENCES IN TRIAL 2, °F.

Age in Weeks	E.G.T.
	Total Group
1	87.7
2	80.8
3	79.7
4	79.5
5	71.6
	Males
1	88.1
2	80.9
3	81.0
4	79.0
5	72.2
	Females
1	87.4
2	80.4
3	78.3
4	79.9
5	70.0

NOTE: E.G.T. is equivalent globe temperature.

II. ANALYSIS OF DATA

Since the objectives of this investigation were to determine the preferences of chicks and relate these temperature preferences to age and to sex, the most logical approach to analyzing the data appeared to be a statistical analysis which would give a measurement of the correlation between the variables. In this experiment the supplementary heat requirement for each bird was optional. The relative humidity for trial 1 and trial 2 ranged from 52 to 57 per cent and from 57 to 65 per cent, respectively. The remaining environmental factors that were thought to affect chick comfort were held as nearly constant as possible. With the established heat gradient, the birds were given the freedom of selecting a position which satisfied their heat requirements for producing comfort. It was assumed that the age of the bird would influence temperature preference, and it was thought that the sex of the bird might also have some relation to temperature preference.

Trial 1, May 7 to June 14, 1965, had a total of sixty-nine observations, while trial 2, August 9 to September 16, 1965, had a total of seventy observations. In trial 1, the morning observation of May 10, 1965, was discarded because all chicks were huddled in one corner of the test pen. Apparently the birds had been frightened by a noise made accidently by the observer upon entering the instrument room.

Daily data analysis. In an attempt to describe the trend of the preferred E.G.T., graphical representations of the relationship between E.G.T. and age for trial 1 are presented in Figure 5 for the total group,

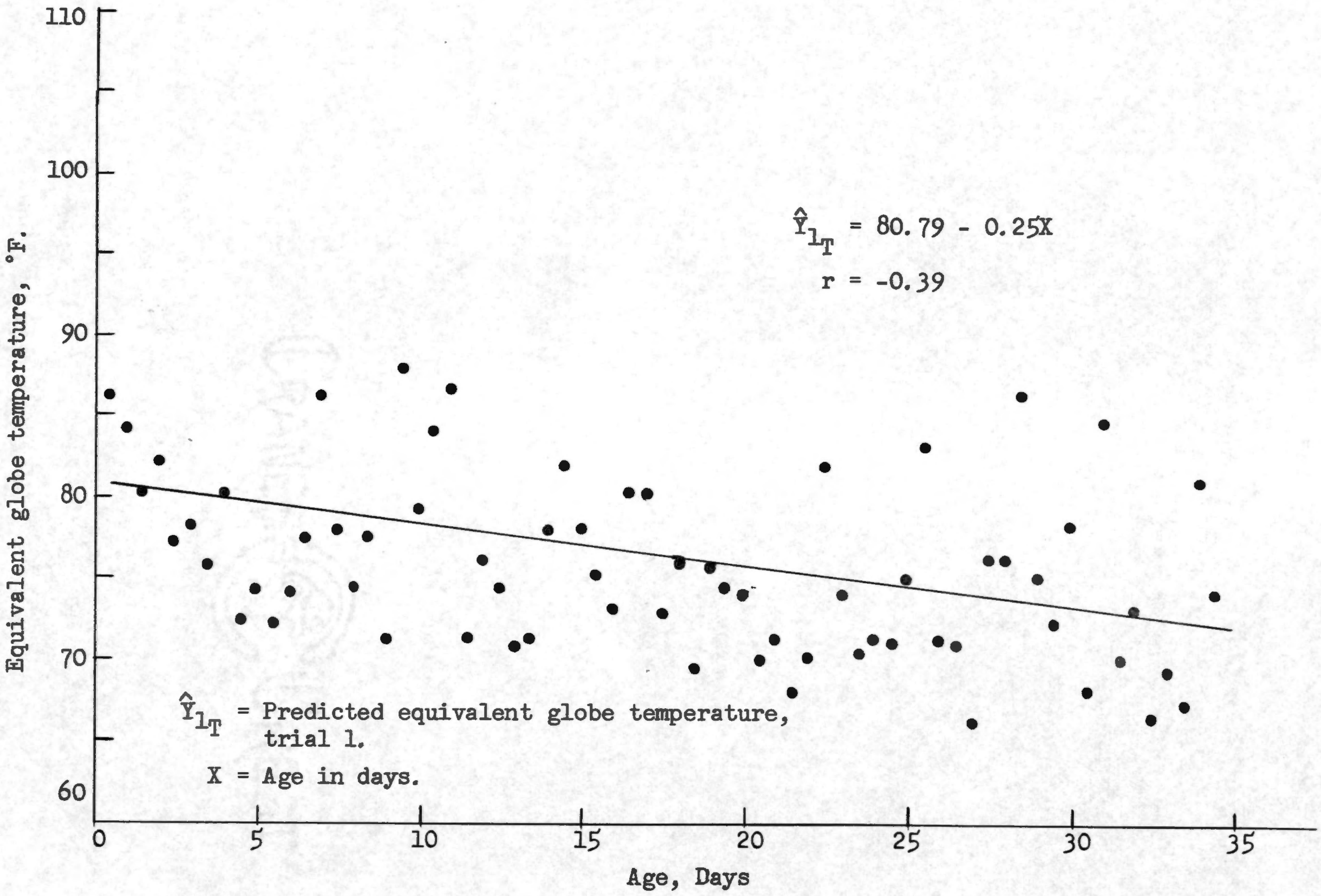

Figure 5. Effect of age on equivalent globe temperature preferences on daily basis (total group).

Figure 6 for male chicks, and Figure 7 for females. The E.G.T. of the total group at one day of age was 80.6°F., for males 81.3°F., and for females 79.9°F., and the E.G.T. at thirty-five days of age was reduced to 72.0°F., 71.5°F., and 72.9°F., respectively. The males showed the fastest rate of E.G.T. reduction, while the females showed the slowest reduction rate. As might be expected, the E.G.T. of the total group was the mean of the male and female E.G.T.

Graphical representations of the relationship between E.G.T. and age for trial 2 are presented in Figure 8 for the total group, Figure 9 for males, and Figure 10 for females. The predicted E.G.T. of the total group at one day of age was 88.6°F., for males 89.1°F., and for females 89.8°F., and the E.G.T. at thirty-five days of age was 72.0°F., 72.0°F., and 71.5°F., respectively. There were practically no differences in the rate of E.G.T. reduction between the total group, the males, or the females. The E.G.T. of the males was between that of the total group and the females. This unusual effect was because the males had a more predominate influence in the total group E.G.T. than did the females.

From these graphical representations there appeared to be a general trend toward a reduction of E.G.T. as the age of the bird increased. This trend is in agreement with the known fact that as the body of the young bird matures, its heat regulating ability develops, and it is less dependent on supplementary heat to maintain its body temperature.

Table VII summarizes the regression lines of E.G.T. on age in days, and presents the values of the correlation coefficient (r) between

