DESIGN AND TEST OF THREE EXPERIMENTAL SHEET STEEL BROODER HOUSES

by

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I. INTRODUCTION

A. Justification for the Study

The buildings of our forefathers in America were constructed for only one purpose: shelter. Little thought was given to any of the factors that should be considered in building construction such as: future needs, economy of labor, capacity, cost, structural details, maintenance, and probable life of the structure. The farmer in those days lived a solitary existence. The majority of produce he realized from his labors was consumed on the farm. His problem was simply that of producing enough for himself and his dependents.

Today farming is an industry in which there is considerable competition. The farmer produces only a portion of the goods he consumes; he specializes in one or several branches of agricultural production. Due to this specialization he is able to produce more in his particular branch of agriculture than he needs, and the surplus he sells to others. Then he in turn buys other materials from other producers to complete the alleviation of his own needs. Thus, division of labor has exerted a tremendous influence on the progress made by the American people.

This division of labor has made the modern farmer a specialist in one or more of the fields of agriculture. He may be a dairyman, a poultryman, a hog or cattle raiser, and so on. By concentrating his activities the farmer learns more about his selected field or fields, and his efficiency in producing is increased. He becomes more concerned about the economics of agriculture; if he is a livestock raiser, he begins to know more about the physiology of his animals and their environmehtal requirements.

Farm buildings have undergone some change for the better, as have some farmers, but there is yet considerable room for improvement. The better farmers of today when they consider erecting a farm structure are concerned about such things as economy of construction, capacity, structural details, maintenance, and probable life of the structure. They consider the requirements of a good roofing material, which are: (1) resistance to fire; (2) structural stability; (3) resistance to the elements of nature; (4) resistance to the penetration of water or water vapor; (5) resistance to heat flow; (6) ease of application; (7) low cost; and (8) pleasing appearance. This foresight by some farmers is one of the reasons that today galvanized sheet steel is recognized as a roofing material possessing definite potentialities for use in farm structures. Of the above named qualities of a good roofing material, galvanized sheet steel possesses all, with the exception of number (5), resistance to heat flow. A number of farmers apply the galvanized roofing directly to nailing strips spaced usually about two or three feet apart. These farmers' objection is that the building gets "too hot in summer and too cold in winter."

In 1937 the Republic Steel Corporation cooperated with the Iowa Agricultural Experiment Station in setting up a project entitled, "The Utilization of Steel in Farm Structures." From research conducted since then have come data which indicate that galvanized sheet steel when used in conjunction with proper insulation possesses desirable qualities in resisting heat flow. Until this present investigation started, all of the experiments had been conducted by using the test house shown in fig. 5. In continuing the work done on this project it seemed desirable to design and construct a farm building embodying the recommended insulation features and subject the building to performance tests. A brooder house where artificial heat is supplied would appear to offer the best possibilities for studying the insulation properties of a farm building since the brooding season usually occurs in cold weather, and the heat problem is occasioned by an air temperature difference between the outside air and the inside air.

B. The Project

1. W. D. Scoates (1937-1938)

Project 562 of the Iowa Agricultural Experiment Station entitled, "The Utilization of Steel in Farm Building Construction," was initiated on July 1, 1937. The project, sponsored by the Republic Steel Corporation, has as its general objective: To improve the construction of farm structures through a better use of steel.

The specific objectives are listed as:

(1) To study structural and functional requirements of farm buildings as they may be related to the use of steel in their construction

(2) To study properties of steel products not now well known and to ascertain more fully their suitability for farm use

(3) To apply the information secured from the above in the design and construction of experimental buildings under controlled conditions (16)

W. D. Scoates, the first research fellow to be initiated on the project, made a survey of "The Uses of Steel in Iowa Farm Buildings" in order to find a suitable project for his research work. From information gathered from his survey he selected a study of "The Range of Temperature under Sheet Steel Roofing" as his year's work.

From his analysis of the problem, Mr. Scoates concluded that in order to conduct his investigation a test house made up of various roof sections well insulated from each other would be necessary. The eight roof sections selected are shown in fig. 1. For reasons justifying this selection the reader is referred to Mr. Scoates' thesis. Plans for the test house, which were later revised, and a photograph of the test house, are shown in fig. 2,3,4, and 5, respectively. Temperatures were measured by means of thermocouples located as shown in fig. 1. A testing period was twenty-four hours' duration, with temperatures being read every hour. The periods began and ended at midnight. Records were kept of the outside wind velocity and direction and remarks about weather conditions. Mr. Scoates proposed to analyze his results as follows:

(1) Temperature curves of the actual compartment room temperatures will show temperatures and time lag for each section and outside air.

(2) Tables of the temperature range, percent range of temperature and the time lag will be made.

(3) Data will be obtained on the actual operating temperatures of sheet steel roofing.

(4) Temperature gradients for each roof section will be plotted on temperature drop diagrams.

(5) A study will be made of the effect of orientation on compartment room temperatures for differences in temperature, temperature range, and time lag.

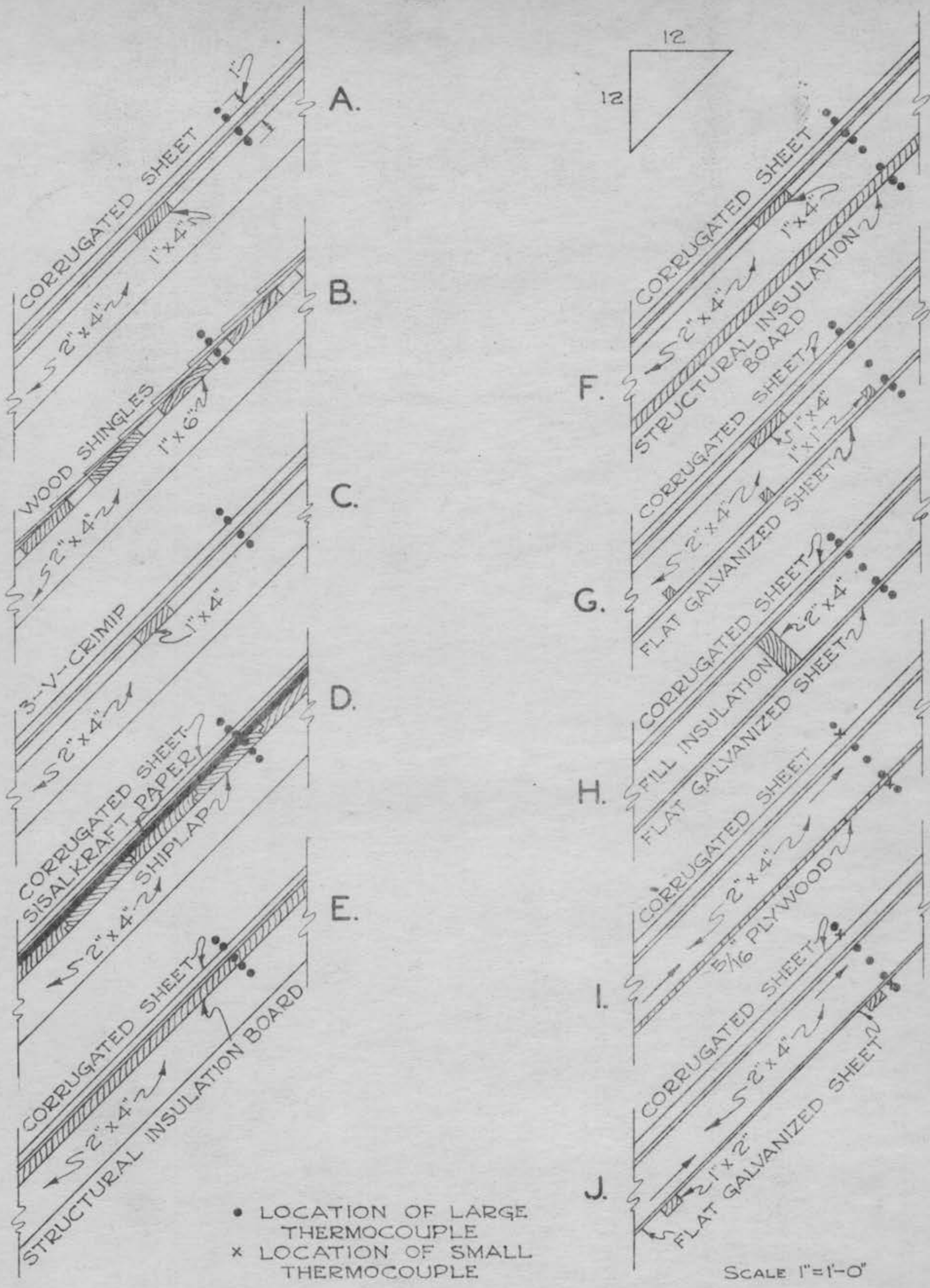
Mr. Scoates collected his data during the month of June, 1938. The only source of heat involved was solar heat. From his analysis of the data these conclusions were drawn:

(1) Type D, which is 1-1/4" corrugated sheet steel roofing with shiplap sheathing and sisalkraft paper, is not acceptable for excluding solar radiation.

(2) Type H is the most efficient of those tested in excluding solar radiation.

(3) The most efficient use of 1" structural insulation board in excluding solar radiation is on the underside of the rafters as in type F.