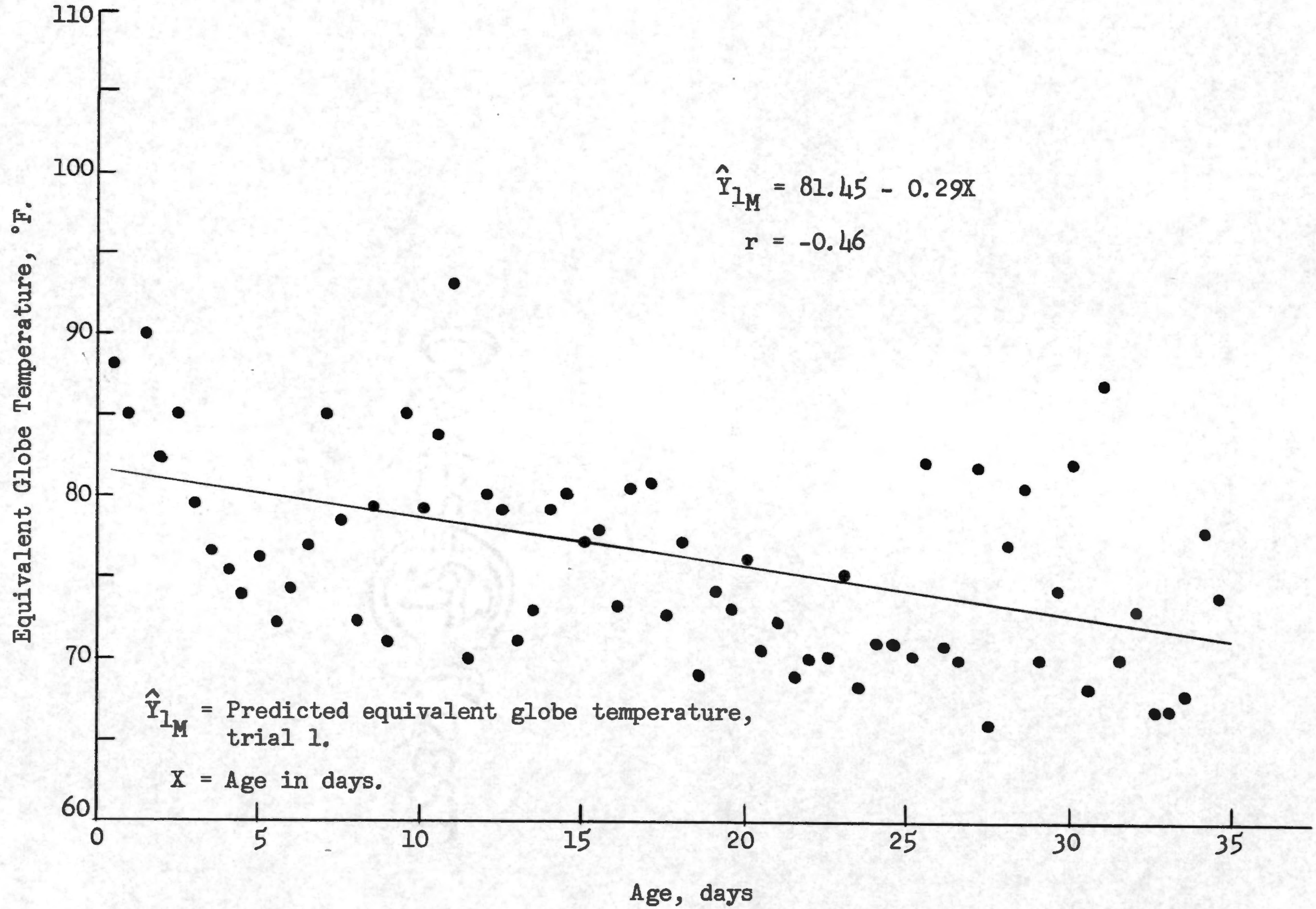

Figure 6. Effect of age on equivalent globe temperature preferences on daily basis (males).

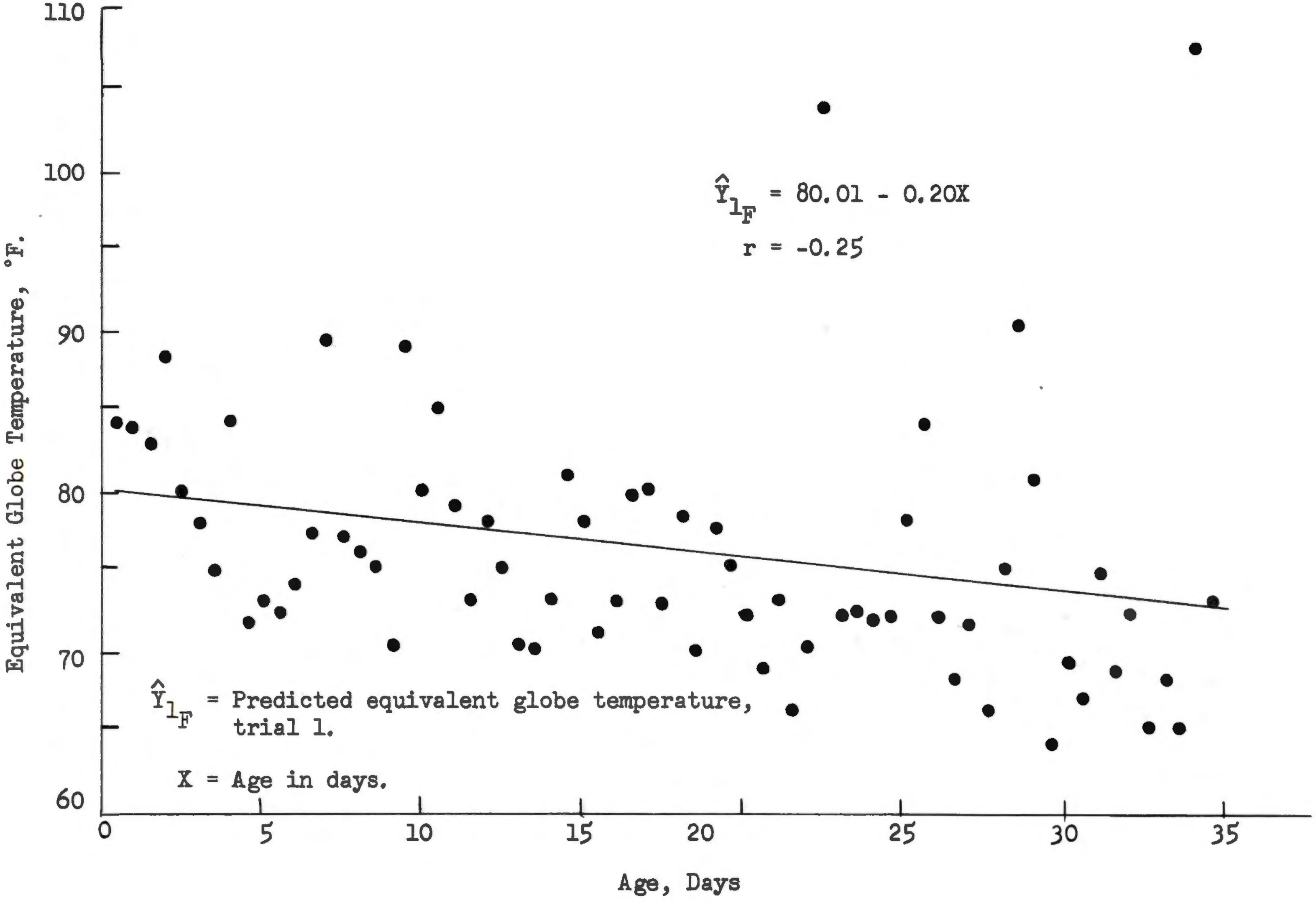

Figure 7. Effect of age on equivalent globe temperature preferences on daily basis (females).

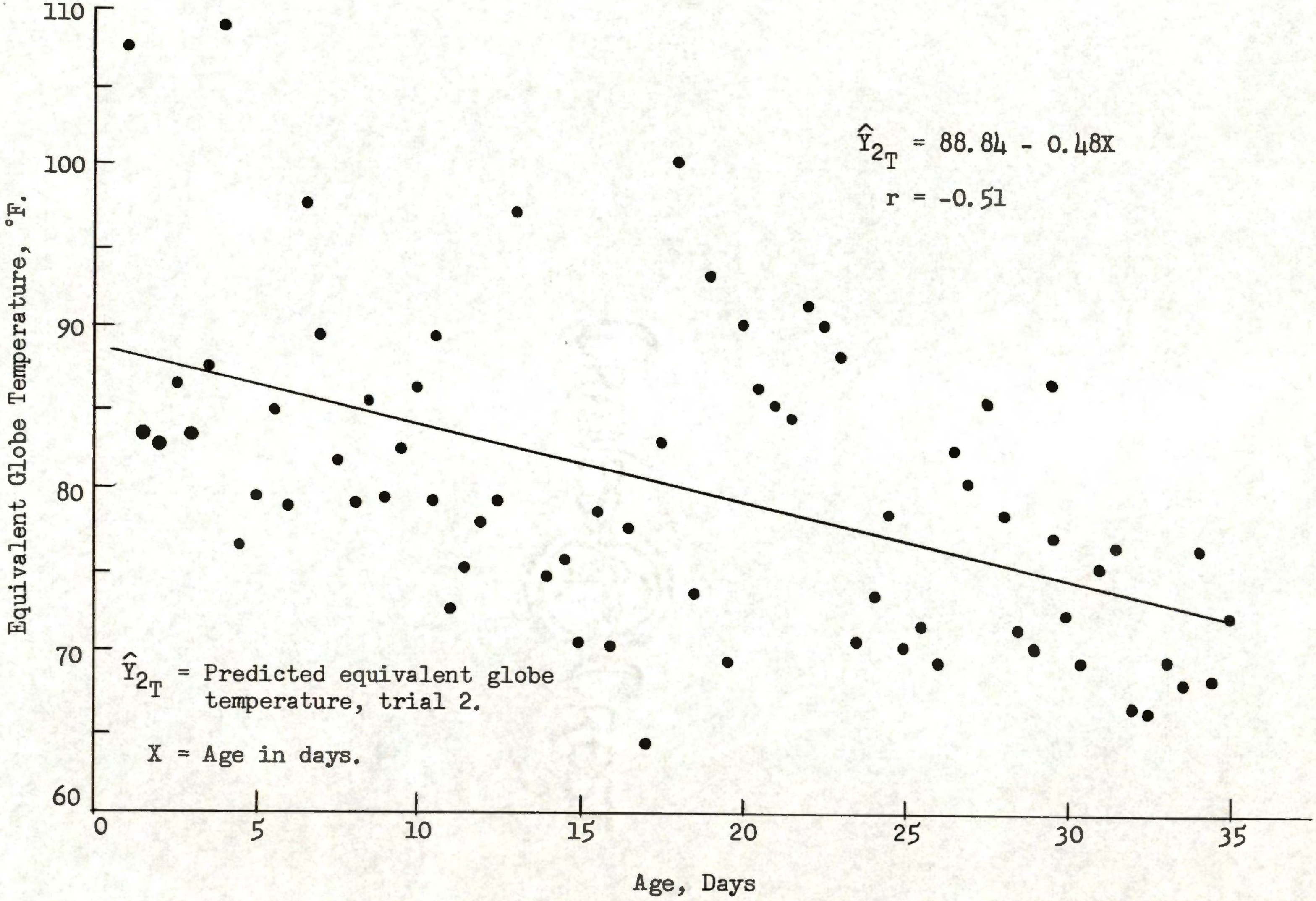

Figure 8. Effect of age on equivalent globe temperature preferences on daily basis (total group).

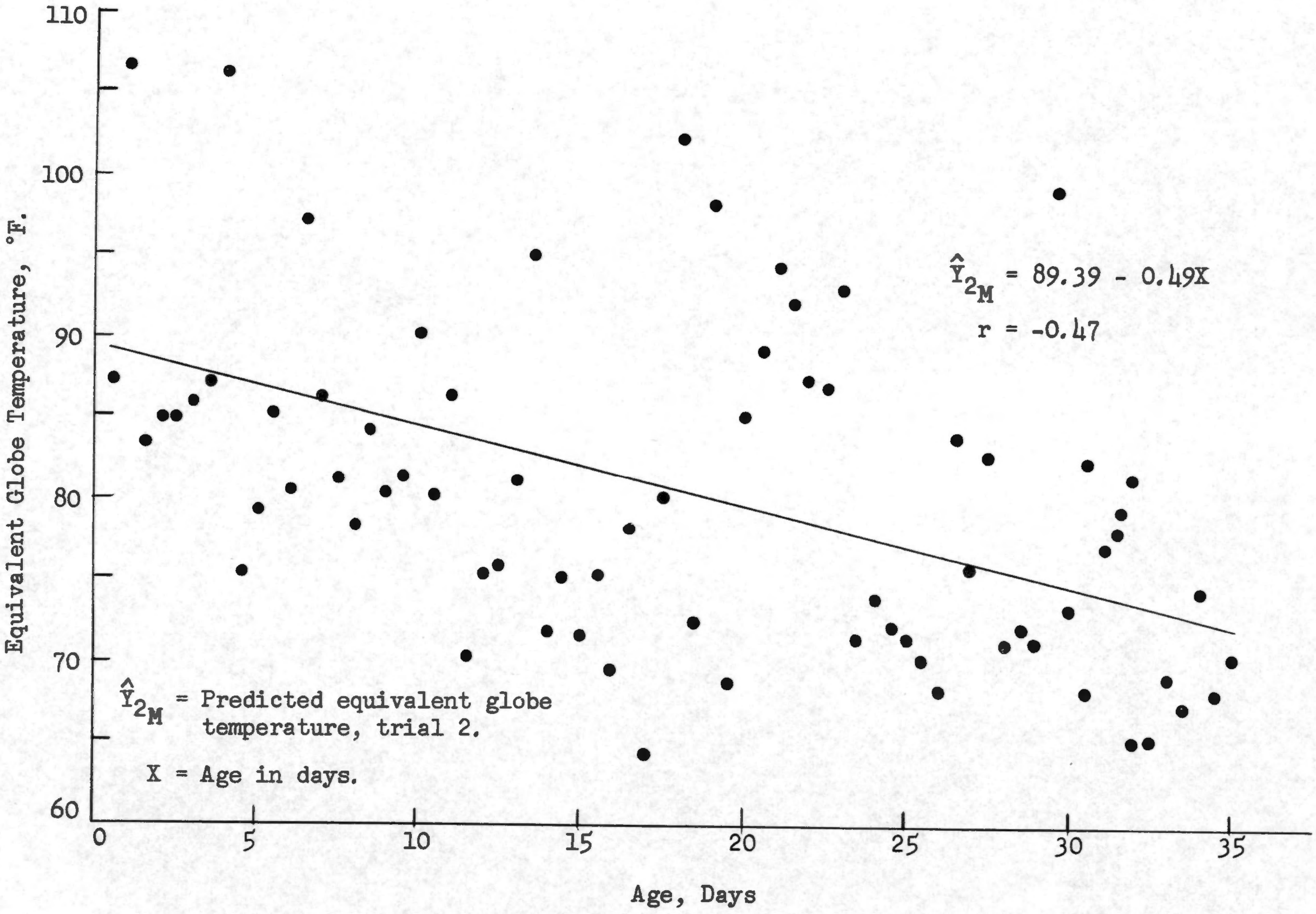

Figure 9. Effect of age on equivalent globe temperature preferences on daily basis (males).

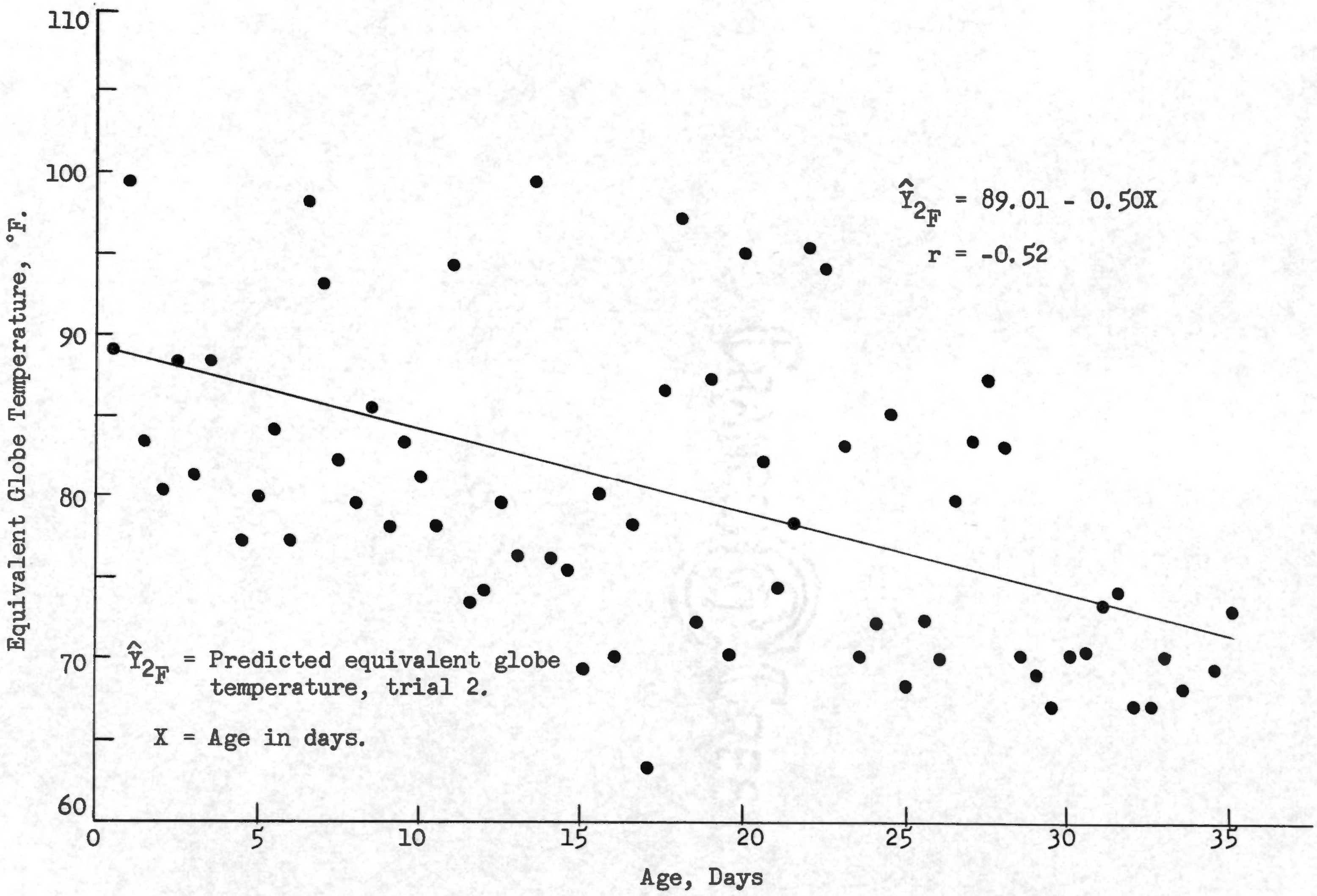

Figure 10. Effect of age on equivalent globe temperature preferences on daily basis (females).

TABLE VII

STATISTICAL RELATIONSHIPS BETWEEN AGE AND TEMPERATURE, DAILY ANALYSIS

	Regression Equations	r	$S_{y.x}$
Trial 1:			
Total group	$\hat{Y}_{1_T} = 80.79 - 0.25X$	-0.39	±5.84
Males	$\hat{Y}_{1_M} = 81.45 - 0.29X$	-0.46	±5.41
Females	$\hat{Y}_{1_F} = 80.01 - 0.20X$	-0.25	±7.75
Trial 2:			
Total group	$\hat{Y}_{2_T} = 88.84 - 0.48X$	-0.51	±8.21
Males	$\hat{Y}_{2_M} = 89.39 - 0.49X$	-0.47	±9.47
Females	$\hat{Y}_{2_F} = 89.01 - 0.50X$	-0.52	±8.24

NOTE: $\hat{Y}$ = Predicted equivalent globe temperature, degrees Fahrenheit.