(4) The use of flat galvanized sheet steel under the



• ROOF • SECTION • DETAILS •

Fig. 1

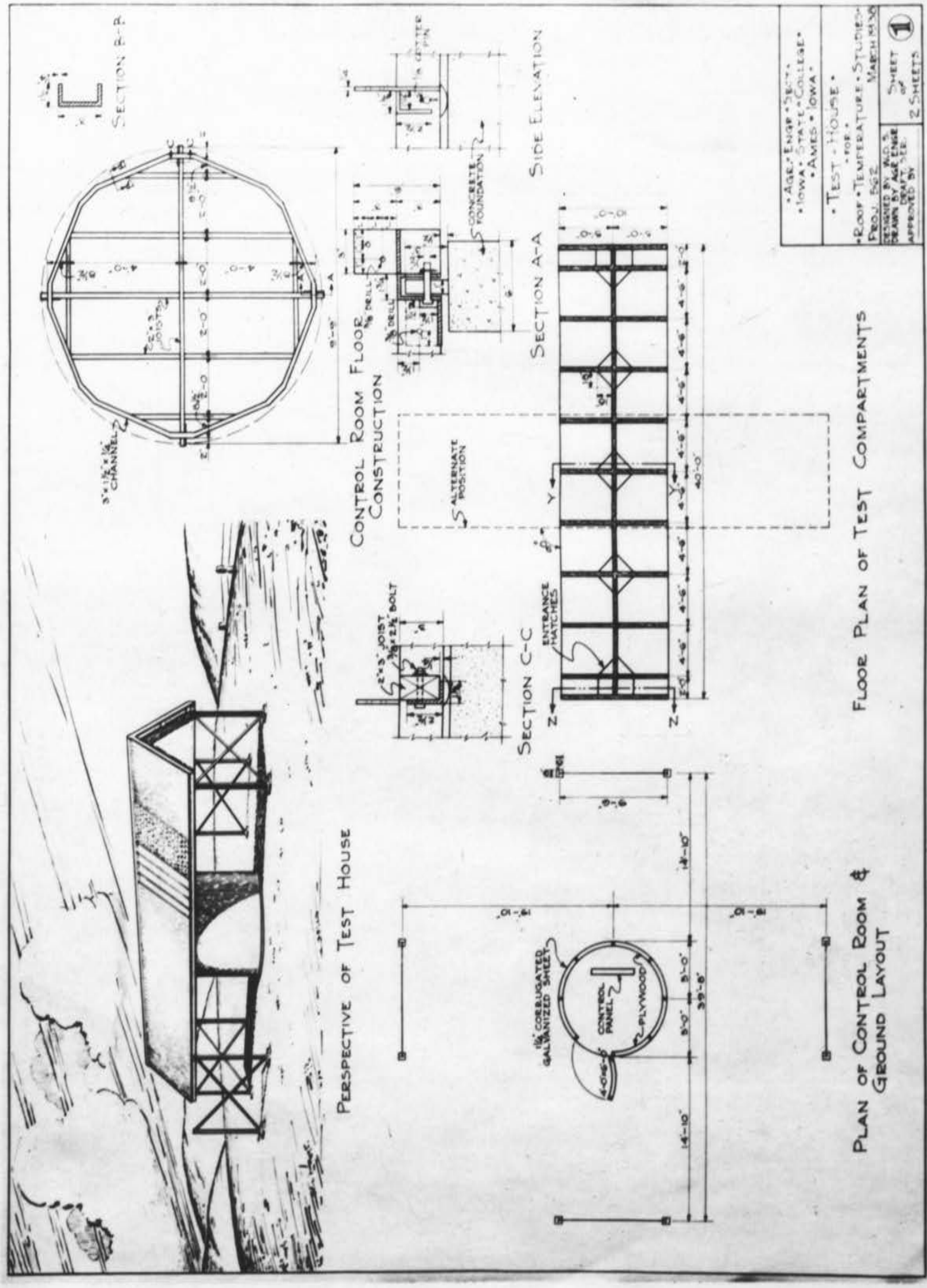


Fig. 2 Test house plans, sheet 1

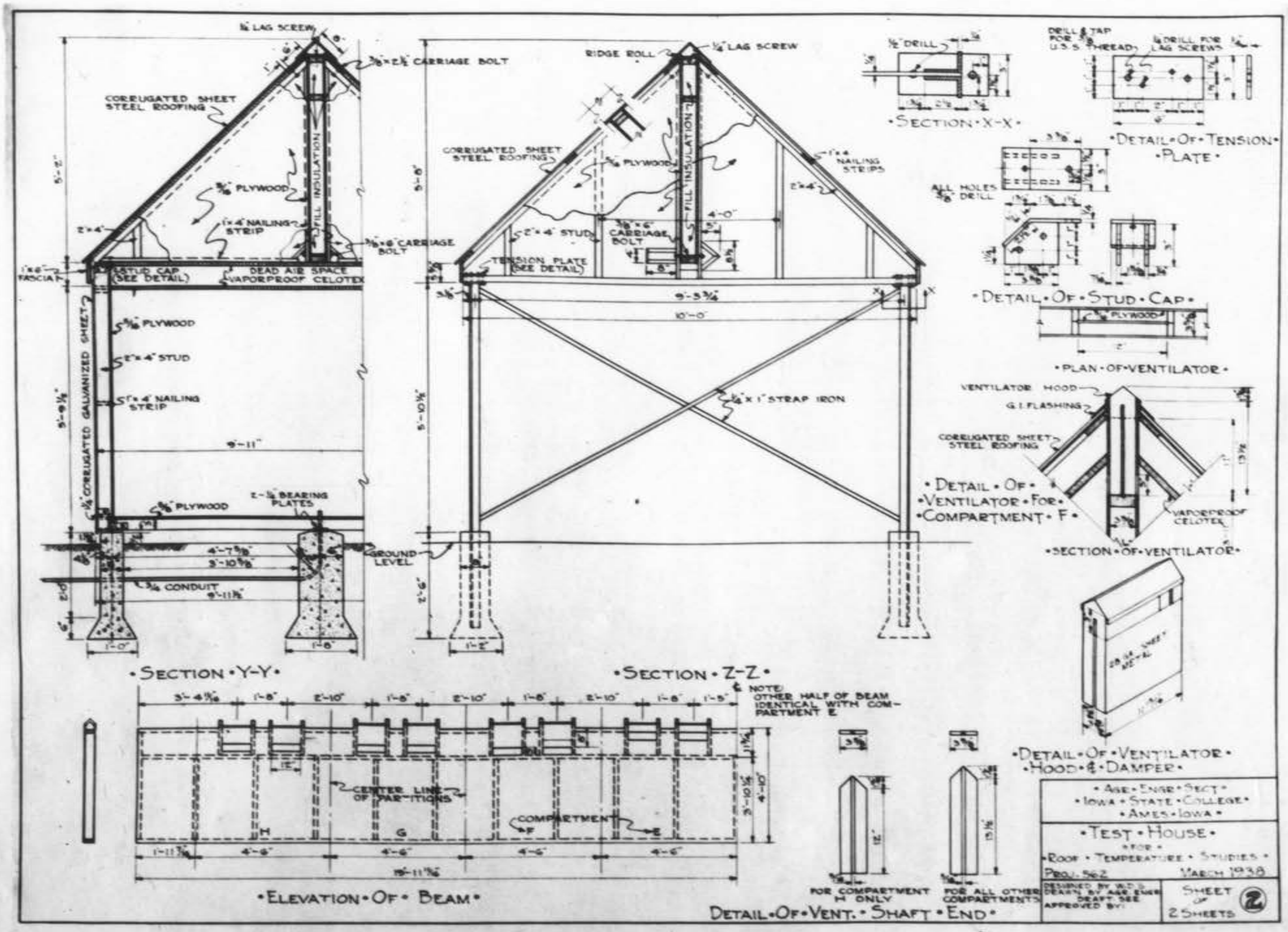


Fig. 3. Test house plans, sheet 2

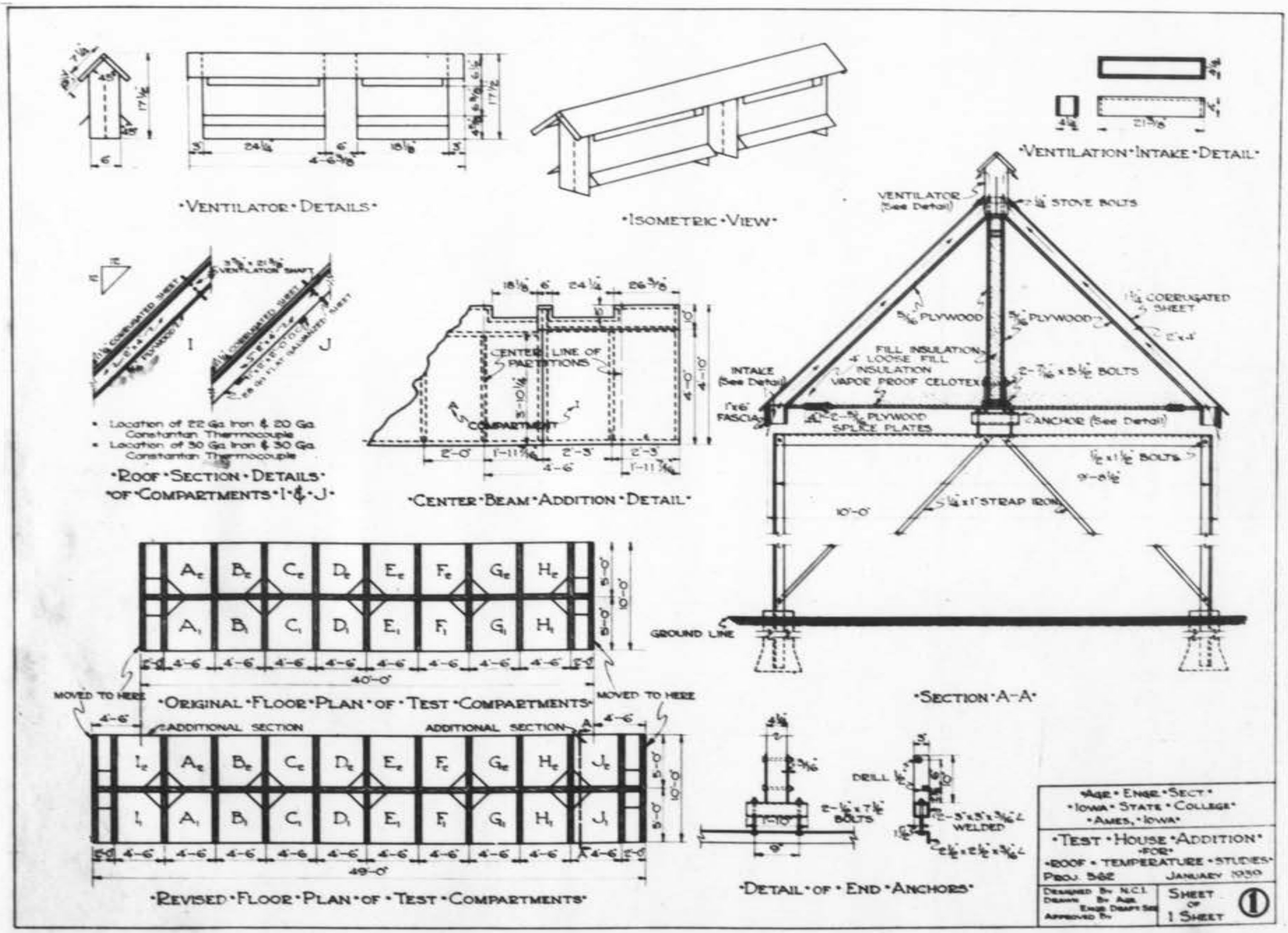


Fig. 4. Revised test house plans

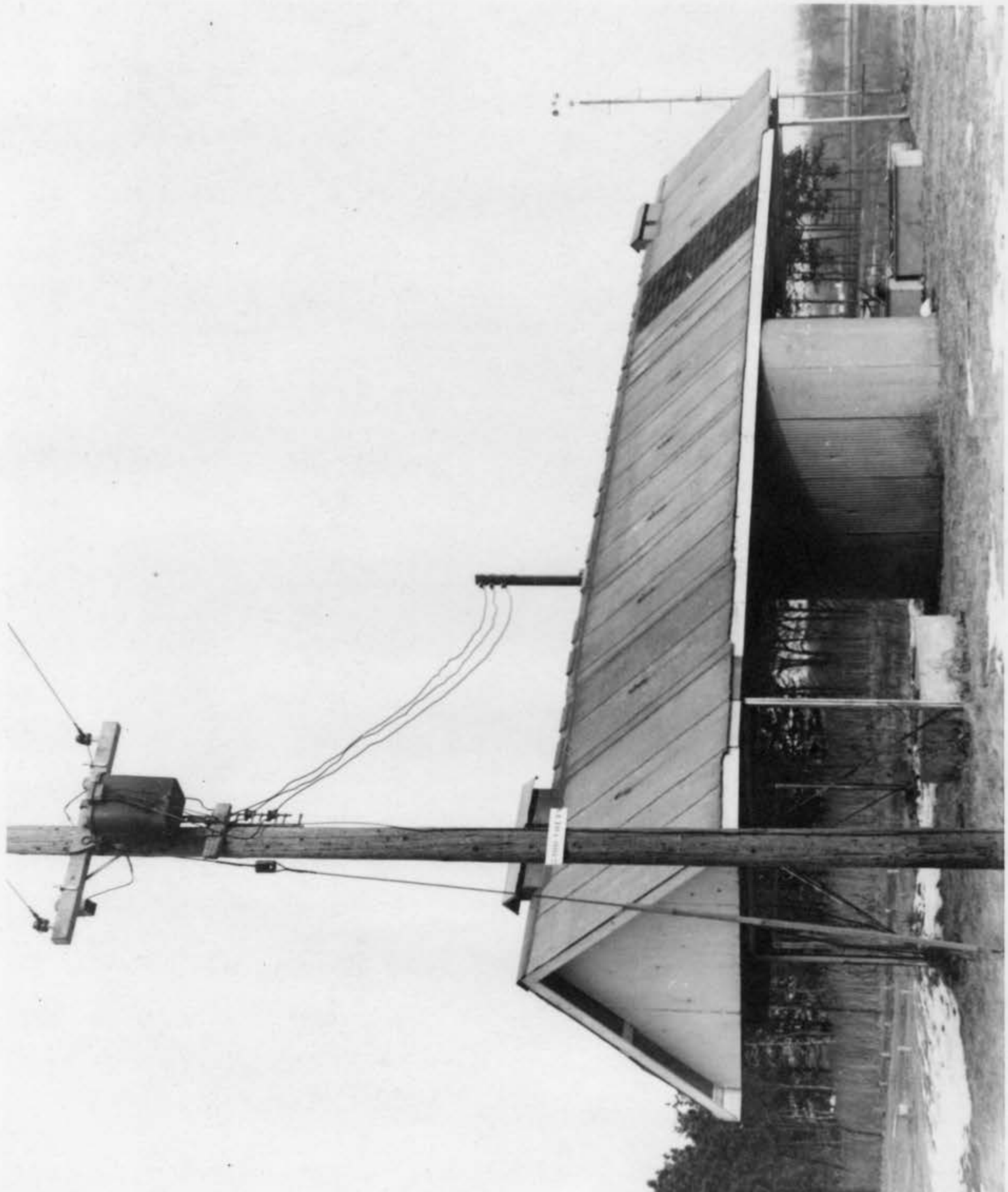


Fig. 5. Photograph of test house

rafters is as effective in excluding solar radiation as 1" structural insulation board in the same place.

2. N. C. Ives (1938-1939)

Following Mr. Scoates was Mr. Ives (9), the second research fellow to work on the project. He set out with the following specific objectives:

(1) To find the factors which affect the amount of heat entering a given roof section when exposed to solar and sky radiation, an air temperature difference, or both of these conditions acting simultaneously

(2) To analyze these factors as to their nature and importance in affecting heat flow through a roof structure

(3) To study and compare the relative abilities of different roof sections covered with galvanized sheet steel roofing with regards to their insulation properties to stop heat flow from solar radiation and on an air temperature difference.

The test house was revised by adding two additional roof sections, as shown in fig. 4, in order to study the effect of ventilating the insulating air space between the rafters. New instruments introduced were a pyranometer, an Epply pyrheliometer with a Leeds and Northrup recording potentiometer for obtaining solar and sky radiation, and a Friez three-cup anemometer mounted on a 16-foot steel tower adjacent to the test house as shown in fig. 5.

In his analysis of the problem Mr. Ives made a study of heat flow in its relation to his work. He found it convenient to divide the factors of heat flow into two broad classifications to facilitate his study:

(1) The environmental factors

(2) The physical properties of the roof structure

This classification appears logical since man can control the physical properties of a roof structure, while the environmental factors are unchangeable.

Significant statements found in Mr. Ives' analysis of the problem are:

> For all practical purposes, it would appear that the surface coefficients as obtained for air flow parallel to the surface might well be used without any correction for the angle of the wind.
>
> The effect of minute particles as found in many types of "loose-fill" insulation would be to reduce the heat transfer by radiation through these materials to a point where it may be neglected. Emphasis should be given to the fact that 65 to 80 percent of all heat flow takes place by radiation across a vertical air space between ordinary walls.

His conclusions resulting from his analysis of the problem are:

> (1) The environmental factors affecting heat flow through a roof section should be determined accurately if the resistance offered by a structure is to be analysed with a reasonable degree of certainty
>
> (2) The impinging radiation intensity, wind velocity, and outside air temperature are the essential environmental factors to be measured
>
> (3) Relative humidity may be neglected as an influencing factor on heat flow by transmission

Mr. Ives also made a study of solar radiation and methods of measuring its intensity. Curves for finding the altitude of the sun at any hour during any of eight evenly-speced days throughout the year, and curves for finding the azimuth of the sun once the altitude is known are presented. These curves were drawn for use at Ames, Iowa, Lat. N. 42° 1.6', Long. 93° 38' W. "Although these curves were plotted for the year 1938, they may with slight error be used for any year." The altitude of the sun for any other days than those shown on the curves may be determined by interpolation.

Six sets of data were taken by Mr. Ives at the following approximate dates:

Five days in June, 1938

Five days in July, 1938

Four days in August, 1938

One day in September, 1938

Three days in October, 1938

Two days in January, 1939

On the last date in January the compartments were artificially heated by means of Mazda electric lamps and carbon filament lamps in order to determine the overall thermal transmittance coefficients for the roof sections. These U values were determined from the well-known heat transfer formula:

$$H = AU(t_i - t_d) \qquad (1)$$

where H = heat transmitted in Btu's per hour

A = area through which heat is transmitted

U = thermal transmittance coefficient in Btu's/hr./sq.ft./°F

t_i = inside air temperature in ^oF

t_d = outside air temperature in ^oF

Mr. Ives presented his data in the form of temperature gradient diagrams, compartment temperature diagrams, and diagrams showing "the difference between the outside air temperature, the compartment air temperature, and the outside surface temperature for each of the eight roof sections studied under summer weather conditions." Also included were some experimentally determined U values.

Among the conclusions arrived at by Mr. Ives are:

(1) For the same conditions, roof section, type F, possessed more resistance, due to the Celotex insulation board than roof section, type G.

(2) Ventilation within the roof section is not practical for winter conditions. Summer readings are necessary to determine its effect on heat flow due to solar radiation.

(3) Roof section, type H, showed superior resistance to heat flow due to an air temperature difference.

(4) Solar radiation for winter weather conditions materially affects the amount of heat flow through a structure, but due to its inconsistency it should be neglected when designing for maximum heat loads in winter.

(5) Under summer weather conditions a sheet of flat galvanized sheet steel proved to be slightly more efficient in its resistance to heat flow than a one-inch Celotex insulation board, as was shown in roof sections, types F and G.

3. A. N. Dingle (1939-1940)

Following Mr. Ives was Mr. Dingle (3), the third research fellow to work on the project. Mr. Dingle outlined the following objectives:

(1) The establishment of some physical constants which would definitely evaluate the performance of each roof type

(2) The determination of the intensity of diffuse radiation from various points of the heavens for different sky conditions

(3) A comparison of the effects of different methods of surface treatment on the thermal characteristics of the roof sections

Mr. Dingle decided to concentrate his activities mainly toward fulfilling his first-named objective since it seemed more importunate. The physical constants in question were:

(1) The overall thermal transmittance U

(2) The thermal capacity, M

(3) The cooling constant, K

The overall thermal transmittance coefficient U, may be determined from the formula:

$$U = \frac{Q}{A(T_i - T_d)} \qquad (1)$$

Where Q = heat lost in Btu's per hour

A = area through which heat is transmitted in $ft.^2$

T_i = inside air temperature in ^oF

T_d = outside air temperature in ^oF

Actually U is not a constant. Its value depends on the inside surface film coefficient, the outside surface film coefficient, the conductivities of the materials making up the wall or roof section, and the conductivity of the "dead" air space, should there be one. Of these coefficients, Mr. Dingle states it can be supposed that all except the outside surface film coefficient remain constant for all practical purposes regardless of environmental changes. With the idea of isolating this outside surface film coefficient Mr. Dingle set up this equation:

$$P = \frac{Q}{A(T_i - T_{os})} \qquad (2)$$

Where T_{os} is the temperature of the outside surface in ^{o}F. It follows then that

$$\frac{1}{U} = \frac{1}{P} + \frac{1}{f_o} \qquad (3)$$

in which f_o is the outside surface film coefficient. Therefore, if P and U are known f_o can be calculated. It should be noted that P is greater than U unless f_o is negative.

A time lag is a characteristic possessed by all closed structures. A structure is said to possess a time lag if the inside temperature maxima and minima occur later than the outside temperature maxima and minima. Mr. Dingle showed that the time lag is a function of the U value of a structure and of the thermal capacity, M, as follows:

$$M = cpv \qquad (4)$$

Where M = thermal capacity in Btu's/OF

c = specific heat in Btu's/lb.

p = density in lbs./ft.^{3}

v = volume in ft.^{3}

The thermal capacity per square foot of area is:

$$m = \frac{M}{A} \qquad (5)$$

Where m = unit thermal capacity in Btu's/^{o}F/ft.^{2}

A = total area in ft.^{2}

Then:

$$L = \frac{m}{U} \qquad (6)$$

Where L = time lag in hours

For convenience the reciprocal of L was used:

$$k = \frac{1}{L} = \frac{U}{m} \qquad (7)$$

Units for k = 1/hr., and the value of k varies directly as the value of U.

From his theoretical analysis Mr. Dingle was able to say that "as k approaches zero, the T_i of the structure becomes more and more independent of the environmental temperature. If k were set equal to zero, T_i would not vary at all." He also showed that the k of his analysis was identical with that found in Newton's law of cooling:

$$T = T_o e^{-kt} \qquad (8)$$

Where T = temperature difference between a liquid and the surrounding atmosphere at time $t = n$

$T_o = 0$

e = Naperian base

k = "cooling constant"

t = time factor

From Newton's law of cooling k may be determined, and if k and U are known, m may be computed from eq. (7). It can be seen that in order to obtain a correct value of m, the values of k and U must be obtained for the same environmental conditions. Since this was impractical Mr. Dingle proposed a solutionfor m which theoretically would eliminate the effect of the outside surface film coefficient. This method introduces a new constant whose value depends on the difference between the inside temperature and outside surface temperature.

$$\text{Then } m = \frac{P}{k'} \qquad (9)$$

In recording data Mr. Dingle used the same record forms that Mr. Ives used. Contrary to all expectations P was found to vary as much as U, even though the test house had been thoroughly caulked before the tests were begun. Mr. Dingle attributed this to the effect of solar radiation on the enclosed insulating air space in those roof sections possessing such a feature. No explanation was offered for the other roof sections.

Among the conclusions Mr. Dingle arrived at are:

(1) The best criterion of the relative performance of a roof section is its cooling constant, k.

(2) The overall thermal transmittance, U, is not a constant physical characteristic but rather varies with weather conditions.

(3) In general an increase in wind velocity is reflected as an increase in U, and an increase in radiation causes U to decrease.

(4) The difference between U values for a given roof type may be interpreted as an expression of the differential of wind and radiation effects in terms of Btu's x $^{o}F^{-1}$ per square foot of roof surface.

(5) The cooling constant values of roof types F,G, H,I, and J indicate that H is the most desirable for cooling performance and long time lag, F, is second, G, third, and I and J are about equal in fourth place. Obviously, I and J, being ventilated, are shown to disadvantage under winter conditions.