X = Age in days.

r = Correlation coefficient.

$S_{y.x}$ = Standard errors in degrees equivalent globe temperature.

E.G.T. and age in days, and the standard errors ($S_{y.x}$) in degrees of E.G.T. The r values are the correlation coefficients for the general regression lines for the total group, the males, and the females. The $S_{y.x}$ values are also presented for both trials for the total group, the males, and the females.

From a review of the linear regression equations, it was apparent that the reduction of the E.G.T. had been numerically described for both trials. A t-test was made at the five per cent level of probability, and the results confirmed that a significant reduction of the E.G.T. did occur in relation to increasing age. However, in this investigation the rate of reduction was determined mainly by the E.G.T. for the first few days of life.

The preferred E.G.T. for the total group at one day of age in trial 2 was 7.8°F. greater than that of trial 1. This difference can probably be explained by two facts. First, trial 1 was conducted during midsummer; therefore, only two heat lamps were necessary to establish the required heat gradient. Since there were only two lamps, the temperature of the outer zones were slightly lower than in the previous trial. This may have forced the chicks to move toward the hotter zones of the gradient, resulting in an apparent higher E.G.T.

Second, the birds used in trial 1 were much more active and vigorous than those of trial 2. On several occasions during trial 1, the observer could not make an observation on the initial attempt because of the physical activity of the birds. Disease was probably the factor which accounted for less vitality of the birds during trial 2 since four chicks died and several were afflicted by the staggers. Lippincott and Card (23) have suggested less heat is probably required for active chicks than for those of less vitality.

In trial 1 the r values were -0.39 for the total group, -0.46 for the males, and -0.25 for the females. The r values for trial 2 were -0.51 for the total group, -0.47 for the males, and -0.52 for the females. These small values of r indicate only a small portion of the variation was attributable to the regressions. A test of the significance of the r values at the five per cent level reveal that each of the computed values were significantly greater than zero. The same test was performed at the one per cent level, and all the r values were significant with the exception of the females of both trials.

The reasons for these low r values probably lie in the procedure in which the data was recorded. When several observations were made, birds were found to be lying in the heat zone directly under the heat lamps where the E.G.T. ranged from approximately 127°F. to 287°F. The birds in this zone appeared to have moved into this hot area from the cool area outside the heat gradient where feed and water was located. The birds would remain in this hot zone until they were apparently warm again, and then move into another zone in which they could remain comfortable for an extended period of time. These unusually large individual E.G.T. values resulted in unrealistically high mean values, which consequently reflected in the correlation coefficients. These unusually high mean values were especially reflected in the r values for the females of trial 1 and trial 2.

Sometimes a relatively low E.G.T. would occur when the ambient heat load became so large the cooling unit could not adequately maintain the desired ambient temperature. When this occurred, the birds would move away from the hot zones of the gradient into the cooler areas around the edge of the gradient. Then the E.G.T. would be a relatively low value.

Weekly data analysis. The data analyzed on a weekly basis of age are probably more beneficial to the poultryman, the grower, and the agricultural engineer. This method of presentation has more reliability than that presented on a daily basis of age. The weekly analysis of data reduces the effects of the unusually high E.G.T. and a more adequate prediction of chick performance can be obtained.

For trial 1 graphical representations of the relationships between E.G.T. and age in weeks are presented in Figure 11 for the total group, Figure 12 for the males, and Figure 13 for the females. The E.G.T. of the total group at one week of age was 78.3°F., for the males 79.0°F., and for the females 77.5°F., and the E.G.T. at five weeks of age was 72.8°F. for the total group, 71.6°F. for the males, and 73.5°F. for the females. This analysis did not differ from that on a daily basis.

Figure 14 is a graphical representation of the relationship between the E.G.T. and age in weeks for the total group of trial 2. Similar representations for males are presented in Figure 15 and for females in Figure 16. The E.G.T. of the total group at one week of age

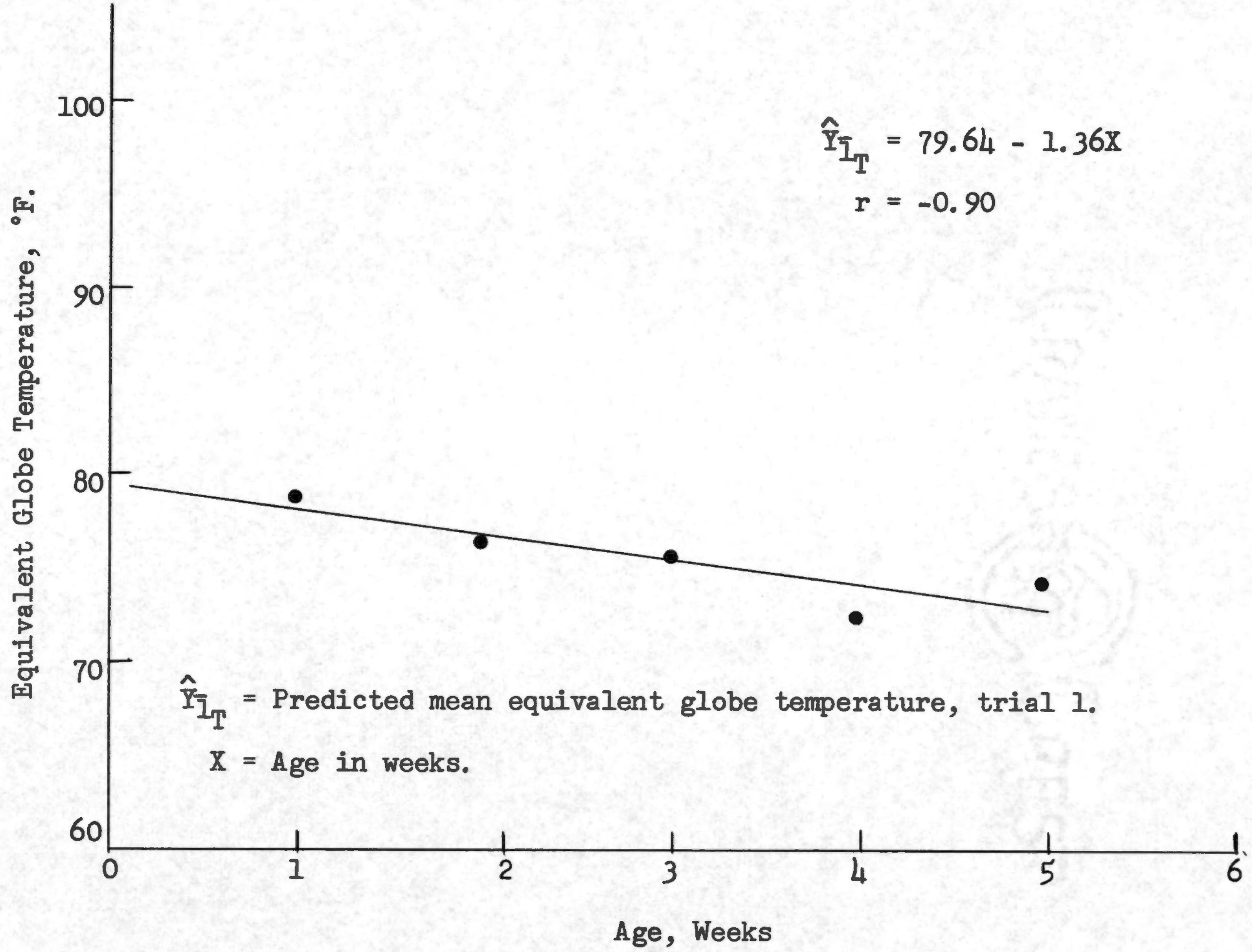

Figure 11. Effect of age on mean equivalent globe temperature preferences on weekly basis (total group).

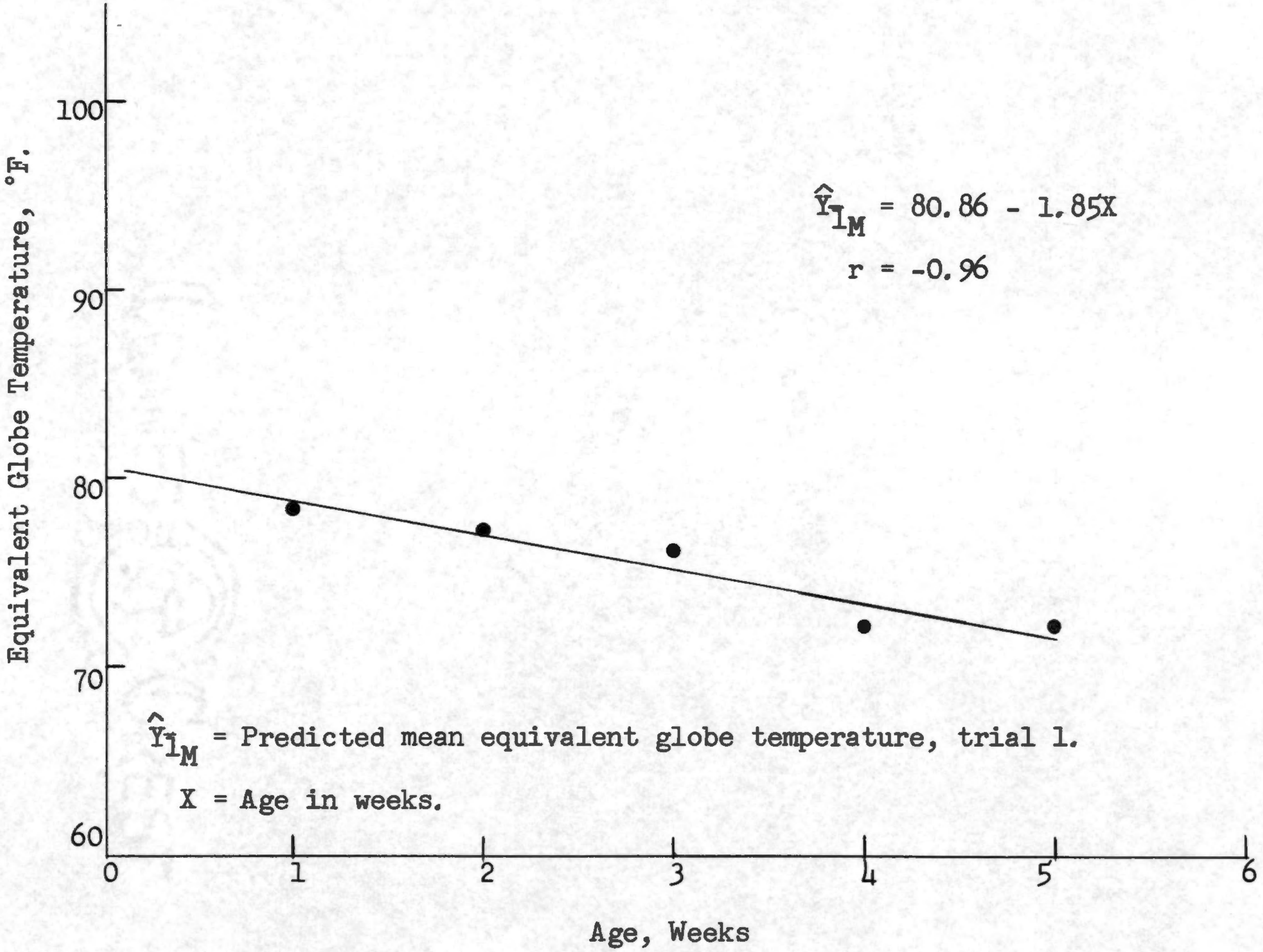

Figure 12. Effect of age on mean equivalent globe temperature preferences on weekly basis (males).

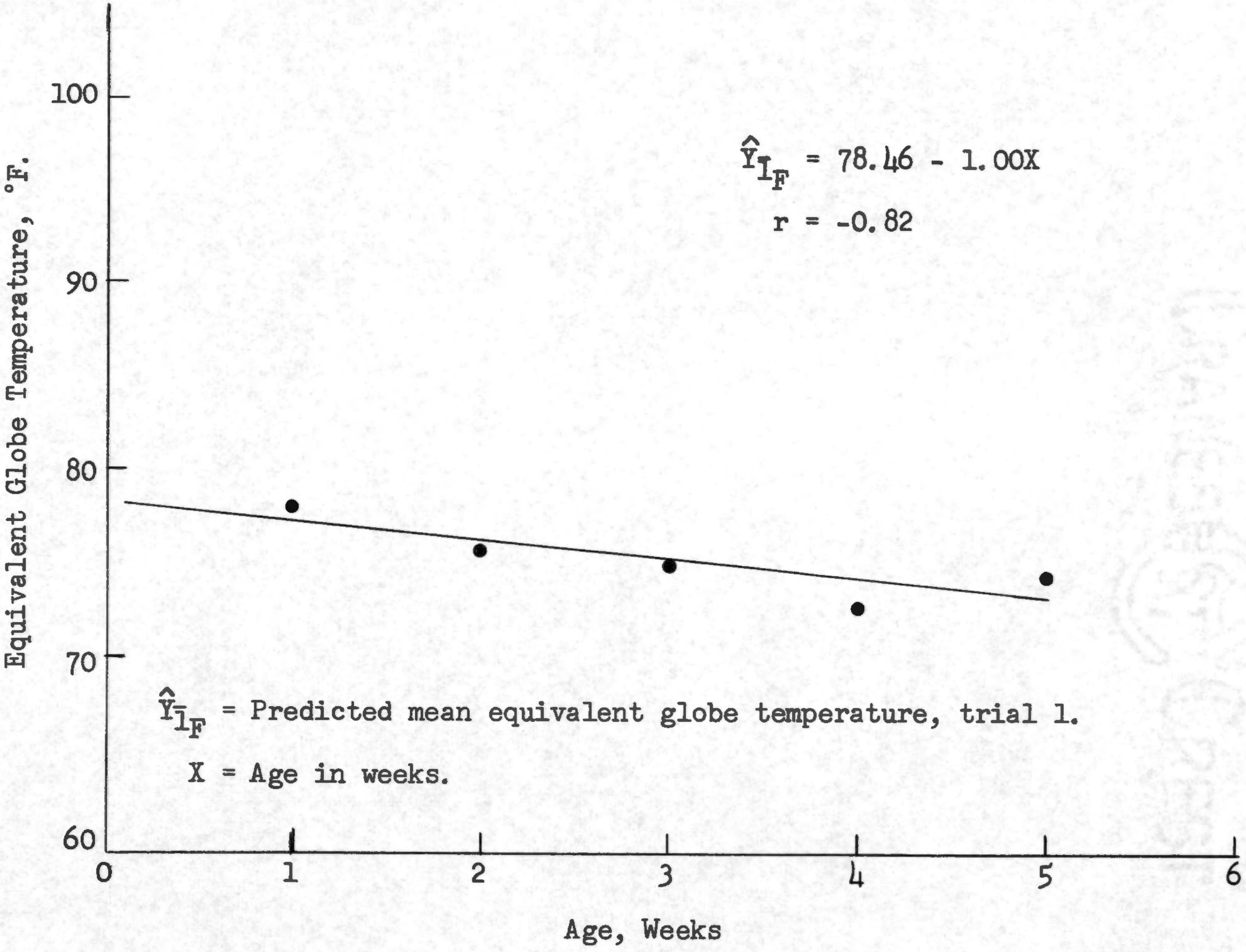

Figure 13. Effect of age on mean equivalent globe temperature preferences on weekly basis (females).