4. W. H. Cox (1940-1941)

It will be recalled that Mr. Dingle in his investigation accumulated a considerable amount of data which was not completely analyzed. Following Mr. Dingle on the project was Mr. Cox (2) whose general objective was to analyze more thoroughly the data previously collected. Specific objectives of Mr. Cox's study were:

(1) To evaluate physical constants to be used in design calculations for the ten roof sections under study in this project.

(2) To compare the temperatures under the various roof sections.

Mr. Dingle had collected data for a total of twenty-one days; Mr. Cox, using a method of averages, obtained the average temperature of each compartment for each hour of the day. These composite figures were supposed to be representative of typical Iowa winter conditions. By plotting curves showing the average compartment temperatures against the time of day, and "changing these curves to compensate for the variation in heat input for the compartments," an answer was supplied to the question, "Which of the roof sections will permit higher temperatures under winter conditions with the same heat supply?"

In determining thermal transmittance coefficients for the various compartments, curves were plotted for each compartment showing the average inside compartment temperature and the average outside air temperature. Measuring the area between the two curves with a planimeter and dividing by the length of the abscissa rendered a composite temperature difference $(t_i - t_d)$ to be used in the calculation of U, eq. (1).

Mr. Cox also made a brief investigation of the absorptivity values of the compartments, i.e., the decimal part of solar heat reaching the interior of a compartment. To determine the absorptivity it was necessary to know the impinging solar heat and the heat gained by the compartment, since the absorptivity of a particular compartment is the ratio of the latter to the former. The heat gained by a compartment was found by multiplying the thermal capacity, m, of eq. (7) by the rise in temperature inside the compartment during the period studied. The impinging solar heat was determined by means of the pyrheliometer records. Mr. Cox computed the compartment absorptivities from data collected on two days in July, 1939. These values are presented in tables in his thesis. Significant conclusions stated are:

(1) The absorptivity of a roof section during a period of temperature use is influenced by the change in outside temperature during that period.

(2) The structural insulation board was much more effective, both in excluding solar heat and preventing

outward heat flow when placed under the rafters than when placed next to the sheet steel roofing. The Celotex, when placed under the rafters, was more efficient in preventing heat flow under both winter and summer conditions than the sheet steel in the same position.

(3) Roof type H showed lowest U value and lowest absorptivity of all roof sections, proving the loose-fill insulation to be an effective insulating material.

5. W. J. Nemerever (1943-1944)

The data collected by previous investigations on this project during summer weather conditions were found to be adequate and satisfactory, but it was decided that the winter data needed supplementing. With this in mind, Mr. Nemerever (13), the fifth research fellow on the project, took as his general objectives:

(1) The construction of a heating system of the test house which would maintain a constant temperature within the compartments, regardless of outside air temperature fluctuations

(2) The obtention and analysis of winter data yielded by tests with the above-characterized heating system

In order to fulfill his objectives Mr. Nemerever had to make several improvements on the test house. First, if a constant temperature were to be maintained within the compartments, heaters that are thermostatically regulated were found to be a necessity. Accordingly, 660 watt, 115 volts, nichrome wire electric radiant heater elements to be regulated by type T42A Minneapolis-Honeywell thermostats were chosen. These heaters were placed in the compartments in positions off-center in order to facilitate the development of convection currents which would tend to distribute the heat uniformly. To eliminate any radiation effect the thermostats and the thermocouple hot junctions were shielded with pieces of bright tin sheet from the radiant heat rays emitted from the heaters. A new ten k.v.a. transformer was installed on the last pole of the transmission line about forty feet from the test house, thereby insuring ample voltage. Electric meters were installed to record the watt-hour input into each compartment. These meters were tested and certified to register with 0.2 percent at full load. The Taylor recording thermometer was used to record outside temperatures; the Friez three-cup anemometer was used to record wind velocities; and the Eppley pyrheliometer with Micromax recorder was used to record solar radiation. The pyrheliometer was mounted at an angle of forty-five degrees with the horizontal, facing south, thus being in a position parallel to the south facing of the test house roof, and thereby eliminating any trigonometric conversions.

Two experimental runs were made in late January and early February 1944. Readings were taken twice daily of the watt-hour meters, the inside compartment temperatures, and the wind velocities. The compartment temperatures were read in order to check on the operation of the thermostats.

In computing U values the outside air temperature and the inside compartment temperature (constant) were plotted on the same sheet for each compartment. Then by measuring the area between the two curves with a planimeter, and dividing by the length of the abscissa, the average temperature difference was obtained. The total heat input was found for each compartment by multiplying the number of kilowatt hours by 3413, the thermal equivalent in Btu's of one kilowatt hour. U values were computed by using the general heat transfer formula, corrections being made for solar heat absorbed and heat lost through the compartment floors.

Among Mr. Nemerever's conclusions are:

(1) No significant difference exists between the values of U of galvanized corrugated (A) and galvanized 3-V-crimp (C) sheet steel roofing.

(2) It is more advantageous to have a structural board placed a few inches below rather than adjacent to corrugated steel roofing (types E and F).

(3) Type F, i.e., corrugated galvanized sheet steel roofing on the outside, with 25/32" insulation board on the underside of the rafter, is more efficient than type G, i.e., corrugated galvanized sheet steel roofing on the outside, with flat galvanized sheet steel on the underside of the rafter.

(4) The lowest U value was attained by type H, i.e., flat galvanized sheet steel on the underside of the rafter, with the intervening space filled with loose cornstalk insulation.

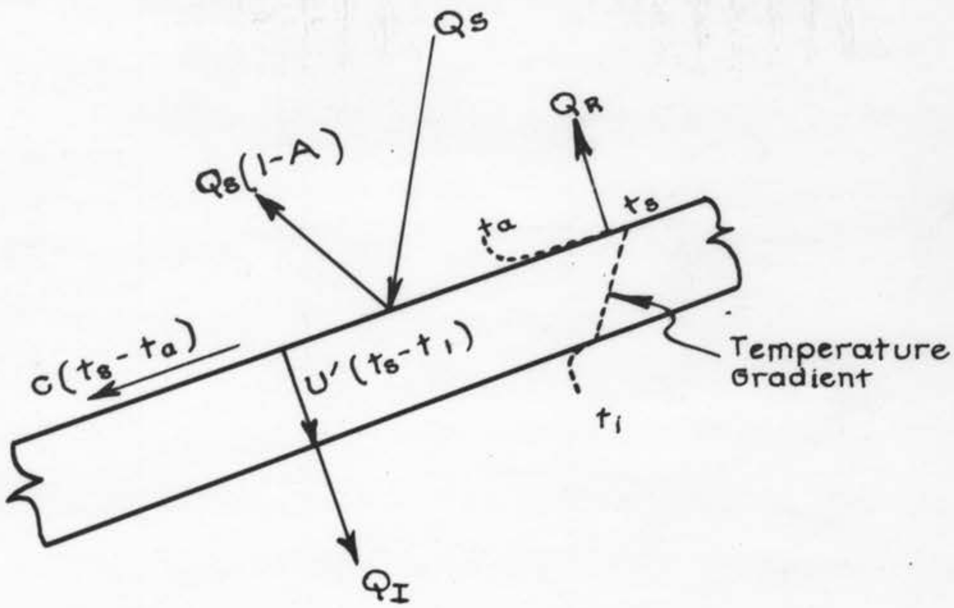
(5) The average outside temperature was not found to affect U values.

II. REVIEW OF LITERATURE

A. Heat Flow through Roof or Wall Sections Covered with Sheet Steel

Fig. 6 from an unpublished report by Henderson (7, p. 28) is included in order to present a picture of heat movement through a roof or wall section exposed to solar radiation. The quantity Q_sA represents the fraction of total impinging radiation normal to the surface, on a unit area, that is absorbed by the surface. For galvanized sheet steel the absorptivity values range from about 0.4 to 0.9 (8). The quantity Q_s (1-A) represents the amount of heat reflected from unit surface area; therefore, it is apparent that the reflectivity of a surface is equal to one minus the absorptivity of the surface. The heat absorbed by the outside surface, Q_sA, increases the outside surface temperature, and due to this increase in temperature the outer surface radiates heat back to the atmosphere. This negative radiation, Q_r, basically varies as the fourth power of the absolute temperature of the outer surface. It may be computed by using the Stefan-Boltzman law (10) provided all quantities except Q_r are known. For radiation from a unit area the equation is:

$$Q_r = 0.173 \times 10^{-8} \times e(T_1^4 - T_2^4) \qquad (10)$$



$$Q_s A - C(t_s - t_a) - Q_r = U'(t_s - t_i) = Q_I$$

Q_s = Intensity of suns radiation normal to surface, BTU/sq.ft./hr.

A = Surface absorptivity coefficient.

C = Film coefficient of conduction, outside surface (varies with wind velocity).

t_s = temperature of outside surface, F°.

t_a = Outside air temperature, F°

Q_R = Heat energy radiating from surface to sky, BTU/sq.ft./hr.

U' = Overall conductance coefficient for roof exclusive of outside surface fraction.

t_i = Inside air temperature F°

Q_I = Heat gained or lost by inside BTU/sq.ft./hr.

Heat movement through a roof exposed to solar radiation. Constant heat flow is assumed.

Fig. 6. Diagram of solar radiation impinging on a roof section

Where e = emissivity of the radiating surface. The value varies from 0.228 for bright galvanized sheet iron to 0.276 for gray, oxidized galvanized sheet iron

T_1 = absolute temperature of the radiating body

T_2 = absolute effective sky temperature

Up to the present time no investigator has been able to assign any value or values to the effective sky temperature or temperatures. Observers at Fargo, North Dakota (17) in measuring nocturnal radiation obtained values ranging from one to twenty-seven Btu's/sq.ft./hr., with the average being about twelve. Henderson (7, p. 27) from his investigation of heat flow through roof sections covered with corrugated sheet steel inferred that a value of six Btu's/sq.ft./hr. for negative radiation was applicable "for night or shaded conditions." The quantity of heat represented by $C(t_s-t_a)$ is that heat lost to the air by conduction, since the surface temperature is higher than the outside air temperature. The heat designated as $U'(t_s-t_i)$ is the amount of heat that enters the interior of the structure if constant heat flow is assumed. As long as t_s remains higher than t_i, no heat can flow from the inside through the roof section to the outside of the structure. If the inside temperature is higher than the outside surface temperature, none of the solar heat absorbed by the surface can reach the interior of the structure; it is subsequently lost to the atmosphere by conduction $C(t_s-t_a)$, and negative radiation, Qr.

Henderson (7, p.42) included in his report a set of curves which show the relative humidity inside a structure at which condensation will begin for various inside and outside air temperatures and thermal transmittance coefficients (U values). Radiation was neglected in preparing the curves, because of its complex nature, but Henderson states that "radiant exchange would be an asset, tending to improve conditions. The graph than would still apply, giving the maximum conditions for satisfactory performance."

B. Brooder House Design

The essentials of proper poultry housing as listed by Moore et al. (12) are:

1. Protection from extreme heat, cold, or sudden changes in temperature
2. Freedom from drafts
3. Sufficient ventilation
4. Abundance of light and sunshine
5. Sanitation and control of parasites
6. Sufficient floor space
7. Convenience in routine management
8. Protection against rodents and predatory animals
9. Economical construction
10. Durability

In connection with the first and third items above, Giese (6) concluded that:

> 1. Uniformity of temperature is the most important factor in poultry house ventilation.
>
> 2. Excessive relative humidities, while not desirable, are not particularly detrimental if the temperature remains fairly constant.
>
> 3. Air purity as indicated by carbon dioxide content is not paramount, and birds can be subjected with impunity to atmospheres containing a much higher percentage of carbon dioxide than is usually found in poultry houses.
>
> 4. House construction and insulation exercise a greater influence on poultry house temperatures, within usual limits, than the circulation of air.

Moore (12) also states that "the major problem in poultry house ventilation is that of moisture control during the winter months, specifically to maintain dry litter and to prevent condensation of moisture on the walls and ceiling." In listing the factors which influence the operation of any ventilation system, Moore noted the effect of available heat, either natural or artificial, stating that additional heat stimulates air movement and "has a drying effect in that as air is warmed its moisture-holding capacity is increased."

Nicholas and Callenbach (14) from a study in which four 12x16 ft. Pennsylvania State brooder houses were used concluded that "insulation plays an important part in maintaining desired temperatures and humidities in poultry brooder houses." Thus from these statements one can deduce that insulation is a factor of prime importance to be considered in brooder house design.

The general temperature recommendations as given by Wilcke et al. (18) for day-old chicks are ninety to ninety-five degrees Farenheit at the edge of the hover and about two inches from the floor. The temperature at the edge of the hover should be reduced about one degree each day until the brooder is no longer needed. Prickett (15) in a study of chick brooders found that day-old chicks were healthy and vigorous all over the hover areas wherever actual temperatures measured with thermocouples at a height of two and one-half inches above the litter were within a range of 80° to 110°F. "Not until we reached temperatures as low as 75° or as high as 125°F did we find areas definitely avoided by the chicks." Dukes (4) in discussing the effect of environmental temperature states:

> The temperature of the environment influences the metabolic rate, a temperature below or above certain points raising the heat production of the body. There is an environmental temperature at or below which the rate of metabolism in the resting, fasting animal is increased to prevent a fall of body temperature. At this temperature which varies considerably in different species, heat lost by radiation and conduction and by the evaporation of water is at its lowest point. This is called the critical temperature. If the environmental temperature falls below the critical, heat production by the organism must increase if the body temperature is to remain constant. If the environmental temperature is raised above the critical, radiation, and conduction and the evaporation of water are increased so that the temperature of the body and the rate of metabolism are not increased.

Mitchell and Haines (11) in investigating the critical temperature of the chicken considered the following values to be approximately correct:

For a fasting, resting hen the critical temperature is 62°F.

For a fasting, active hen the critical temperature is 35°F.

For an active hen consuming a ration composed largely of corn sufficient in amount to support an egg production of one per day, the critical temperature can be estimated at 15°F.

These temperatures were determined on the supposition that Newton's law of cooling bodies would apply. The law is

$$H = K(t-t') \qquad (11)$$

Where H = heat emission (or heat production) at the critical temperature

t = normal body temperature of the animal

t' = the critical environmental temperature

K = a constant equal to the increase in heat emission (or heat production) per degree drop in temperature. K = 2.6 cal.*/°F./day

Winchester and Kleiber (19) found, from a study of the effect of environmental temperature on White Leghorn chicks that no deaths occurred amohg the chicks kept at 21°C (67.8°F.) or above. Of five chicks kept at 18°C (64.4°F.) two had died by the end of the tenth day of the experiment, and of the same

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*Kilogram calorie = 1000 calories

number kept at 16°C (60.8°F.) three had died. The chicks were five days of age when the experiments, which lasted from nine to eleven days, began. They also state that "environmental temperature had a pronounced effect on the composition of body substance gained. The amount of fat stored per gram of increase in body weight was greatest at 35°C (95°F.) and 38°C (100.4°F.)."

The usual size for a movable brooder house is 10x12 ft. There are a number of different shapes in use such as the shed-roof, the gable-roof, the semicircular-roof, the gambrel-roof, and the gothic-arched-roof types of houses. Dunkelberg (5) concluded that a gothic-arched roof is desirable on a movable poultry shelter. He also stated that a 10x12 ft. movable poultry shelter should have the long dimension in depth.

In discussing the amount of window space needed in a poultry house Cooke (1) says:

> Windows should be limited to the amount necessary to provide light for eating. More than this makes for loss of heat in winter and overheating in summer. It is poor economy to spend money for insulation and then lose much of its benefit by using an excessive amount of glass.

In general it may be said that the recommended amount of window space is from four to six percent of the floor area of the structure.

III. OBJECTIVE OF INVESTIGATION

The general objective of this investigation was to design, construct, and then study the performance of three experimental sheet steel brooder houses. The three houses were to be identical in all respects except insulation. After studying the performance of these houses under actual conditions of usage, they were to be compared as to their insulation qualities and general performance.

IV. METHOD OF PROCEDURE

A. Design of Houses

1. Size

For this investigation, where three brooder houses had to be constructed in a relatively short time by two men, it seemed logical to select the smallest size colony brooder house that is in general usage, namely the 10x12 ft. size. This size house is more convenient to handle when moving from one location to another than the larger sizes, and a house of this size is sufficiently large to permit a thorough study of its performance, particularly with reference to heat transfer.

2. Shape

Before selecting any particular shape for the proposed brooder houses, scale drawings were made of four 10x12 ft. brooder houses of the following shapes:

No. 1 - gable-roof brooder house

No. 2 - gambrel-roof brooder house

No. 3 - gothic-roof brooder house

No. 4 - semicircular-roof brooder house

These four houses were then compared as to their adaptabilities to sheet metal construction and the inclusion of features which would permit ventilation of the air spaces between the rafters. The latter was found to be desirable in summer weather by Ives (9). From these comparisons it was evident that the gothic-roof brooder house offered the best possibilities, chiefly because the curving air space between the rafters would offer the least resistance to air flow of the four types of houses. The final construction selected was a bit unusual in that the outside corrugated steel sheets are applied with the corrugations running horizontally instead of vertically as is customary. In this manner the curved laminated rafters give stiffness in one direction while the corrugated steel sheets give stiffness in a direction normal to that of the rafters. In such a construction the rafters may be spaced four feet apart, and there is no necessity for having any nailing girts or spacers between the rafters. Another advantage of this construction is the elimination of any bending of the sheets in the direction of the corrugations.