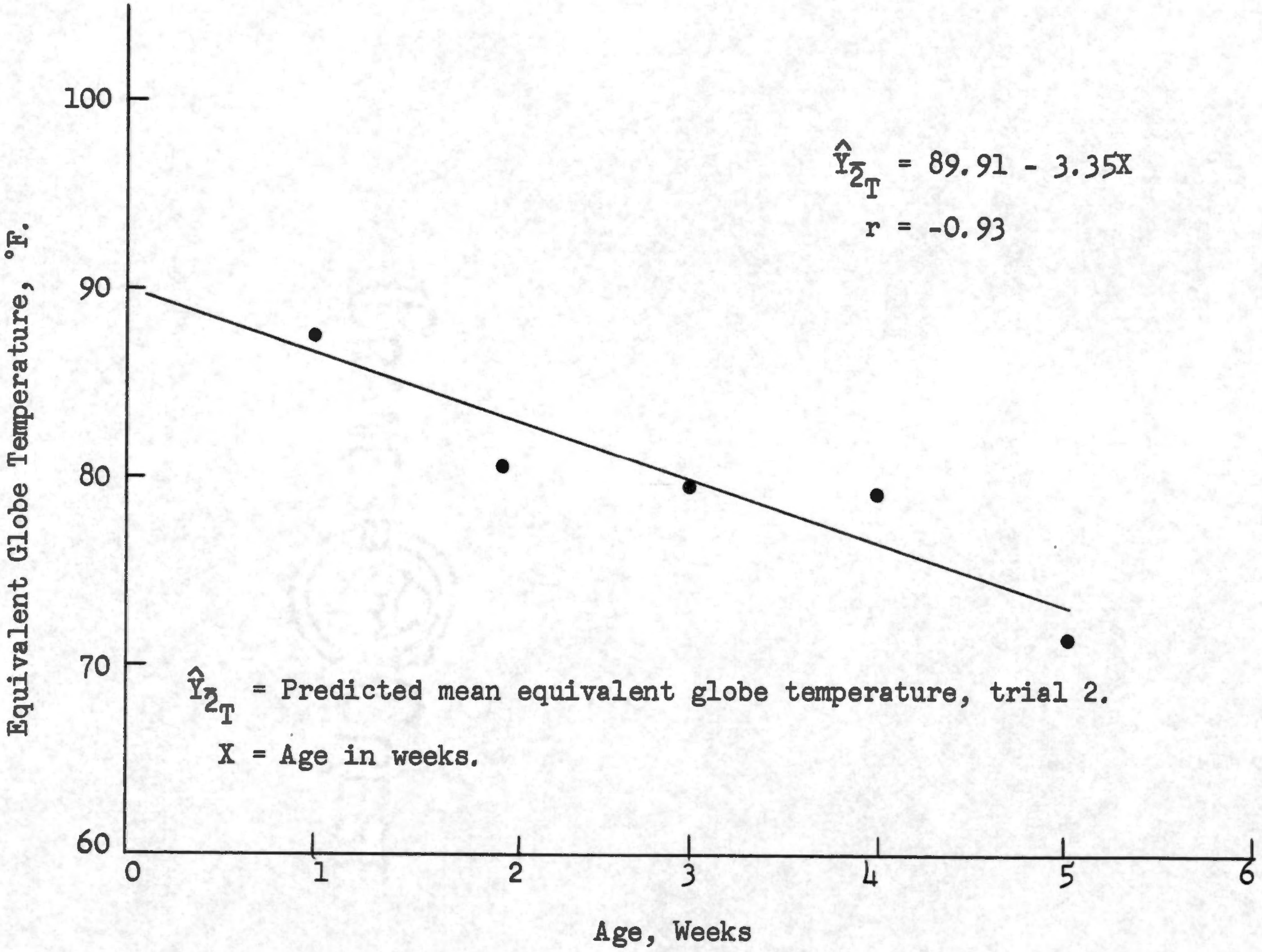

Figure 14. Effect of age on mean equivalent globe temperature preferences on weekly basis (total group).

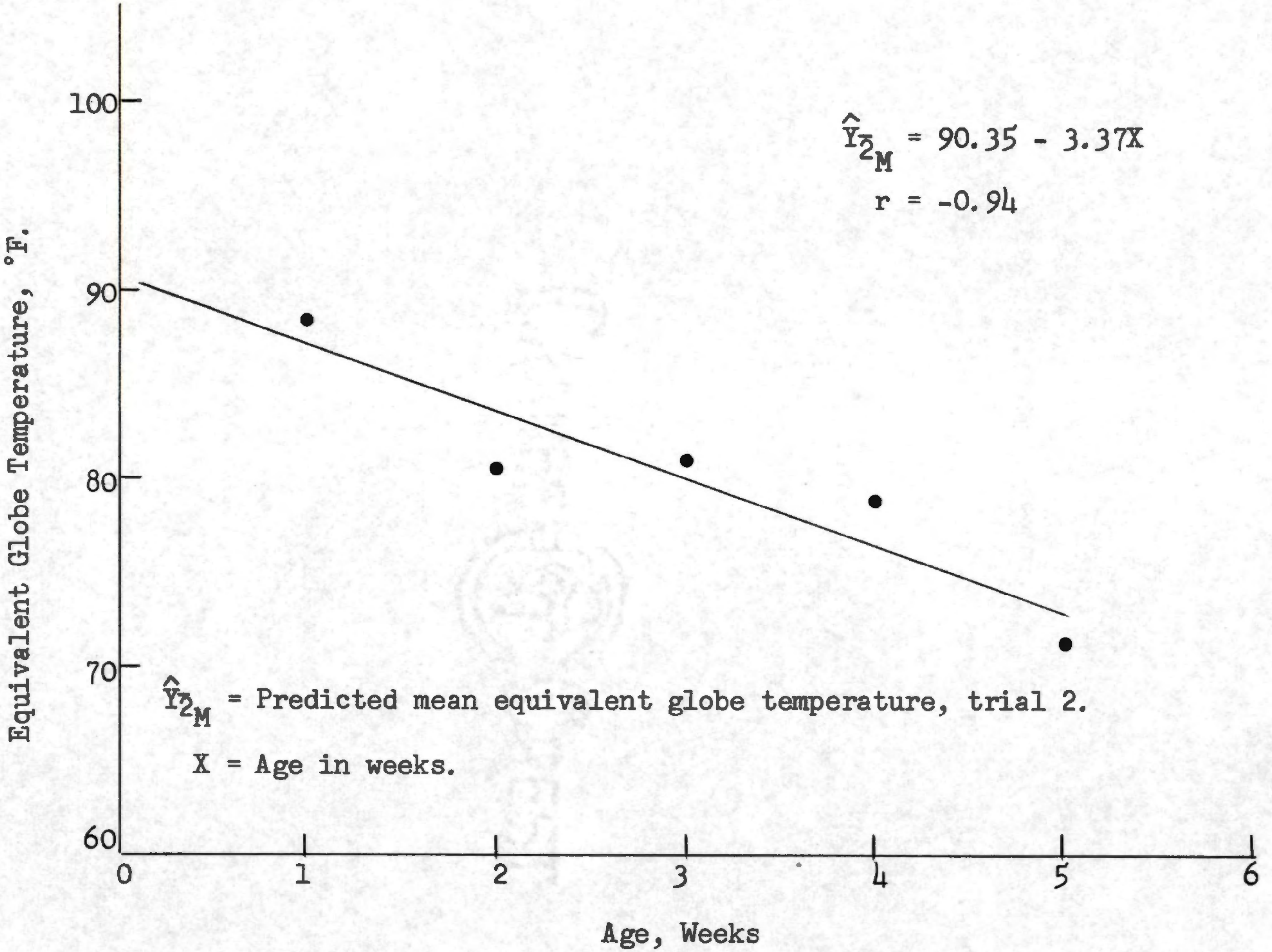

Figure 15. Effect of age on mean equivalent globe temperature preferences on weekly basis (males).

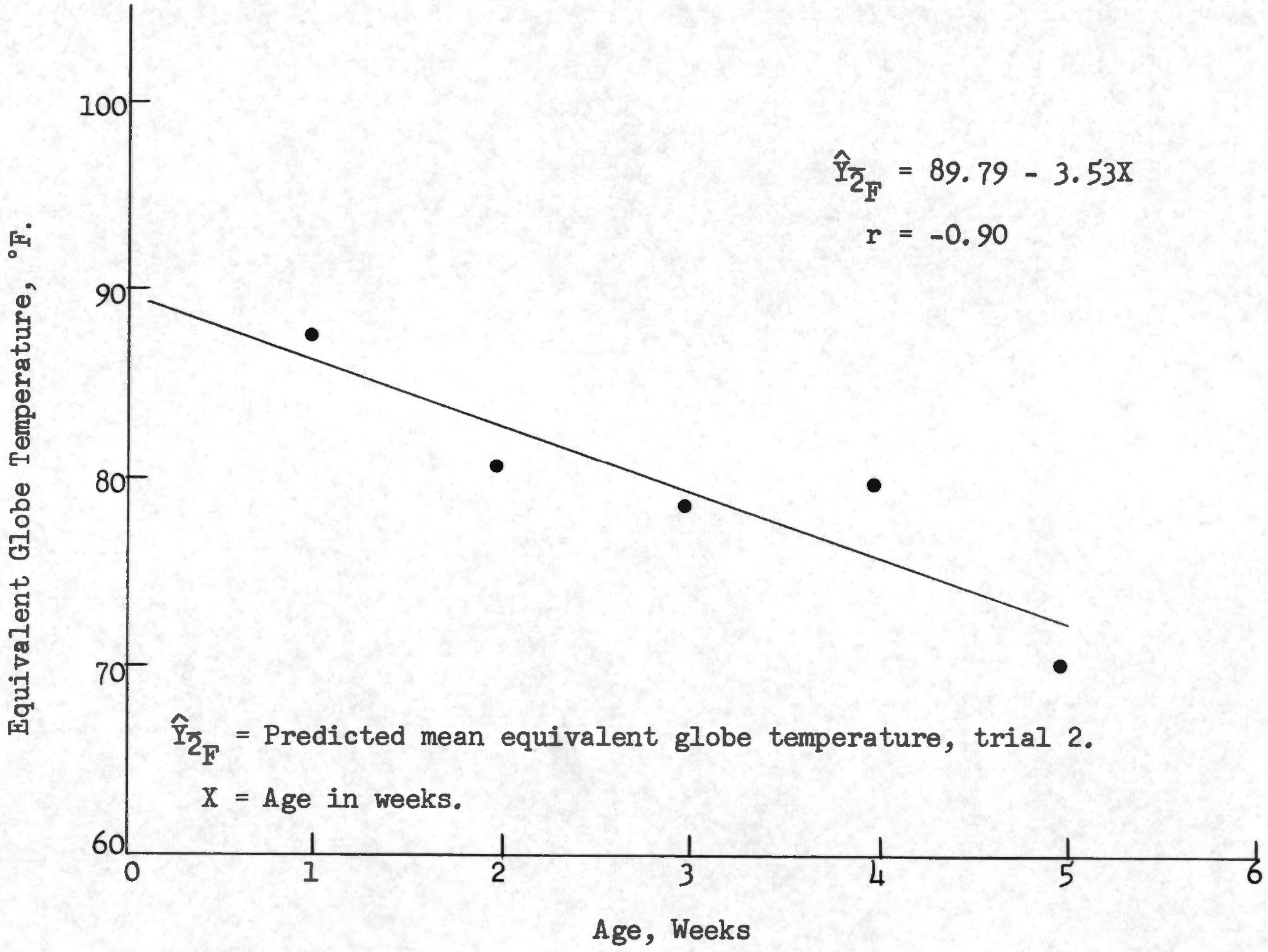

Figure 16. Effect of age on mean equivalent globe temperature preferences on weekly basis (females).

was 86.6°F., for males 87.0°F., and 86.3°F. for the females, and the E.G.T. at five weeks of age was 73.2°F. for the total group, 73.5°F. for the males, and 72.1°F. for the females. As in the daily analysis there was no significant difference in the rate of E.G.T. reduction. However, the total group of the weekly analysis was between the E.G.T. of the males and the females.