3. Rafters

The curved laminated rafters were not designed with the intention of using the smallest possible section that would support the applied loads. Instead, the selection was governed by the size of the roofing nails, the number of laminations required in order to prevent "springback" when the rafter is removed from the form, and the necessity for having an

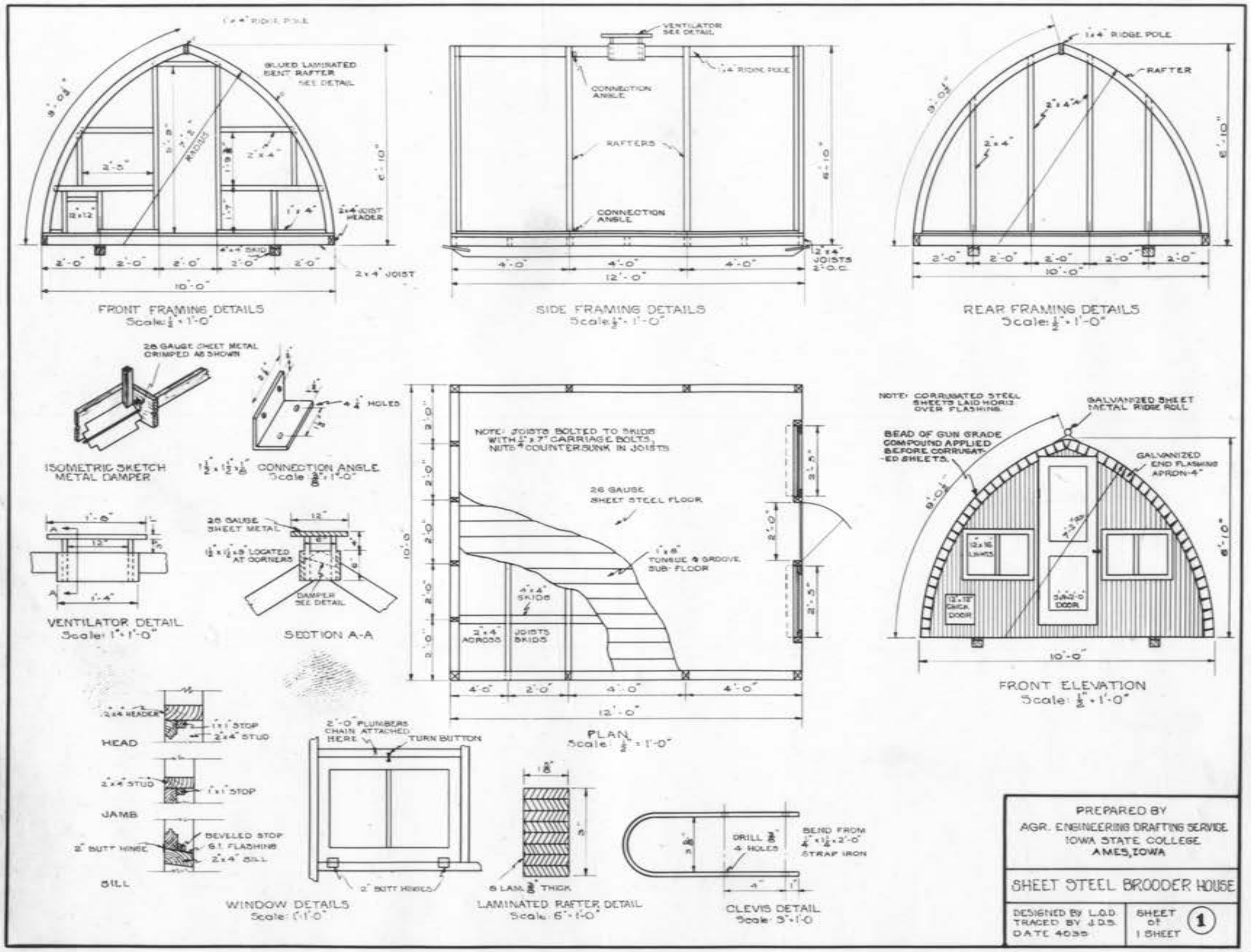


Fig. 7. General drawing of brooder houses

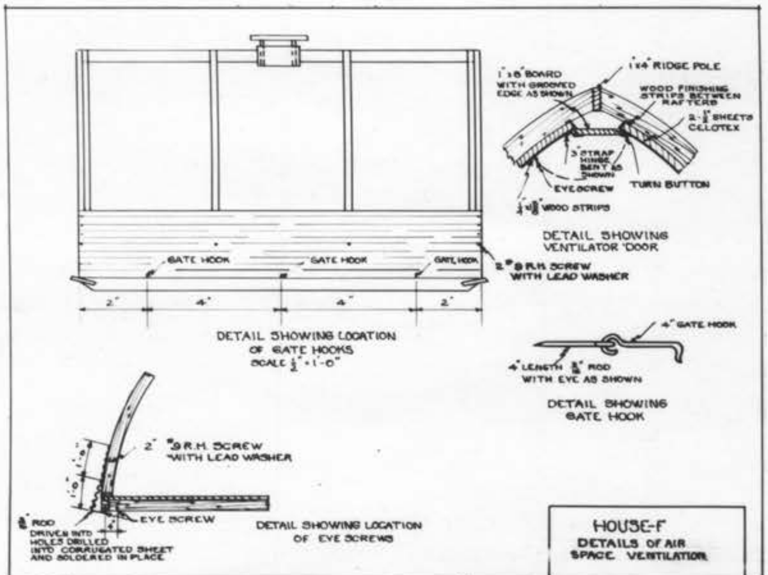


Fig. 8. Details of air space ventilation, house F

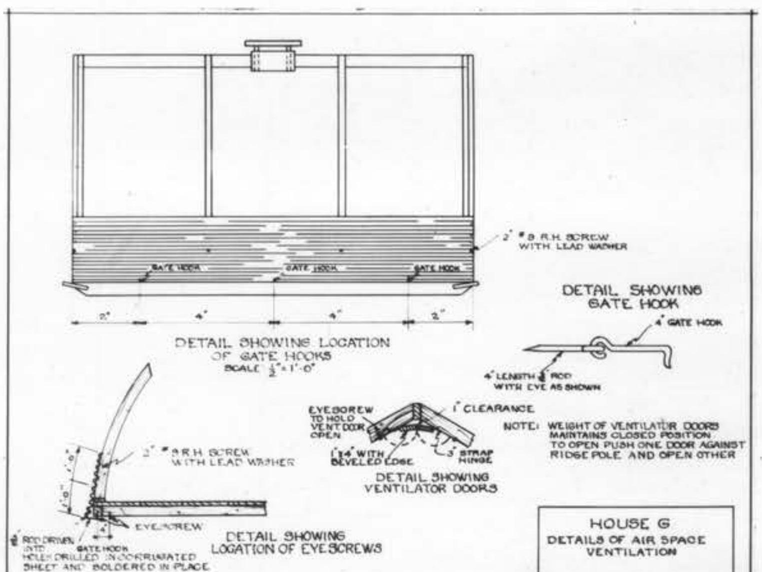


Fig. 9. Details of air space ventilation, house G

TABLE 1. Bill of Materials, House F

Lumber	Grade	Pieces	Size	Length	F.B.M.
Skids	1 com	2	4"x4"	12'-0"	32
Studs and framing	"	5	2"x4"	12'-0"	40
T. & G. flooring	"	16	1"x8"	12'-0"	128
For rafter strips	C Fin.	11	2"x4"	10'-0"	73
Joists	"	7	2"x4"	10'-0"	47
Joist headers	"	2	2"x4"	12'-0"	16
Sills & ridgepole	"	5	1"x4"	12'-0"	20
Ventilator	"	1	1"x6"	4'-0"	2
Ventilator	"	1	1"x12"	2'-0"	2

Sheet Steel	Size	Quantity
28 ga. 1-1/4" corrugated	2'x12'	9
28 ga. 1-1/4" corrugated	2'x10'	6
26 ga. flat galvanized	2'x10'	6
1-1/4" corrugated end wall flashing	(2' length)4" apron	((25
28 ga. galvanized ridgeroll	8" girth	11 L.F.

Insulation and Millwork	Size	Quantity
1/2" Celotex sheets	4'x8'	18
Door	5'-9"x2'-0"	1
Basement sash	12"x16" 2 lt.	2

Miscellaneous and Hardware	Quantity
Caulking compound	2 lbs.
Aluminum paint	1 qt.
Casein glue	2 lbs.
Hinges: 4" butt	2
2" butt	4
3" T.	6
Carriage bolts: 1/4"x7"	14
1/4"x2-1/2"	32
1/4"x2"	12
3/8"x4-1/2"	8
Screws: 1-1/4" #9 F.H.	16
3/4" #8 F.H.	8
Turn buttons, 1-1/2"	5
Angles, 1-1/2"x1-1/2"x1/8"x2-1/2"	20
Strap iron, 1/4"x1-1/4"	8 L.F.
Gatehooks and eyescrews: 4"	8
2"	2
Padlock hasp	1
Plumber's chain	4 L.F.
Hardware cloth, 1/4" mesh, 2' width	30 L.F.
Nails: sheet steel roofing	2 lbs.
8d. finishing	4 lbs.
10d. finishing	2 lbs.
3/4" barbed roofing	4 lbs.

TABLE 2. Bill of Materials, House G

	Grade	Pieces	Size	Length	F.B.M.
Skids	1 com.	2	4"x4"	12'-0"	32
Studs and framing	"	5	2"x4"	12'-0"	40
T. and G. flooring	"	16	1"x8"	12'-0"	128
For rafter strips	C Fin.	11	2"x4"	10'-0"	73
Joists	"	7	2"x4"	10'-0"	47
Joist headers	"	2	2"x4"	12'-0"	16
Sills and ridgepole	"	5	1"x4"	12'-0"	20
Ventilator	"	1	1"x6"	4'-0"	2
Ventilator	"	1	1"x12"	2'-0"	2

Sheet Steel	Size	Quantity
28 ga. 1-1/4" corrugated	2'x12'	9
28 ga. 1-1/4" corrugated	2'x10'	6
26 ga. flat galvanized	2'x10'	6
28 ga. 5 V-crimp	2'x12'	8
28 ga. 5 V-crimp	2'x10'	6
1-1/4" corrugated end wall flashing	4" apron	50 L.F.
28 ga. galvanized ridgeroll	8" girth	11 L.F.

Millwork	Size	Quantity
Door	5'-9"x2'-0"	1
Basement sash	12"x16" 2 lt.	2

Miscellaneous and Hardware	Quantity
Caulking compound	2 lbs.
Aluminum paint	1 qt.
Casein glue	2 lbs.
Hinges: 4" butt	2
2" butt	4
3" T.	10
Carriage bolts: 1/4"x7"	14
1/4"x2-1/2"	32
1/4"x2"	12
3/8"x4-1/2"	8
Screws: 1-1/4" #9 F.H.	16
3/4" #8 F.H.	8
Turn buttons, 1-1/2"	5
Angles, 1-1/2"x1-1/2"x1/8"x2-1/2"	20
Strap iron, 1/4"x1-1/4"	8 L.F.
Gatehooks and eyescrews: 4"	8
2"	4
Padlock hasp	1
Plumber's chain	4 L.F.
Hardware cloth, 1/4" mesh, 2' width	30 L.F.
Nails: sheet steel roofing	2 lbs.
8d. finishing	4 lbs.
10d. finishing	2 lbs.
3/4" barbed roofing	4 lbs.

TABLE 3. Bill of Materials, House H

Lumber	Grade	Pieces	Size	Length	F.B.M.
Skids	1 com.	2	4"x4"	12'-0"	32
Studs and framing	"	5	2"x4"	12'-0"	40
T. and G. flooring	"	16	1"x8"	12'-0"	128
For rafter strips	C Fin.	11	2"x4"	10'-0"	73
Joists	"	7	2"x4"	10'-0"	47
Joist headers	"	2	2"x4"	12'-0"	16
Sills and ridgepole	"	5	1"x4"	12'-0"	20
Ventilator	"	1	1"x6"	4'-0"	2
Ventilator	"	1	1"x12"	2'-0"	2

Sheet Steel	Size	Quantity
28 ga. 1-1/4" corrugated	2'x12'	9
28 ga. 1-1/4" corrugated	2'x10'	6
26 ga. flat galvanized	2'x10'	6
28 ga. 5 V-crimp	2'x12'	8
28 ga. 5 V-crimp	2'x10'	6
1-1/4" corrugated end wall flashing	4" apron	50 L.F.
28 ga. galvanized ridgeroll	8" girth	11 L.F.

Millwork	Size	Quantity
Door	5'-9"x2'-0"	1
Basement sash	12"x16" 2 lt.	2

Miscellaneous and Hardware	Quantity
Loose-fill cornstalk insulation	135 ft.^{3}
Caulking compound	2 lbs.
Aluminum paint	1 qt.
Casein glue	2 lbs.
Hinges: 4" butt	2
2" butt	4
3" T.	2
Carriage bolts: 1/4"x7"	14
1/4"x2-1/2"	32
1/4"x2"	12
3/8"x4-1/2"	8
Screws: 1-1/4" #9 F.H.	16
3/4" #8 F.H.	8
Turn buttons, 1-1/2"	5
Angles, 1-1/2"x1-1/2"x1/8"x2-1/2"	20
Strap iron, 1/4"x1-1/4"	8 L.F.
Gatehooks and eyescrews, 4"	2
Padlock hasp	1
Plumber's chain	4 L.F.
Nails: sheet steel roofing	2 lbs.
8d. finishing	4 lbs.
10d. finishing	2 lbs.
3/4" barbed roofing	4 lbs.

insulation space sufficiently large to permit the insertion of any loose-fill insulation.

4. Ventilators

There is some divergence of opinion as to which is the better type of ventilation outlet for a poultry house, the floor outlet or the ceiling outlet. The choice of a ceiling outlet in this case was governed by the fact that the air passing through the space between the rafters and entering the house by the hinged doors shown in fig. 9 should not be made to take a downward path to enter the ventilator outlet. The ventilator was located in the center of the ceiling in order that this air entering through the hinged doors would travel the minimum horizontal distance before entering the ventilator.

5. Windows

The windows selected were 12"x16", 2-light, basement windows having an area of 5.33 sq. ft. On a percentage basis the glass area is 4.44% of the floor area of the house. The wihdows are hinged at the bottoms inside the house toenable them to swing open and thus serve as air intakes for the ventilation system. The opening of the windows is controlled by the plumber's chain shown in fig. 7.

6. Insulation

The three brooder houses were to be identical in all respects except insulation. The insulation used for the three houses corresponded to that of roof types F,G, and H of the test house, fig. 1, and to avoid confusion the houses were designated by the letters F,G, and H. Thus house F had 1-1/4" corrugated sheet steel on the outside of the rafters, an air space, and an inch thickness of Celotex insulation board (two 1/2" boards) on the inside; house G had 1-1/4" corrugated sheet steel on the outside, an air space, and 5 V-crimp sheet steel on the inside of the house; and house H had 1-1/4" corrugated sheet steel on the outside, 5 V-crimp sheet steel on the inside, and the intervening space filled with creosote-treated ground cornstalks.

7. Details

Since a movable brooder house is usually subjected to considerable jolting and vibration when being moved from one location to another, a rigidly constructed house will give much longer service than a house that is not so well braced. It is thought that the houses used in this investigation possess considerable stiffness and rigidity without excess weight. An examination of fig. 7 will show that the floor joists are bolted to the skids by 1/4"x7" carriage bolts, the small angles shown are bolted to the rafters, and the rafters in turn are bolted to the ridgepole. Possible weak points in the framing are where the ridgepole butts against the ventilator (fastened by screws through angles) and where the rafters are attached to the sills (secured by screws through the angles into the sills), but these points are strengthened considerably when the outside corrugated steel sheets are applied.

B. Construction of Houses

1. Rafters

The laminated rafters used in these houses were made, two at a time, in the form shown in fig. 12. A ten-foot length of 2"x4" Douglas fir when ripped made six strips which after planing on two sides possessed a thickness of 3/8". Both sides of the strips were coated with casein glue, placed in the forms, and the bolts tightened. 8d finishing nails were driven at intervals of about six inches along the rafters to aid in applying pressure while the glue was drying. The rafters were left in the form overnight, which was sufficient time for the glue to set.