The effects of the relatively small number of unusually high E.G.T. is not nearly so pronounced in the weekly means as when presented on a daily basis. Table VIII gives a summary of the regression lines, correlation coefficients, and standard errors based on age in weeks.

Similar tests to those used for the daily analysis were made for the weekly analysis. At the five per cent level there was a significant temperature reduction with an increase in age for all groups. However, at the one per cent level only the males of both trials showed a significant temperature reduction. The least standard error was ±0.75°F. for the males of trial 1, and the greatest was ±2.46°F. for the females of trial 2.

The r values for these weekly regressions varied from -0.85 to -0.96 which is considerably higher than those for the daily analysis. These values were of such a magnitude that a definite relationship could be established between the E.G.T. and the age of the birds in weeks. A t-test at the five per cent level indicated that each of the computed r values was significantly greater than zero. Test of the differences between the r values by the Fisher method (22) indicated there were no significant differences between any of the r values.

TABLE VIII

STATISTICAL RELATIONSHIPS BETWEEN AGE AND TEMPERATURE, WEEKLY ANALYSIS

	Regression Equations	r	$S_{y \cdot x}$
<u>Trial</u> <u>1</u>:			
Total group	$\hat{Y}_{1_T} = 79.64 - 1.36X$	-0.90	±0.91
Males	$\hat{Y}_{1_M} = 80.86 - 1.85X$	-0.96	±0.75
Females	$\hat{Y}_{1_F} = 78.46 - 1.00X$	-0.82	±0.98
<u>Trial</u> <u>2</u>:			
Total group	$\hat{Y}_{2_T} = 89.91 - 3.35X$	-0.93	±1.92
Males	$\hat{Y}_{2_M} = 90.35 - 3.37X$	-0.94	±1.76
Females	$\hat{Y}_{2_F} = 89.79 - 3.53X$	-0.90	±2.46

NOTE: Y = Predicted equivalent globe temperature, degrees Fahrenheit.

X = Age in weeks.

r = Correlation coefficient.

$S_{y.x}$ = Standard errors in degrees equivalent globe temperature.

In comparing the daily analysis to that of the weekly analysis, the only difference was that the r values were much higher which which suggests that the regressions account for quite a large per cent of the variance. In both the daily and weekly methods of analyses, the E.G.T. at five weeks of age was approximately 71.5°F. Fisher's method of testing for differences between r values indicated there was a significant difference between the correlation coefficients of the two analyses, with the weekly analysis being more significant than the daily analysis.

CHAPTER IV

SUMMARY AND CONCLUSIONS

An investigation was performed to determine the temperature preferences of chicks and to determine if these preferences were related to age and to sex. To accomplish these objectives, the birds were given complete freedom of movement under an infrared brooding system.

A heat gradient was established with infrared heat lamps in a test pen where the ambient temperature was maintained at approximately 60°F. Two trials of twenty male and twenty female chicks were placed in the test pen for periods of five weeks each. Daily recordings of temperature preferences were obtained, and statistical analysis was performed.

The temperature preferences of the chicks were recorded by sensing elements developed to duplicate the recordings of a globe thermometer. The recorded temperatures were assumed to be an index of chick comfort within the effects of the heat gradient.

Since only two trials were conducted in this study, no definite conclusions can be drawn. However, analysis of the results indicates the following trends:

1. Chicks have a well-defined temperature preference and will select a narrow zone of temperature when given a choice. This temperature preference is directly related to age and decreases uniformly with age. There are no significant differences between the temperature preferences of males and females.

2. The mean weekly preferred temperatures at one week of age were 78.3°F. and 86.6°F. for trial 1 and trial 2, respectively. The mean weekly preferred temperatures at five weeks of age were 72.8°F. and 73.2°F. for trial 1 and trial 2, respectively.

3. The correlation coefficients for all tests were -0.82 or greater when the data was analyzed on weekly temperature preferences.

4. The standard errors of preferred temperatures of trial 1 and trial 2 ranged from 0.91°F. to 2.46°F. when analyzed on weekly temperature preferences.

5. Disease may have considerable influence on the temperature preferences of chicks.

The findings of this investigation are not to imply that preferred temperatures are the best for the most efficient performance. There remain many other factors which may effect the optimum environmental conditions during the brooding period.

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APPENDIX

TABLE IX

COMPARISON OF AMBIENT, METAL PLATE, AND BLACK GLOBE TEMPERATURES, °F.

Ambient Air	One-inch Sheet Metal Plate	Six-inch Globe
71	89	93
70	92	97
71	91	102
67	91	100
72	94	97
75	92	101
69	95	99
73	100*	98
71	102	100
73	103	99
73	103	104
76	106	103
71	104	101
79	107	106

*One-inch square single strength glass taped over sheet metal plate.

NOTE: Test conducted May 14, 1964, 8:45-10:30 A.M.

TABLE X

COMPARISON OF AMBIENT, METAL PLATE, BLACK GLOBE, AND LEAD BALL TEMPERATURES, °F.

Ambient Air	One-inch Sheet Metal	Six-inch Black Globe	Lead Ball in Box
83	107	110	160
81	104	109	160
83	105	106	156
82	104	104	159
84	105	112	162
79	99	107	154
81	100	100	144
95*	123	109	165
124	152	147	182
133	161	161	190
134	161	166	192
135	158	164	193
128**	150	153	190
116	121	138	186
106	109	124	180

*Box constructed of "Styrafoam" insulation and covered with glass placed over all elements.

**All elements begin to enter shade.

NOTE: Test conducted May 15, 1964, 12:00-2:00 P.M.

TABLE XI

COMPARISON OF AMBIENT, METAL PLATE, BLACK GLOBE, AND LEAD BALL TEMPERATURES, °F.

Ambient Air	One-inch Sheet Metal	Six-inch Globe Thermometer	Lead Ball in Box
82	104	108	143
80	103	110	144
84	103	112	147
84	106	111	149
82	104	114	151
84	107	106	158
82	108	114	160
84	113	109	163
83	103	111	153
85	107	107	151
86	118	112	157
87	115	115	161
86	116	116	161
83	114	117	158
86	115	112	158

NOTE: Test conducted May 17, 1964, 9:30-11:30 A.M.

TABLE XII

COMPARISON OF AMBIENT, METAL PLATE, BLACK GLOBE, AND COPPER PLATE TEMPERATURES, °F.

Ambient Air	One-inch Sheet Metal	Six-inch Black Globe	One-inch Copper Plate
81	103	106	117
84	112	111	125
88	117	117	125
83	105	116	116
82	104	106	118
86	110	110	120
87	115	113	120
88	115	114	124
87	113	118	112
85	113	109	118
88	109	113	114
86	103	110	116
85	108	112	121
87	112	115	121
86	111	113	113
87	107	110	114
88	107	110	118
85	106	111	110

NOTE: Test conducted May 19, 1964, 10:00-11:45 A.M.

TABLE XIII

DAILY TEMPERATURE CHART, °F.

Date: August 9 to August 16, 1965

	Heat Zones											
	A		B		C		D		E		F	
Date	No.	T.	No.	T.	No.	T.	No.	T.	No.	T.	No.	T.
8/9 p	0	134.0	5	91.0	32	75.0	3	70.0	0	68.0	0	67.0
8/10a	2	122.0	27	80.5	3	63.0	0	60.0	0	58.0	0	57.0
p	0	118.0	6	85.5	25	67.0	0	63.0	0	62.0	0	61.0
8/11a	0	122.0	11	81.0	29	64.0	0	60.0	0	59.0	0	58.0
p	0	127.0	6	85.0	14	67.5	1	63.0	0	61.0	0	60.0
8/12a	0	124.0	11	82.0	16	64.5	6	59.0	0	58.0	0	57.0
p	0	127.0	8	86.0	22	69.0	0	65.0	0	63.0	0	62.0
8/13a	2	122.0	25	80.5	0	64.5	0	60.0	0	58.0	0	57.0
p	0	129.0	2	87.0	20	68.5	16	65.0	2	63.0	0	63.0
8/14a	0	126.0	5	83.5	28	67.0	7	63.0	0	61.0	0	60.0
p	0	128.0	7	87.0	26	69.0	4	66.0	0	64.0	0	64.0
8/15a	0	125.0	4	84.0	27	68.0	9	63.0	0	62.0	0	61.0
p	0	128.0	22	88.0	17	70.0	0	66.0	0	64.0	0	64.0
8/16a	0	123.5	19	81.5	20	64.5	0	61.0	0	59.0	0	59.0
Males	3		80		146		24		0		0	
Females	1		78		133		22		2		0	
Total	4		158		279		46		2		0	
Mean		125.4		84.5		67.3		63.1		61.4		60.7

NOTE: Morning observation is a; afternoon observation is p. No. is number of birds in respective heat zones. T. is temperature limits of respective heat zones.