2. Framing

After the joists had been bolted to the skids they were sawed to an even ten-foot length, headers nailed on, and the 1"x8" tongue and groove flooring nailed in place. Then the flat galvanized sheets were laid on the flooring; a bead of gun grade caulking compound was applied at every lap of the

Fig. 10. House G during construction

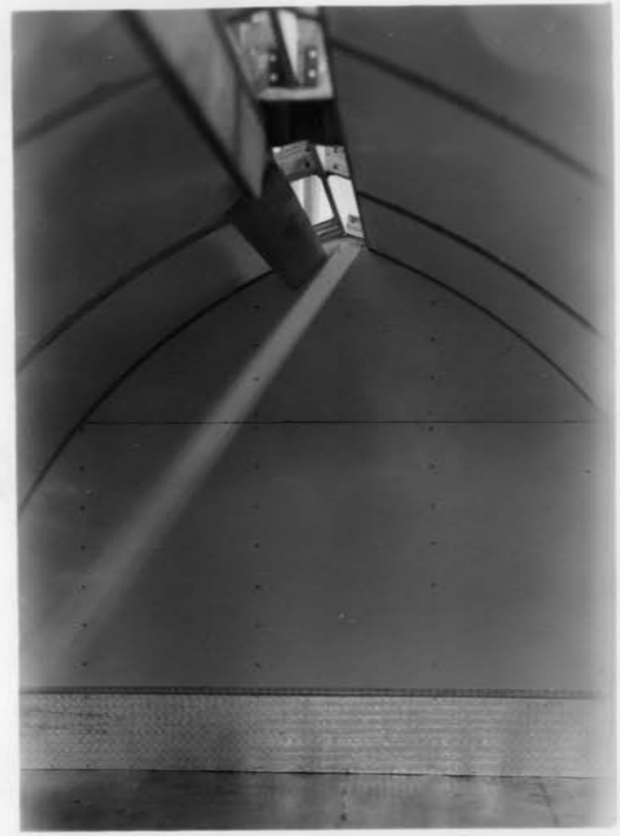


Fig. 11. House F during construction

Fig. 12. Rafter form used in making laminated rafters

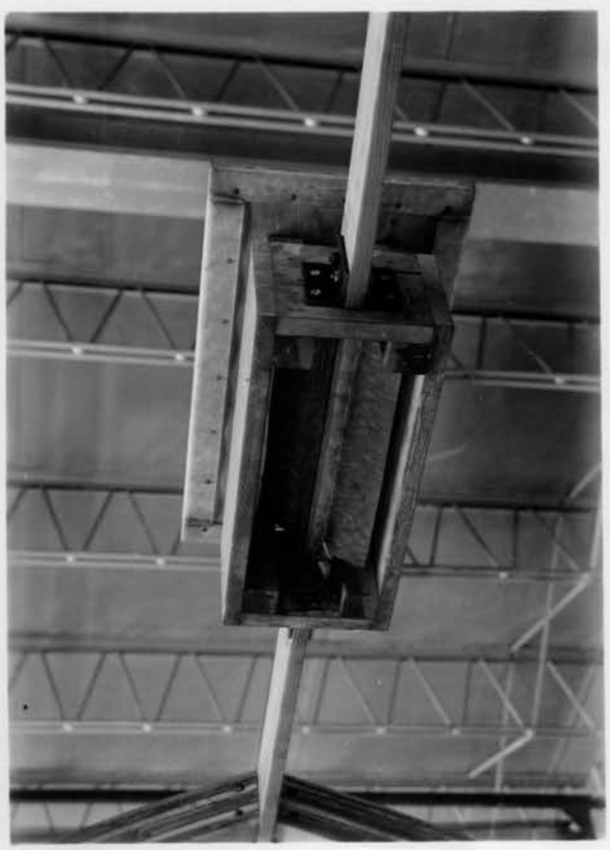


Fig. 13. Detailz of ventilator

sheets and the sheets were nailed with 3/4" barbed roofing nails to the flooring. The 1"x4" sills were nailed in place and the 1-1/2"x1-1/2"x1/8"x2-1/2" angles fastened by screws to the sills. The two sections of the ridgepole were next made up with the angles on opposite sides of the 1"x4" ridgepole, being held in place by two bolts common to both angles. The rafters were erected and held in place by means of C-clamps until they could be secured by bolts. The framing was completed by the installation of the ventilator, the studding, and the door and window framing. The 2"x4" pieces used as window sills were beveled at an angle of 10° with the horizontal to facilitate drainage.

3. Application of inside steel sheets and Celotex

The inside wall surface was applied before any outside sheets were nailed on. The front and rear inside surfaces were applied before those curved surfaces inside the rafters. In the application of the Celotex sheets in house F two 1/2" layers were used, because it was feared that the 1" thick Celotex sheets would be difficult to bend to the inside curve of the rafters. The cracks between adjacent sheets were covered with 1/4"x1-5/8" strips of Douglas fir, fig. 11. The Celotex near the floor was protected from picking by the chicks by a one-foot strip of sheet metal.

4. Wiring

Before applying any outside sheets the houses were electrically wired. A switch to actuate a light bulb at the rear of each house, about five feet above the floor, was installed overheat just inside the door. Two convenience outlets and a watt-hour meter were also installed adjacent to and below the light bulb.

5. Flashing

The 1-1/4" corrugated end wall flashing was applied in an attempt to decrease the air infiltration into the space between the rafters and in order to hide any rough edges of the sheets on the front or rear of the house. In order to fit the curve of the rafters the smooth face of this flashing had to be either crimped, fig. 22, or cut at intervals along its length, the short lengths lapped over each other, and nailed in place as in fig. 23.

6. Outside sheets

For houses F and G the bottom outside sheets were fastened to the rafters as shown in fig. 8 and fig. 9. In summer weather the lower half of the bottom sheet on each side of the house is swung out, and the opening serves as an air intake for ventilating the air space between the rafters, fig. 18. Before attaching these outside sheets a two-foot width of 1/4" mesh hardware cloth was tacked along the lower sides of the

Fig. 14. View of three houses from southwest

Fig. 15. View of three houses from southeast

Fig. 16. Interior of house F

Fig. 17. Interior of house G

rafters, and when the sheets are swung open the hardware cloth will prevent the entrance of rodents or other animals. As each outside sheet was applied to house H the space between the inside and outside sheets was stuffed with loose-fill, creosote-treated cornstalk insulation.

7. Caulking

A bead of gun grade caulking compound was used instead of flashing around the ventilator. This caulking compound never completely hardens, and it will, therefore, stick to surfaces undergoing temperature changes.

8. Painting

To complete the construction of the houses, doors and windows were painted with aluminum paint and hung, and hardware cloth was placed over the windows and around the ventilator.

C. Discussion of Design and Construction

1. Rafters

The selection of the rafter form shown in fig. 12 is open to criticism. There are other methods of constructing these curved laminated rafters that are simpler and requisite of less time. In one such method the curve or shape of the desired rafter is laid out on the floor of the house, and wooden blocks are nailed to the floor at intervals along the inside of the curve. At a distance several inches more than the desired width of the rafter from the inside blocks more blocks are nailed directly opposite the inside blocks. The rafter strips are coated with glue and laid between the two rows of blocks. Wedges are then driven between the outside blocks and the strips, thereby forcing the strips together and causing them to conform to the desired curve. Additional pressure can be obtained by clamping the strips together in the spaces between the blocks or by nailing them at such places. When the glue has set the wedges can be knocked out and another rafter started. When all of the rafters needed have been made the wooden blocks can be removed and construction of the houses continued. In this method the application of pressure while the glue is setting is much simpler than the tedious tightening of bolts used with the form of fig. 12.

2. <u>Sheet steel floor</u>

There might be some question as to whether or not it is economical to cover the floor of the house with galvanized sheet steel. The sheets might corrode due to attack by substances leached out of the litter and droppings in the house before they had been in long enough to justify their expense. During their application there were objectionable wrinkles formed in these sheets due to the fact that most of the sheets were warped slightly. These wrinkles caused small bulges in the sheets which when stepped upon tend to cause the nails fastening the sheets to the floor to work out. The advantages of having the sheet steel floor are: the entire elimination of drafts coming through the floor, and the ease with which the floor surface may be kept clean and free of insect pests.

3. Hinged door at rear for cross-ventilation

In most poultry houses there is provision for cross-ventilation in summer weather. This is a desirable feature as it aids considerably in keeping inside temperatures from rising too high. No provision for cross-ventilation was made in this design, because it is hoped that the ventilation of the air spaces between the rafters will produce the same effect. Should it be found necessary to cross-ventilate the houses later, a small hinged door at the rear will be recommended.

4. Inside steel sheets

In applying the inside steel sheets in houses G and H some difficulty was encountered in fitting the sheets on the inside of the rafters against the sheets on the front and rear of the houses. Had the inside sheets on the front and rear of the houses been flat instead of V-crimp there would have been no difficulty in butting the long sheets on the inside of the rafters against the sheets on the front and rear. It is likely, however, that if flat sheets had been used on the inside front and rear of these houses there would have been some spreading apart of the sheets at the laps which would allow air to infiltrate.

5. <u>Loose-fill insulation, house H</u>

The cornstalk insulation used in house H was obtained by running cornstalks through a hammer mill, with a one-inch screen, and then treating them with creosote. It is interesting to note that the cornstalks were rather wet when ground and therefore liable to "heat" afterward, but after treating with creosote there was no evidence of "heating." The creosote was applied at the rate of one gallon for every six cubic feet of ground cornstalks and was simply sprinkled on the ground cornstalks, and the mixture shoveled around. After a few days the creosote had turned the whole mixture a uniform brown color. Besides aiding in the preservation of the cornstalks the creosote will repel mites and other insects.

6. <u>Protection of Celotex, house F</u>

A one-foot width of sheet steel was placed around the interior of house F, fig. 11, to protect the Celotex from picking by the chickens. This strip of sheet metal should probably be two feet in width, because a grown chicken would have no difficulty in picking the Celotex above the one-foot strip.

7. <u>Caulking of cracks</u>

The only logical way to close all of the cracks in houses F and G appears to be by running a bead of gun grade caulking compound along all cracks. In house H the packed ground corn-stalks will eliminate air infiltration, but caulking would probably be beneficial to exclude the entrance of moisture. If the loose-fill cornstalk insulation absorbs moisture, its thermal transmittance is increased which means greater heat losses during the brooding season. Caulking in this manner would reduce heat losses due to infiltration to a minimum.

8. Spreading of outside sheets at laps

After applying the outside corrugated steel sheets it was noticed that there was objectionable bulging or spreading between the laps of the sheets, fig. 20. This condition is mostly caused by the rafters being slightly out of line with each other. One possible means of correcting this spreading would be to lap the sheets more than one and one-half corru-gations, as is customary. Thus, instead of using four and one-half sheets on each side, the sheets could be lapped more and five sheets applied to each side. Another possible solution to the problem is to fasten the sheets together with sheet metal screws as shown in fig. 21.

9. Crimping of end wall flashing

The end wall flashing was crimped as shown in fig. 18 in

Fig. 18. Rear corner of house F showing crimps in flashing and air intake for ventilating space between rafters

Fig. 19. Device used for crimping end-wall flashing

Fig. 20. Spread at lap of outside sheet

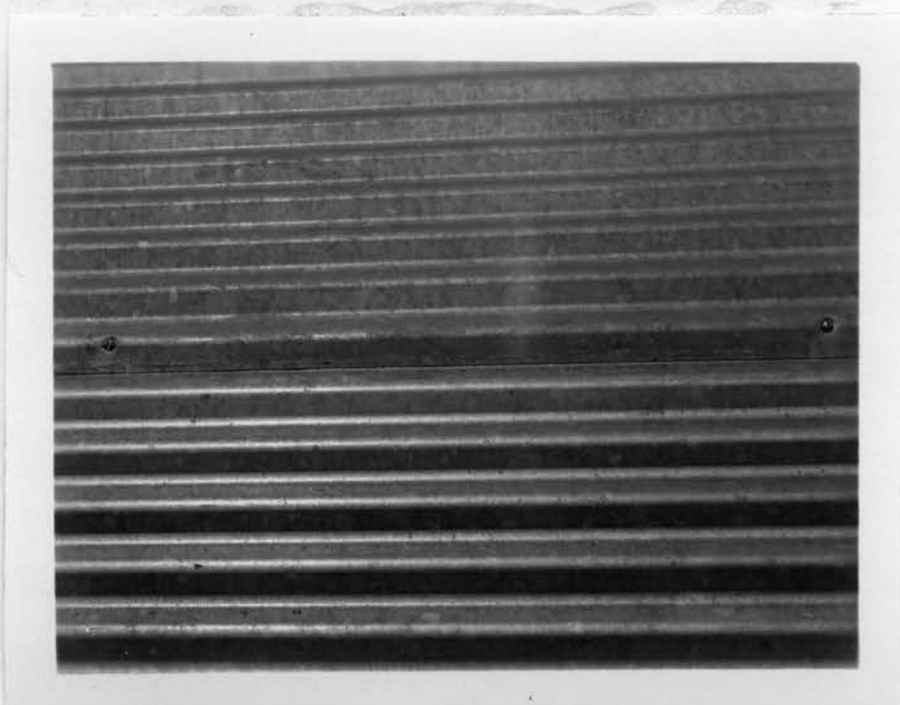


Fig. 21. Same lap after applying #6 sheet metal screws

Fig. 22. House F; note crimping of flashing

Fig. 23. House H; note manner in which flashing conforms to rafter curve

order to make it conform to the curve of the rafters. This crimping can be accomplished by using a pair of long-nose pliers or by some device such as the one shown in fig. 19. This form was used in conjunction with a small mechanical press, but a vise would serve just as well as the press.

D. Testing of Houses

1. Heat input as an indication of performance

Since the three sheet steel brooder houses are identical in all respects except insulation, the only means of comparing them is based on heat transfer. The most obvious method of rating the houses as to their insulation qualities is to record the heat input necessary to maintain a certain temperature in each of the three houses. This can be accomplished by using electric brooders, thermostatically regulated, and watt-hour meters to record the electrical input. Multiplying watt-hours by the constant 3.415 will give the heat input in Btu's, since 3.415 is the thermal equivalent in Btu's of one watt-hour. Since the houses are being subjected to the same weather conditions, it follows that the house with the greatest heat input will be the least insulated; and, conversely, the house with the least heat input will be the best insulated of the three.

To accomplish the above, the three brooder houses were located about twenty feet apart from each other facing south on a small knoll (fig. 14 and 15) at the College poultry farm. Two hundred day-old White Leghorn chicks were placed in each house on March 28. A thermostatically-regulated Makomb electric brooder with a fifty-three inch square hover was put in each house, and the wiring system of each house includes a watt-hour meter of the conventional inside type. These meters have been checked by a previous investigator on this project (13) and found to be accurate within 0.2 percent. To check on the operation of the brooder thermostats, thermometers were placed under the brooder hovers, and read twice daily by the operator.

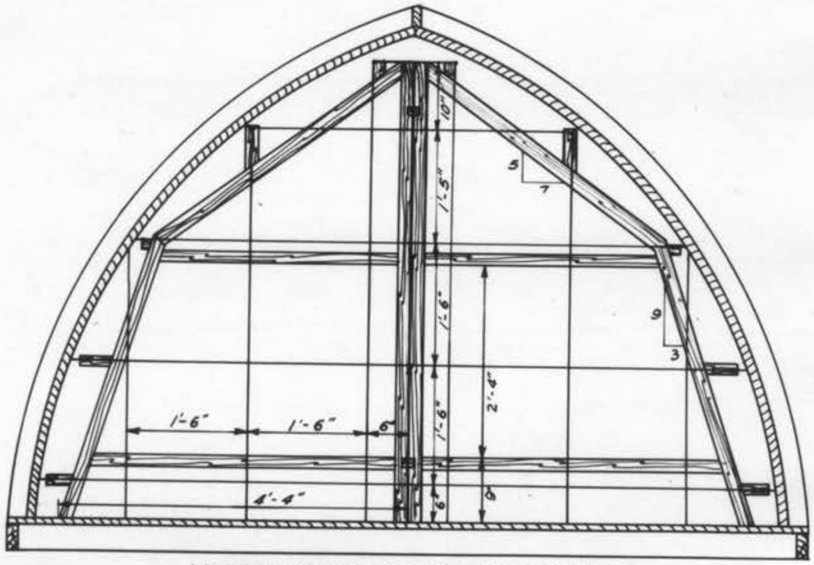
2. <u>Distribution of heat in the houses</u>

In order to further study the thermal characteristics of the brooder houses, readings were made of temperatures in a vertical plane about six inches from the rear wall in each house, and also in a horizontal plane eight inches above the floor in each house. A system of thermocouples seemed to be the most expedient means of obtaining these temperatures; accordingly, three gambrel-shaped frames (fig. 24) made of one and one-half inch strips of clear spruce and hinged in the centers to facilitate handling and arranging in the houses were made first. These frames when opened and in position in the houses have about an inch clearance from the side walls of the houses. A grid system with lines eighteen inches apart was marked off on each frame and copper-constantan thermocouples located at the intersections of the grid lines. For each of these vertical frames there are twenty-eight thermocouple junctions, and one constantan wire is common to all junctions. The copper wire lead from the soldered thermocouple junctions and the one common constantan wire were taken out between the door and the jamb of each house to a plywood instrument panel mounted on an old discarded tablet-arm chair (fig. 26). The operator would sit in the chair with the Leeds and Northrup potentiometer on the tablet-arm and make the temperature readings. After the readings for one house were taken, the instrument panel was removed from the tablet-arm and replaced in the house, and the operator went on to the next house. There was a separate instrument panel for each house.