TABLE XIV

WEEKLY TEMPERATURE CHART, °F.

Date: August 9 to September 16, 1965

	Heat Zones											
	A		B		C		D		E		F	
Date	No.	T.	No.	T.	No.	T.	No.	T.	No.	T.	No.	T.
Total												
8/9-16	4	125.4	158	84.5	279	67.3	46	63.1	2	61.4	0	60.7
8/16-23	1	125.6	67	84.6	263	68.0	110	64.0	4	62.1	0	60.8
8/23-30	11	122.8	73	81.6	198	64.9	157	62.3	17	59.9	0	58.5
8/30-9/6	10	121.9	83	81.4	152	64.8	143	61.5	35	59.4	9	58.4
9/6-13	1	121.5	21	82.8	84	67.0	127	63.9	82	61.9	44	60.6
Total	27		402		978		583		140		53	
Mean		123.5		83.0		66.4		63.0		60.9		59.8
Males												
8/9-16	3		80		146		24		0		0	
8/16-23	1		34		127		60		2		0	
8/23-30	6		45		107		74		9		0	
8/30-9/6	3		44		78		72		11		4	
9/6-13	1		13		38		64		39		26	
Total	14		216		497		294		61		30	
Mean		123.5		83.0		66.4		63.0		60.9		59.8
Females												
8/9-16	1		78		133		22		2		0	
8/16-23	0		31		136		50		2		0	
8/23-30	5		28		91		83		8		0	
8/30-9/6	7		39		74		71		24		5	
9/6-13	0		10		46		63		43		18	
Total	13		186		481		289		79		23	
Mean		123.5		83.0		66.4		63.0		60.9		59.8

NOTE: No. is number of birds in respective heat zones. T. is temperature limits of respective heat zones.

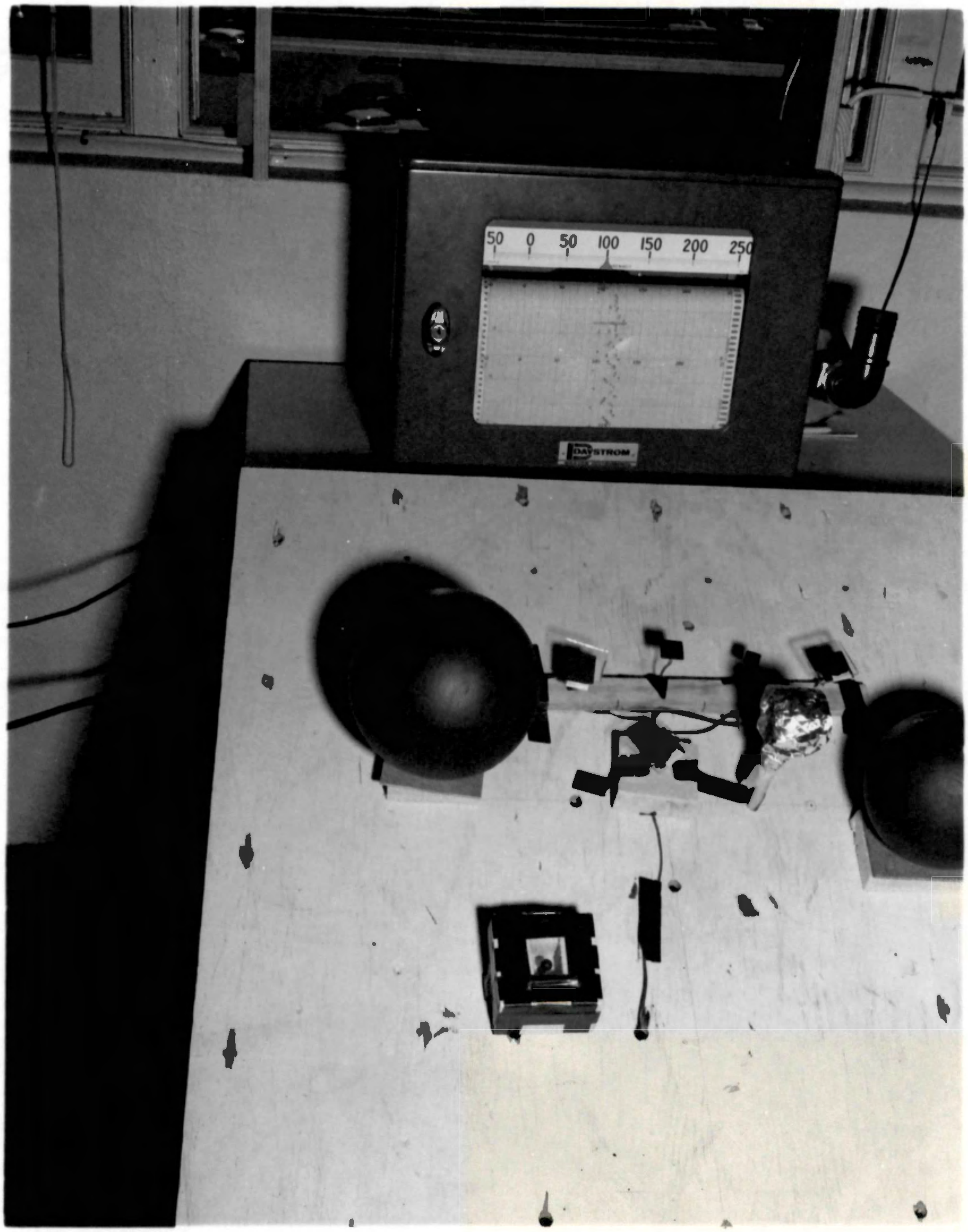

Figure 17. View of calibration test arrangement.

Date:________________Time:_____AM PM Rel. Hum._____%, Room Temp.____°

Station Temperatures

1________
2________
3________
4________
5________
6________
7________
8________
9________
10________
11________
12________
13________
14________
15________
16________
17________
18________
19________
20________
21________
22________
23________
24________

Average Station Temperature

1-2__________
3-4__________
5-6__________
7-8__________
9-10__________
11-12__________
13-14__________
15-16__________
17-18__________
19-20__________
21-22__________
23-24__________

Zone: A_____ B_____ C_____ D_____ E_____ F_____ G_____ Total__________

Indicate number and position of birds on grid--circle females.

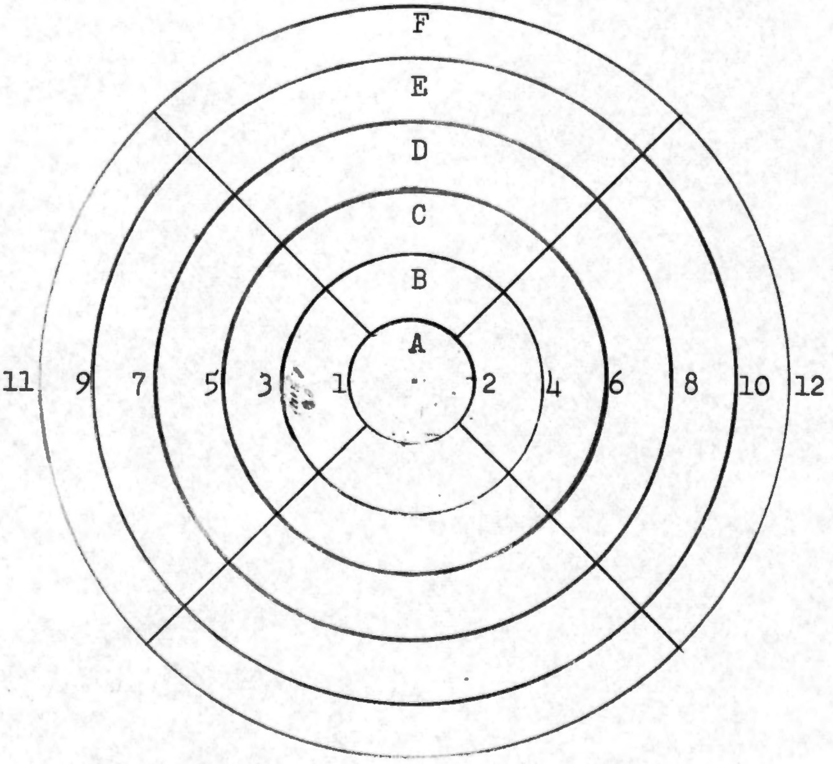

Figure 18. Daily data sheet.