The frame shown in fig. 25 was used to obtain readings of temperatures in a horizontal plane eight inches above the floor in each of the houses. There was a separate instrument for each frame, and readings were made in the same manner as that described for the vertical frames.

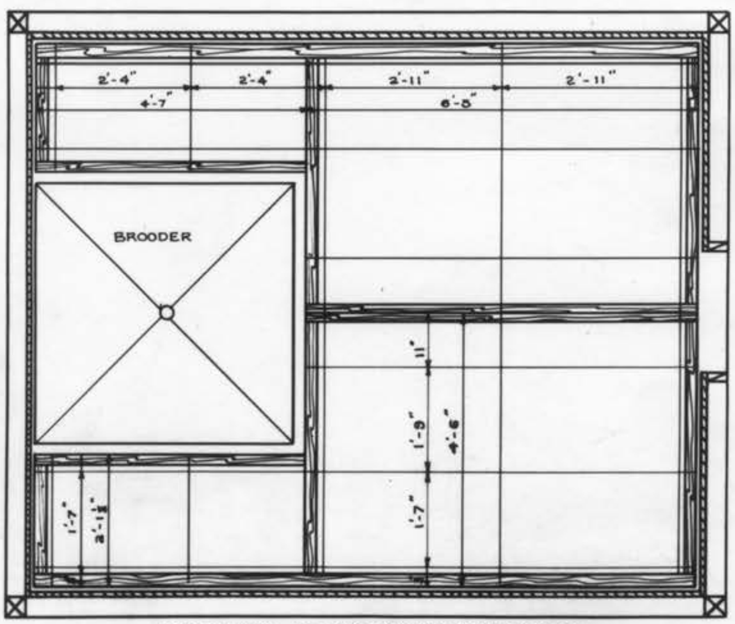
These readings of temperatures at various positions in the houses were averaged and are included in order to present a picture of the relative temperature ranges in the three houses.

3. Instruments used and records kept



VERTICAL FRAME FOR THERMOCOUPLES
Scale: 1"=1'-0"

Fig. 24



HORIZONTAL FRAME FOR THERMOCOUPLES
Scale: ¾"=1'-0"

Fig. 25

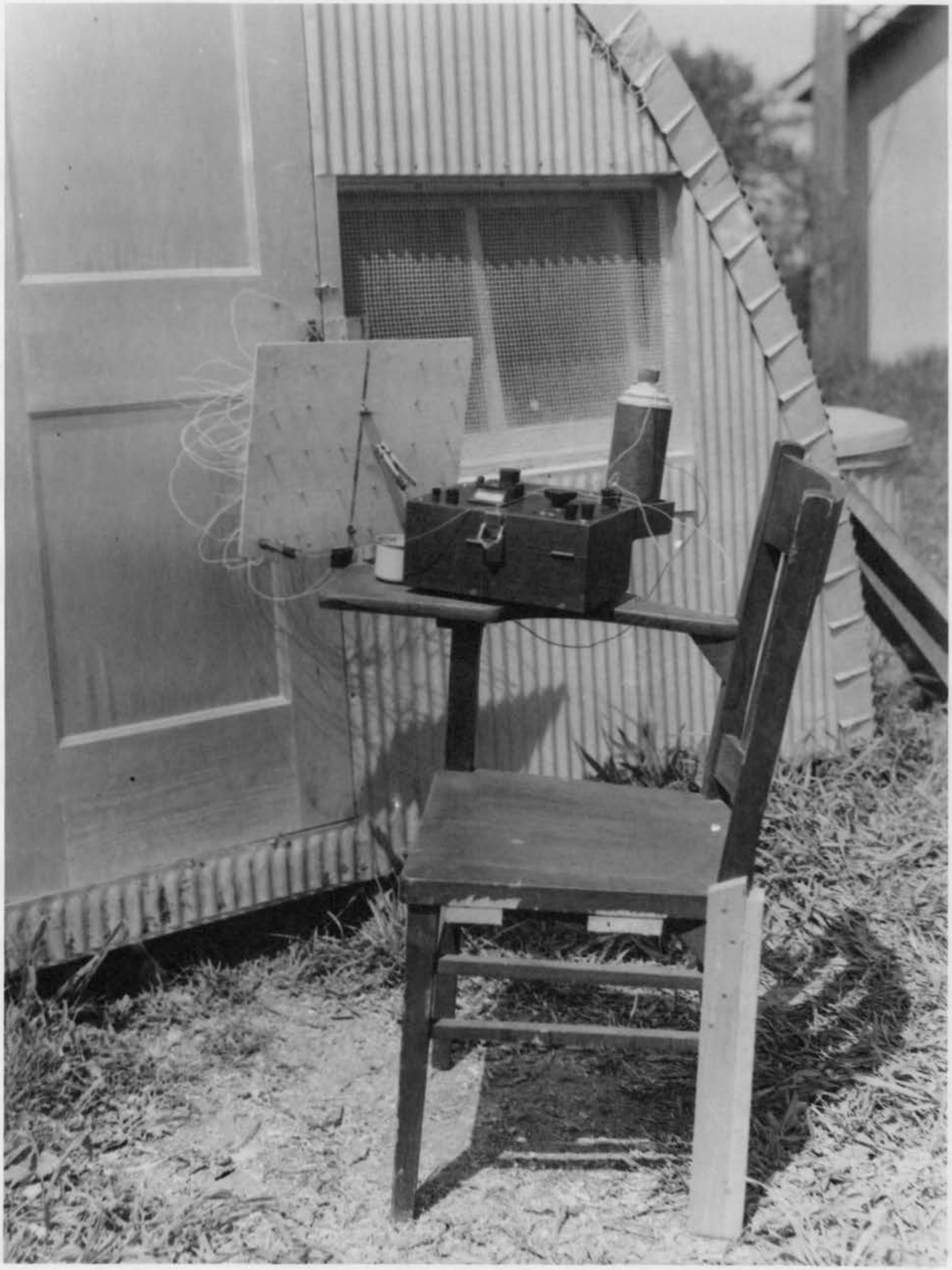


Fig. 26. Apparatus for reading temperatures inside houses

In addition to the watt-hour meter used for recording electrical input and the Leeds and Northrup potentiometer used in reading temperatures there were a Taylor recording thermometer and a Friez three-cup anemometer. The Taylor recording thermometer was mounted on the wall inside the house shown behind the sheet steel brooder houses in fig. 14. The Friez three-cup anemometer was mounted on a carpenter's sawhorse near the brooder houses. This anemometer has an integrating odometer that registers the number of miles of wind passing by over a period of time. The average wind velocity in miles per hour for any length of time can be found by dividing the number of miles of wind for the period by the length of the time period. This instrument was read twice daily.

V. RESULTS

A. Current Consumption

For convenience in analyzing the data collected the testing period of eight weeks, which lasted from March 28 to May 23, 1945, was divided into intervals of one week each. For these weekly periods the average outside air temperature and the average wind velocity were computed, and the current consumption of each house was determined; these values are listed in Table 4. The outside air temperature is the average of temperatures at three-hour intervals throughout each weekly period. The brooder temperatures are the averages of readings taken twice daily for the eight-week period. The total current consumptions for the three houses indicate that the performance of the houses in general was as one would expect, i.e., house H with the lowest U value required the least heat input, and house G with the highest U value required the greatest heat input of the three houses. It should be noted that these heat inputs are not in direct proportion to the U values of the houses. An explanation for this difference is given in the section of this thesis headed, "Discussion of Results."

TABLE 4. Current Consumptions for Three Houses

Weekly Period	Average Outside Air Temperature °F	Average Wind Velocity mi./hr.	Current Consumption, kwh House F	House G	House H
1st week	53	3.8	63	104	53
2nd "	55	7.9	62	96	53
3rd "	48	6.8	74	116	66
4th "	53	5.2	83	124	84
5th "	52	3.2	106	122	91
6th "	56	4.4	117	113	87
7th "	49	4.7	125	122	93
8th "	61	4.7	128	114	85
		Totals -	758	911	612

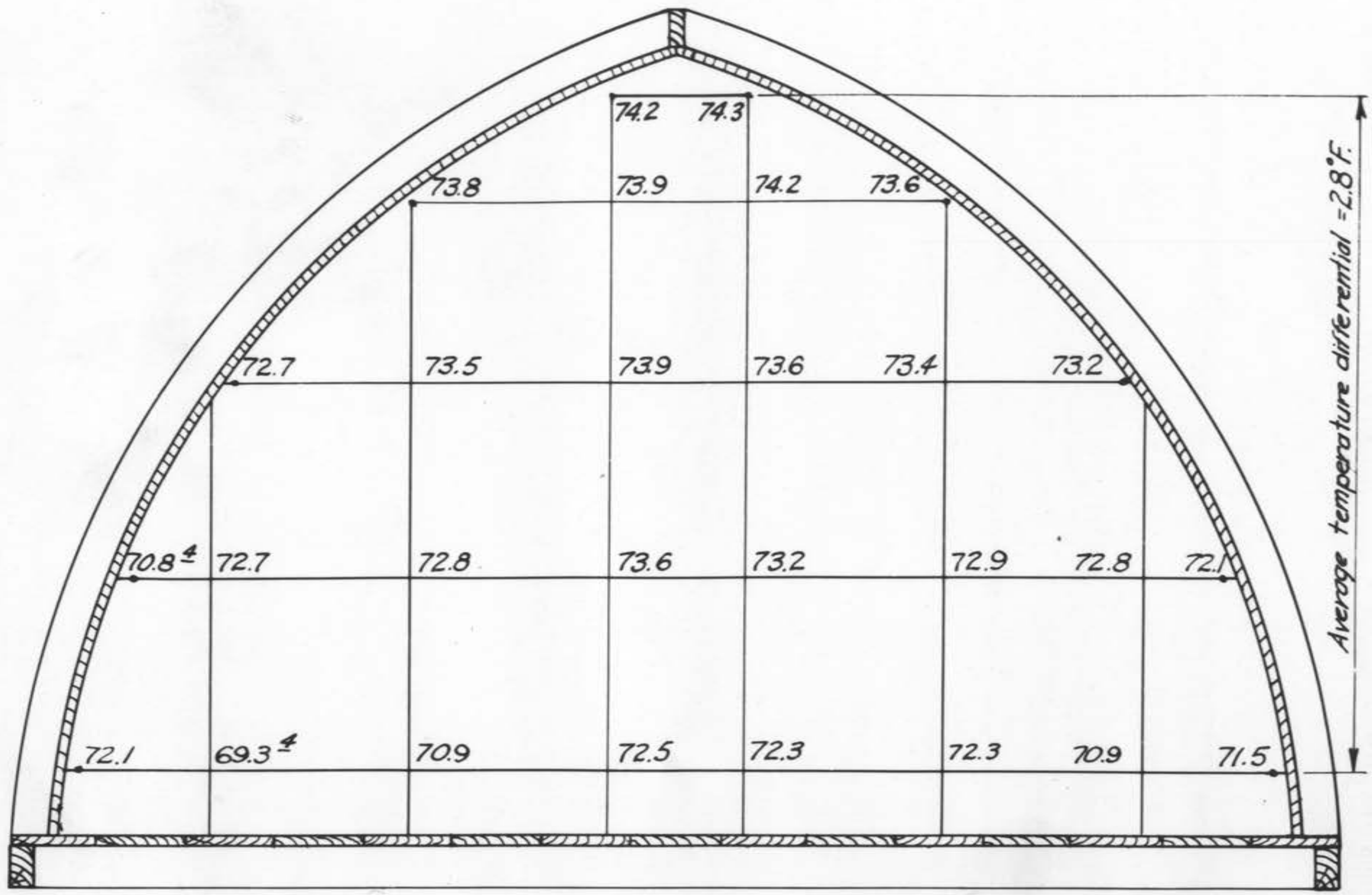
Average brooder temperature, House F - 81.5°F

Average brooder temperature, House G - 80.2°F

Average brooder temperature, House H - 81.5°F

B. Heat Distribution

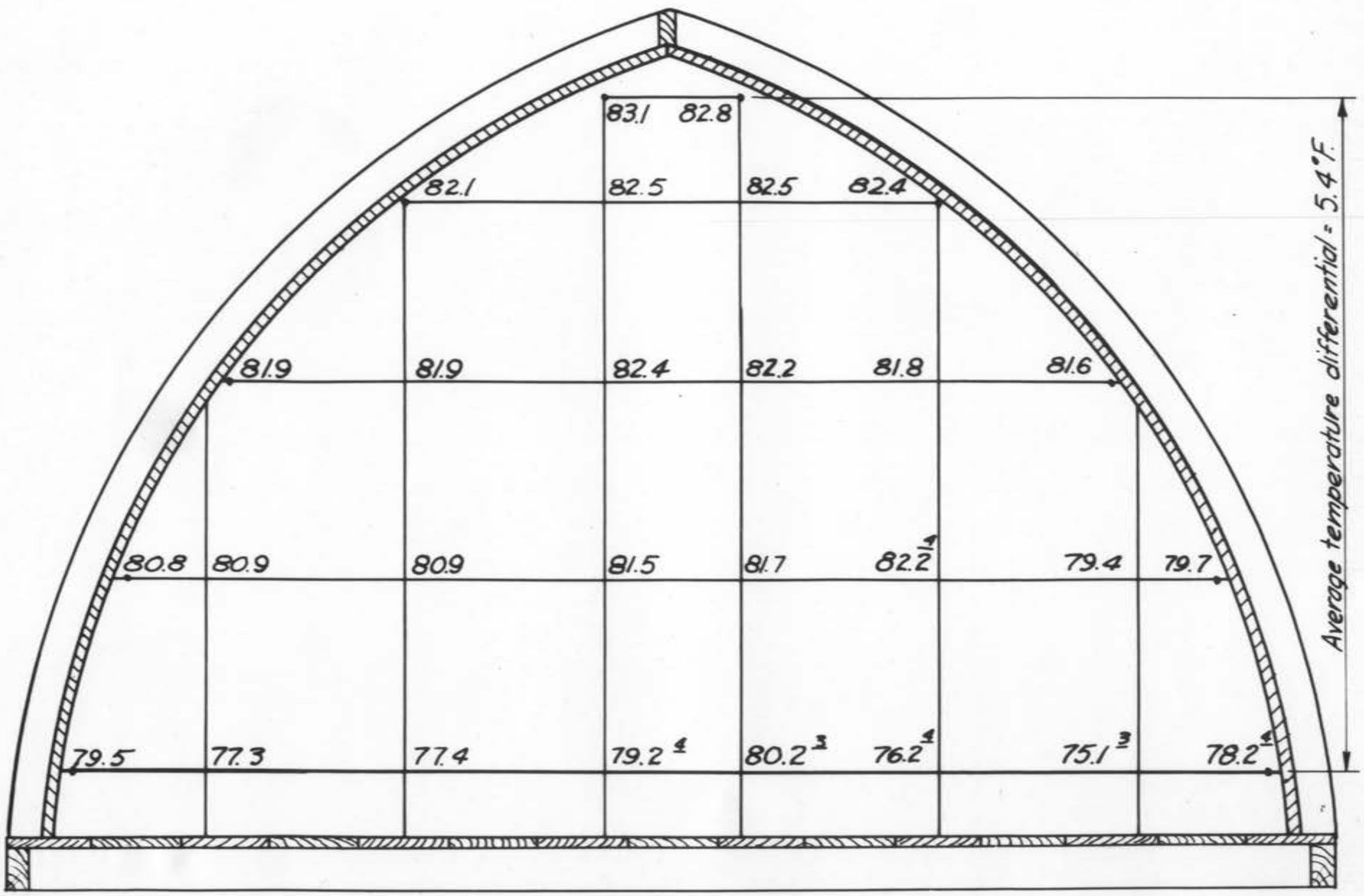
Fig. 27 through 32 show the distribution of heat in a vertical plane at the rear of each house and the distribution of heat in a horizontal plane eight inches above the floor in each house as determined by five sets of readings. These readings were taken during periods of mild weather and little wind. For the readings of temperatures in a vertical plane the average outside air temperature was $63^{o}F$, and for the readings of temperatures in a horizontal plane the average outside air temperature was $70^{o}F$. Less than five readings were obtained from some thermocouple junctions due to breakage of the wires which were continually being stepped on or jostled by either the operator or the chickens. As soon as a break was discovered it was repaired, but the breaks in some cases couldn't be discovered until after a set of readings had been taken. A set of readings for the three houses usually required about two hours for completion. The average temperature differential for the temperatures in a vertical plane in each house was calculated on the assumption that all points at the same height should be at the same temperature; accordingly, all temperatures at the six-inch height were averaged and subtracted from the average of the temperatures at the highest level read in the house. No attempt was made to determine a temperature differential for the temperatures in a



TEMPERATURES IN VERTICAL PLANE AT REAR OF HOUSE F

4 -Average of four readings

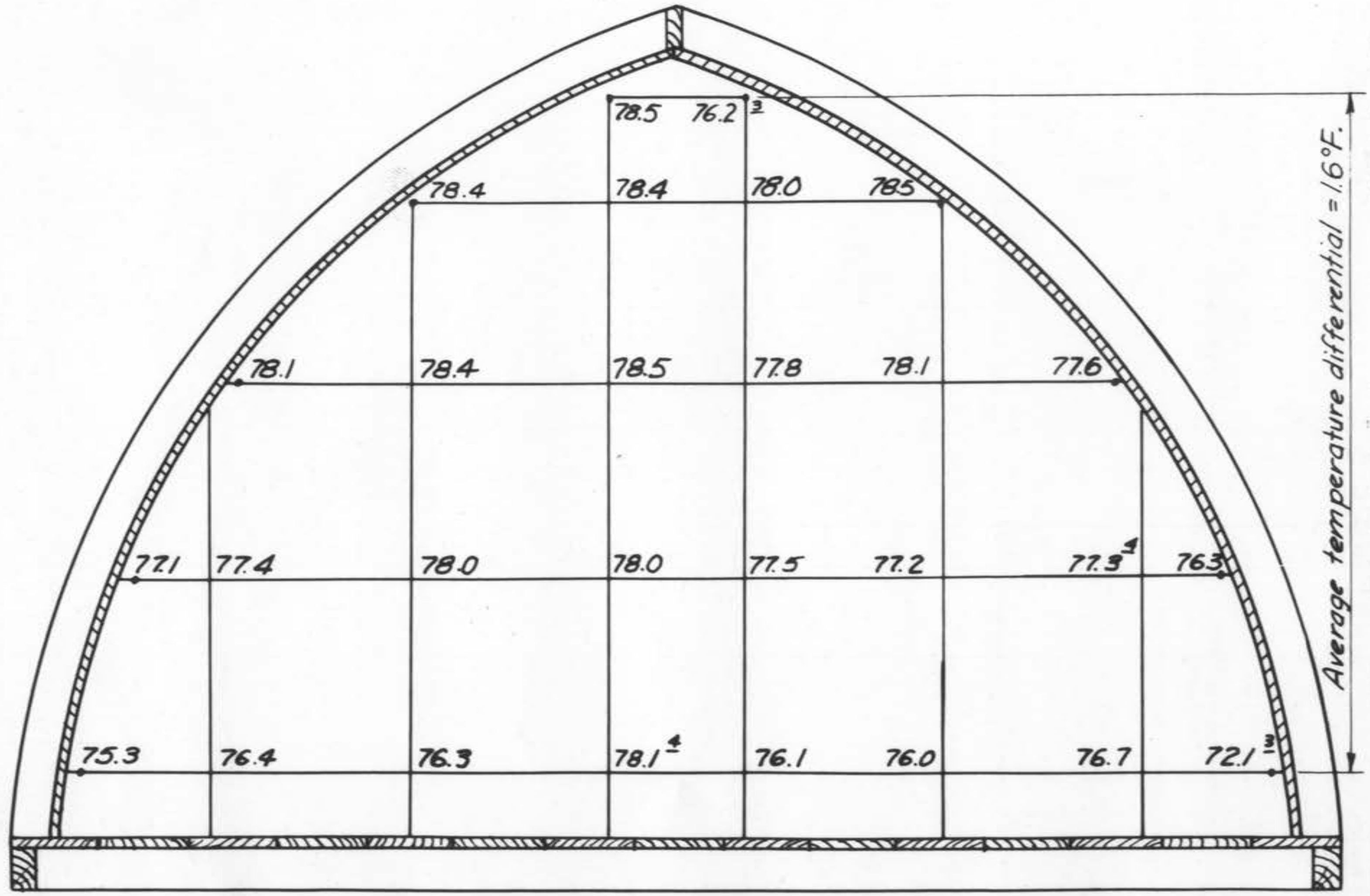
Fig. 27



TEMPERATURES IN VERTICAL PLANE AT REAR OF HOUSE G

3 - Average of three readings
4 - Average of four readings

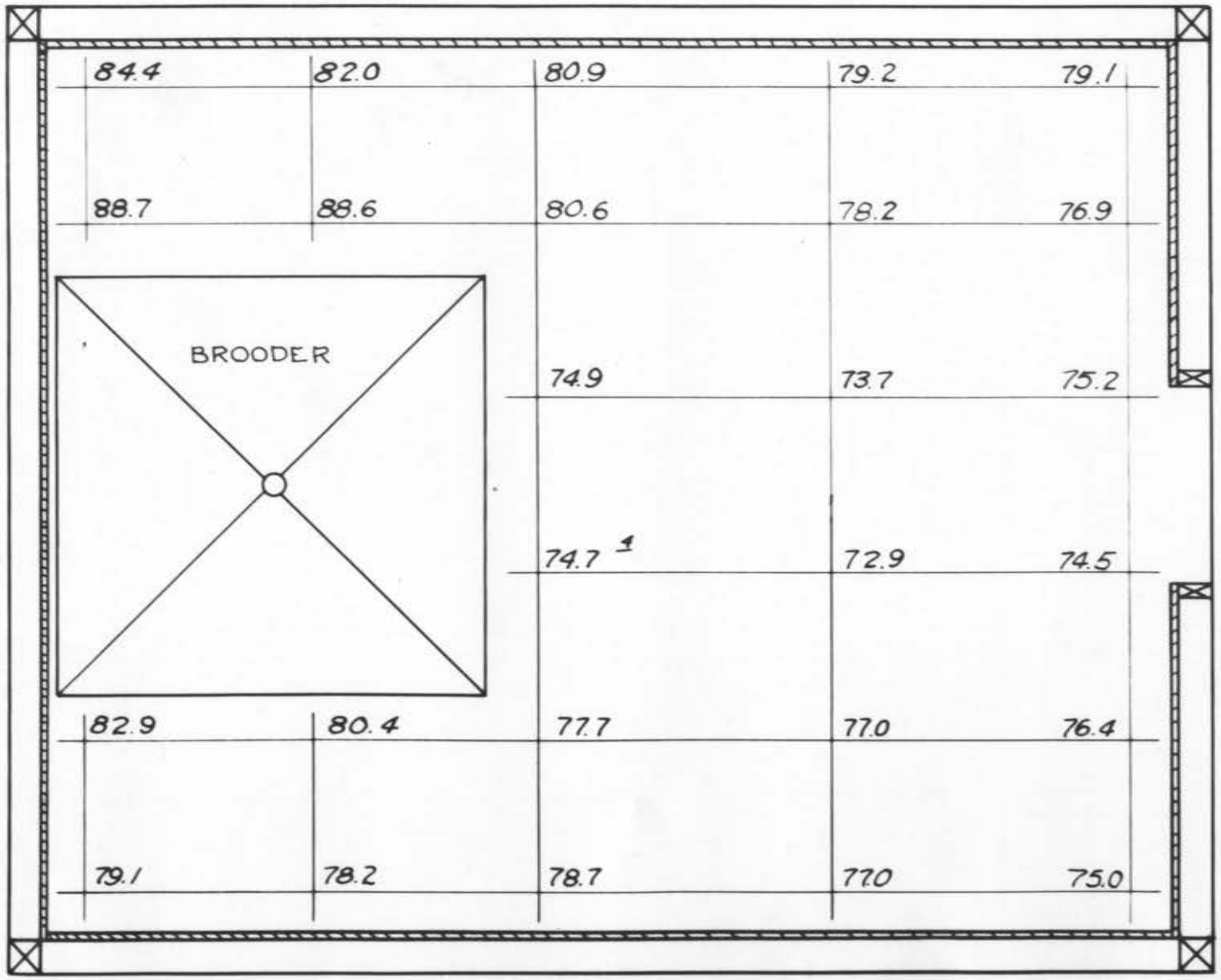
Fig. 28



TEMPERATURES IN VERTICAL PLANE AT REAR OF HOUSE H

3 - Average of three readings
4 - Average of four readings

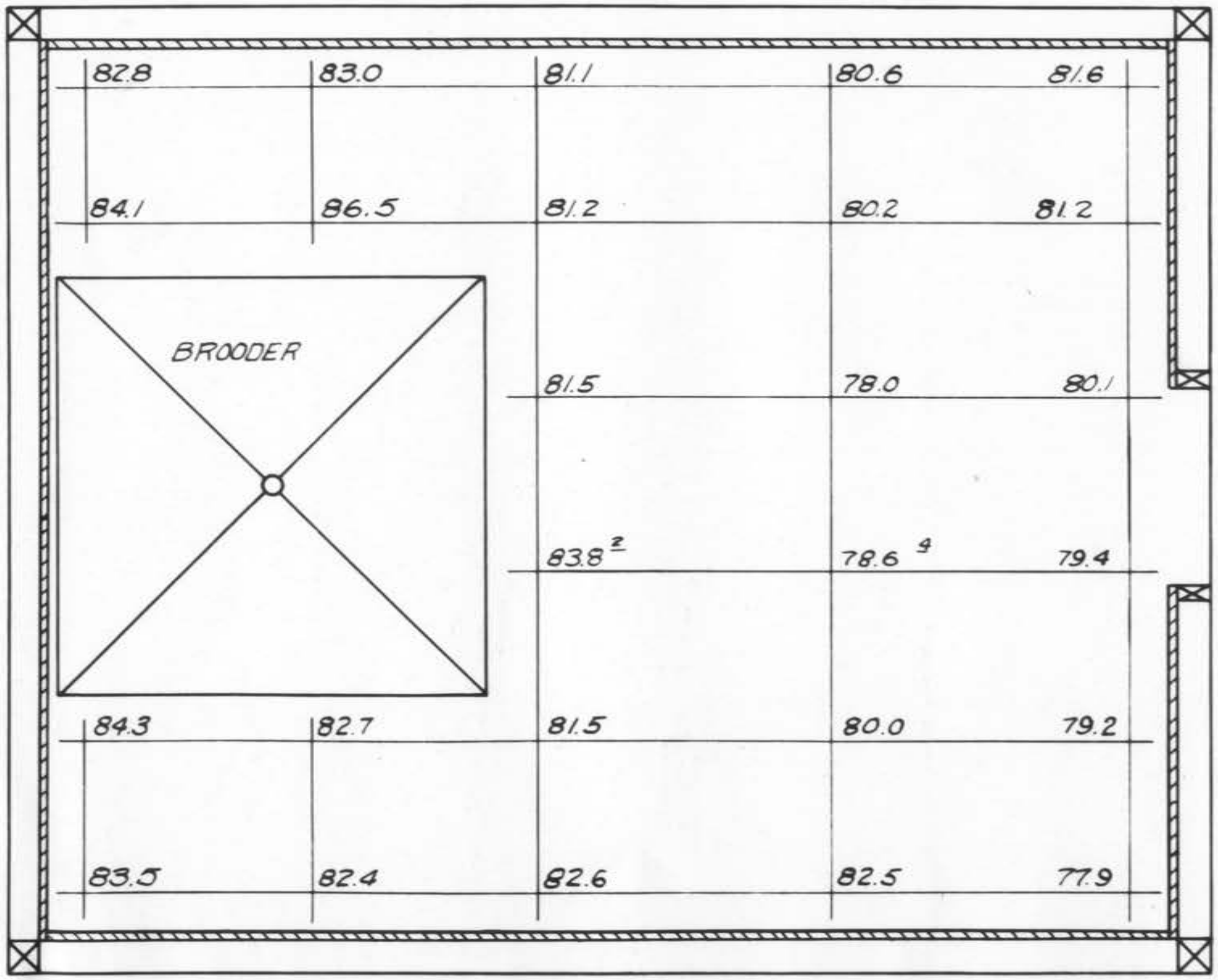
Fig. 29



TEMPERATURES IN HORIZONTAL PLANE EIGHT INCHES ABOVE FLOOR IN HOUSE F

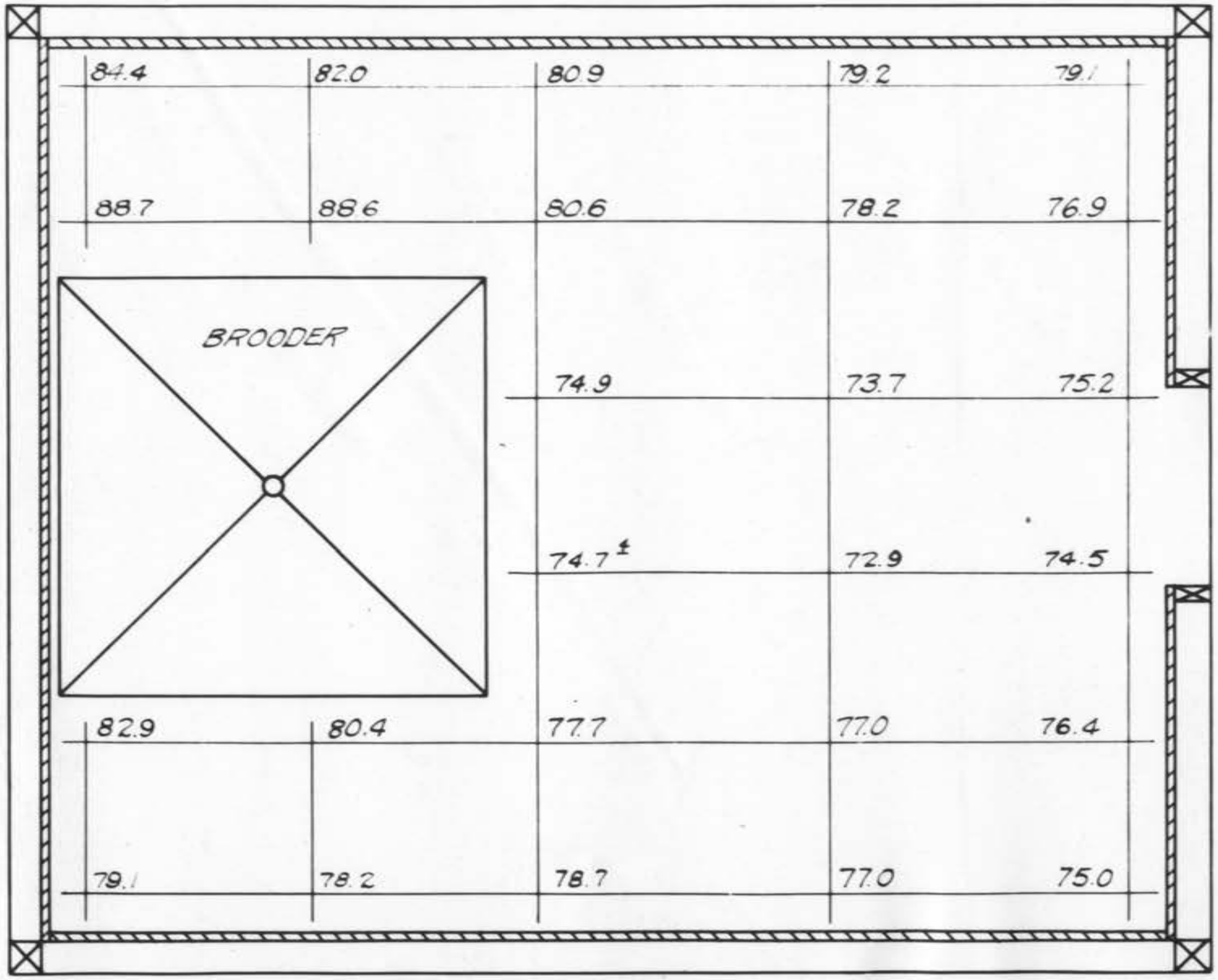
[1] - *Average of four readings*

Fig. 30



TEMPERATURES IN HORIZONTAL PLANE EIGHT INCHES ABOVE FLOOR IN HOUSE G
2 - Average of two readings
4 - Average of four readings

Fig. 31



TEMPERATURES IN HORIZONTAL PLANE EIGHT INCHES ABOVE FLOOR IN HOUSE H

± -Average of four readings

Fig. 32

horizontal plane, because of the extreme variation in these temperatures. For instance, if a chicken happened to be touching one of the thermocouple junctions, the temperature of that junction, as indicated by the potentiometer, would approach the body temperature of the chicken and thereby introduce a considerable error. Since the windows were partially open to aid in ventilation, convection currents were set up which had some effect on the temperatures at the thermocouple junctions. The temperatures of some of these junctions were observed to vary as much as six or eight degrees occasionally; so these readings of temperatures in a horizontal plane should not be considered very significant. There was a definite tendency, however, for those junctions nearest the walls and out of the regions of convection currents to be at higher temperatures than those junctions near the center of the house. There was very little variation observed in the temperature of any junction on a vertical frame during a reading. The reason for this is that the vertical frames were close to the rear walls of the houses and, therefore, mostly out of the path of convection currents. Furthermore, the readings of temperatures with the vertical frames were taken early in the eight-week period when the chicks were younger and the windows, which served as air intakes for the ventilation system, were not opened as widely as later.

VI. DISCUSSION OF RESULTS

A. Current Consumptions

While this investigation produced results of some significance, there were some serious faults that should be mentioned. First, the thermostats on the Makomb 700-watt electric brooders had such a wide range of temperatures (about 20°) that it was almost impossible to get the brooder temperatures equal in the three houses, and once these brooder temperatures were about equalized, the thermostats were allowed to remain at those settings for the remainder of the eight-week period. This procedure is obviously not in line with the recommendations of poultry experts, but in this case it was the only means of securing a basis for comparing the houses. In fig. 33 and 34 the current consumptions shown in table 4 for the three houses were plotted against the average outside air temperature and the average wind velocity for each weekly period. By the method of "least squares" straight lines were passed through these points. One would expect ordinarily to find the current consumptions decreasing with an increasing outside air temperature and increasing with an increasing wind velocity, but on both graphs the opposite is indicated. The reason for this non-correlation is the effect of ventilation on the current consumptions. In general, as the brooding

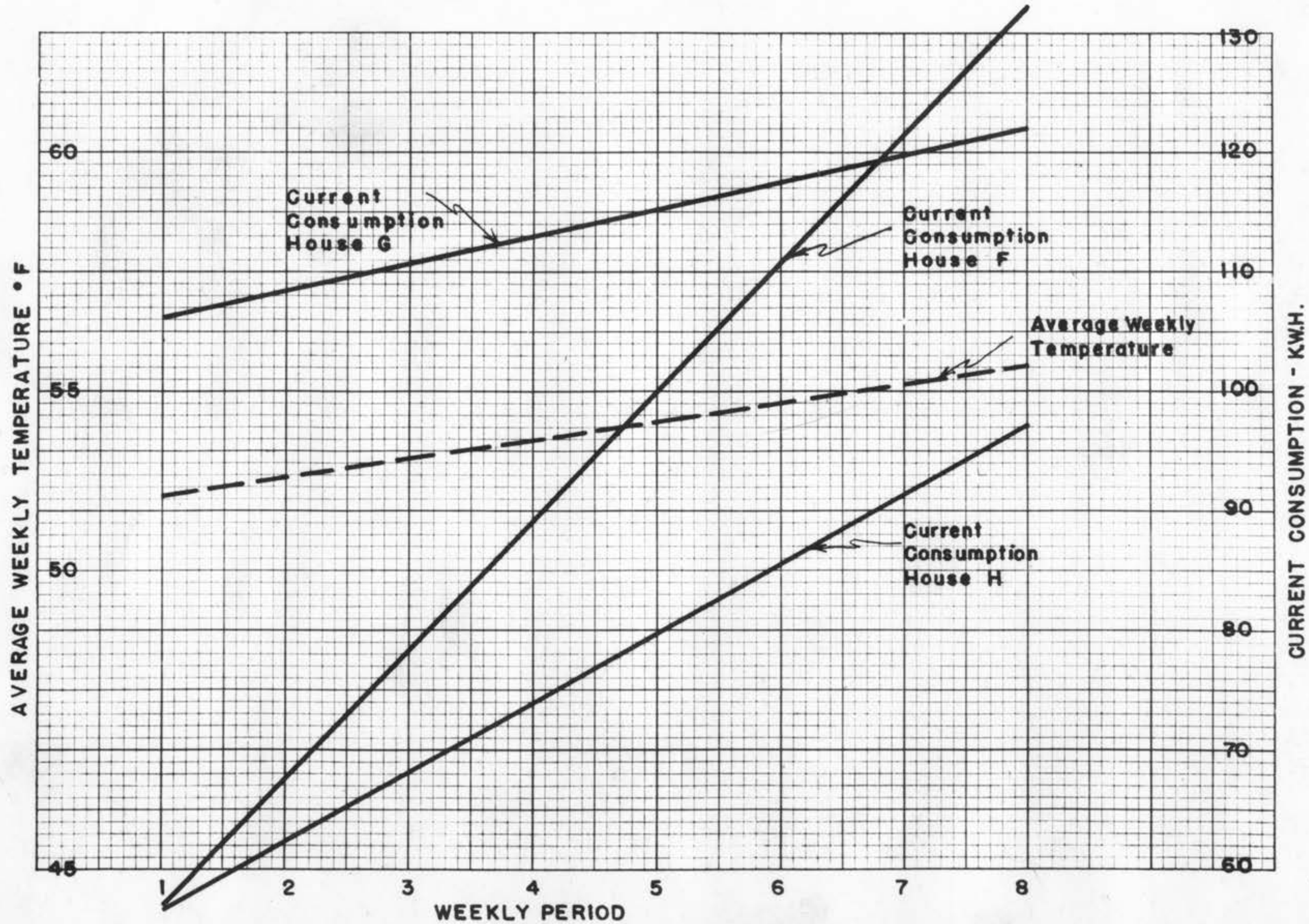


Fig. 33. Trends of outside air temperature and current consumptions of three houses

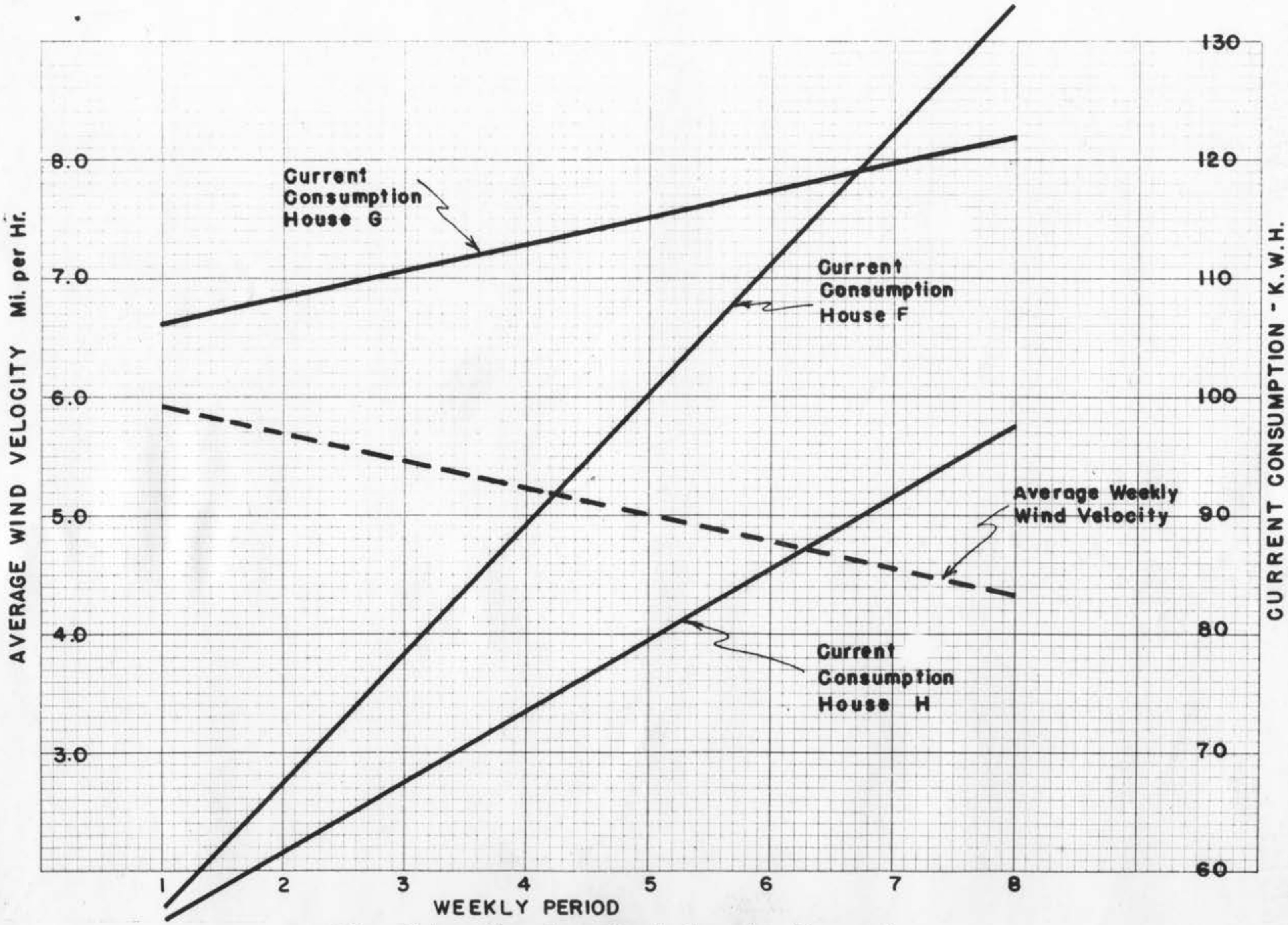


Fig. 34. Trends of wind velocity and current consumptions of three houses

season progressed, the operator opened the windows wider. If the average brooder temperature were 81° and the thermostat range were 20°, the heating element would begin to operate when the temperature dropped below 71° and would continue to operate until the temperature reached 91°. If the ventilation system were in operation, the cooler air from outside the house would enter and follow the path of the convection currents around the interior of the house, being warmed all the while. Then this warmed air would leave via the ceiling outlet, taking with it a quantity of heat. If there were enough air entering the house to remove heat by convection currents through the ceiling outlet as fast as the heating element could produce it, the brooder temperature would never rise to the required 91°; and, consequently, the heating element would be in continuous operation. Such conditions would certainly result in wastage of current, and it is feared that in this instance such was the case. Even if such were true, the houses were all ventilated to the same extent, and the difference in heat inputs for the three houses for the eight-week period should be due to their insulation qualities.

An examination of table 4 will show that the heat inputs for the three houses are more nearly equal for the last few weeks of the testing period than for the first few weeks. For the first two weeks the windows in the houses were kept closed, and the heat lost through ventilation was a minimum;

the heat loss for each house was more dependent on the insulation qualities of the house. For the last few weeks of the test the windows were open most of the time, and the majority of the heat lost was through ventilation. Since the ventilation was approximately the same for each house, the heat losses for the houses tended to become equal.

From fig. 33 and 34 it is apparent that the line representing the current consumption of house G has the least slope of any of the current consumption lines. This is explained by the fact that house G, because of its construction and insulation features, was subject to considerable infiltration and exfiltration of air which conducted heat away by air currents in the first few weeks just as if the ventilation system were operating. When the windows were opened later to permit ventilation there was no sudden upward surge in the current consumption of the house.

The total heat inputs for the three houses are not in proportion to their U values, because the heat produced by the poultry, which is no small factor, remains fairly constant, while the total heat supplied varies. There are three sources of heat in a poultry brooder house: solar heat, heat produced by the poultry, and artificial heat. The determination of the solar heat absorbed by these houses is very difficult because of the curved roof surfaces which make it very arduous to determine the angle of incidence of the sun's rays on each surface. To illustrate the fact that the heat from the brooder is not in proportion to the U value of a particular house, let us assume night conditions (to eliminate solar radiation), and the following equation will apply:

$$H_b + H_c = AU(t_i - t_d)T \qquad (12)$$

Where H_b = heat in Btu's supplied by the brooder

H_c = heat in Btu's supplied by the poultry

A = total area in sq. ft. transmitting heat

U = overall thermal transmittance coefficient in Btu's/hr./sq.ft./°F

t_i = inside air temperature °F

t_d = outside air temperature °F

T = time in hours

It can be seen from the above equation that the total heat supplied, which is the sum of H_b and H_c, should vary directly as the value of U, but the quantity H_b alone will not vary directly as the value of U. However, for an increase in U there will have to be an increase in H_b if H_c remains practically constant.

B. Temperature Recording Apparatus

There were some limitations to the use of the temperature recording apparatus shown in fig. 26. Obviously the equipment could not be used during any precipitation, and because the

Leeds and Northrup potentiometer contains a standard Weston cell it cannot be used when the temperature is below freezing. When a strong wind was blowing it was impossible to obtain an accurate reading with the potentiometer, because the gusts of air blowing across the clothespin leads on the instrument panel created a separate thermoelectric effect. Thus, the readings of temperatures in vertical and horizontal planes in the houses could only be made in mild weather with little wind.

C. Weights of Brooder Houses

At the end of the test period the houses were weighed. The weights of the three houses are:

House F - 1569 lbs.

House G - 1401 lbs.

House H - 1722 lbs.

The differences in these weights are due to the different kinds of insulation used in the houses, since the houses are identical in all other respects. It is evident that the weight of the loose-fill cornstalk insulation used in house H is in the neighborhood of 321 lbs., because houses G and H are identical except for the cornstalk insulation in house H. It is possible that the weights of houses F and H might change slightly due to absorption of moisture by the Celotex and the ground cornstalks. The weight of a Colony brooder house is important, because it is an indication of the movability of the house.

There should be no concern over the movability of these sheet steel brooder houses, because the weight of a conventional shed-roof brooder house is approximately 2000 lbs.

D. Costs of Materials

The costs of the materials used in the three houses were:

House F - $114.55

House G - $109.46

House H - $124.88

Because of the difficulty of arriving at a price for the ground cornstalks, the cost shown for house H does not include this item. The cost for house H does include the price of the creosote used in treating the cornstalks, $17.25.

In order to supply an answer to the question, "Does it pay to insulate?", let us compare houses F and H to house G. From the figures above it is evident that house F cost $5.09 more than house G, and house H cost $15.42 more. During the first two weeks of the test the houses were not ventilated, and the current consumptions of the houses were influenced mainly by their insulation. From table 4, house F used 75 kwh less current than house G for the first two weeks, and house H used 94 kwh less than house G. If the cost of electricity should be $.05 a kilowatt-hour, the saving in electricity would be $1.88 per week for house F and $2.35 a week for house H. At these rates of saving the extra insulation would be paid for in about three weeks for house F and in about six and one-half weeks for house H. It should be realized that these figures are only relative, but they do indicate the financial benefits to be obtained from insulation.

E. Suggestions for Future Study

The main weaknesses in this investigation were the lack of complete control over the brooder temperatures and the lack of control over the ventilation of the houses. In order to compare the current consumptions of brooder houses it is essential that the brooder in each house be thermostatically-regulated and the brooders in all of the houses be kept at the same operating temperature. It is much easier to maintain equal temperatures under several brooder hovers if the temperature differential of the thermostats is only a few degrees. Then the brooder temperatures can be gradually decreased as the chicks grow older and still all brooders can be operating at the same temperatures. In order to know how much heat is lost through ventilation it would be desirable to know the temperature, humidity, and velocity of air passing through the ventilation flues of the brooder houses. If a recording anemometer and a hygro-thermograph could be installed in the ventilation flue of a house, these quantities could be determined. To determine the effect of ventilating the air space between the rafters of houses F and G, interior temperatures should be measured with a system of thermocouples similar to that used in this investigation and compared with temperatures in house H. It would be desirable to then compare the interior temperatures in all three of these houses with interior temperatures in a conventional-type brooder house that has cross-ventilation.

VII. CONCLUSIONS

1. Sheet steel applied horizontally in a direction normal to that of the rafters eliminates the necessity for having diagonal bracing or nailing girts between rafters, and the rafter spacing may be as much as four and one-half feet.
2. Bulging or spreading of the outside corrugated steel sheets at the laps can be prevented by the use of #6 sheet metal screws spaced about one foot apart.
3. By using corrugated end wall flashing crimped as shown in fig. 18 and 22 the openings at the ends of the horizontal corrugated steel sheets can be effectively closed and a pleasing appearance obtained.
4. In the order of their thermal performance the houses rank as follows: house H first, house F second, and house G third.
5. For the first two weeks of the test when the windows were not opened for ventilation, houses F and H were markedly superior in performance to house G; but during the last few weeks of the test when all of the houses were ventilated extensively, the current consumption for the houses tended to become equal. This indicates that most of the heat input for the houses during the latter

part of the test period was lost through ventilation.

6. From table 4 and fig. 33 and 34 it is apparent that ventilation had the least effect on house G, because there was no marked change in its current consumption from week to week, i.e., the slope of the current consumption line is less than those of the other houses. Because of the nature of its construction (two sheets of steel with an air space between) it is possible for air to pass from inside the house to outside regardless of whether or not the windows are open.
7. For reasons expressed in conclusion number six, caulking of the cracks would benefit house G more than either of the other two houses, because infiltration is reduced to a minimum in houses F and H.
8. The average differences in temperatures at the rear of the houses between points near the floors and points near the ceilings (as shown in fig. 27,28, and 29) were: 1.6^{o}F for house H, 2.8^{o}F for house F, and 5.4^{o}F for house G.
9. During periods when the average inside air temperatures of the houses were higher than the outside air temperature, convection currents tended to lower the temperatures of points in the centers of the houses. The temperatures of points near the walls were higher, thus indicating that they were out of the paths of air currents.

10. The actual cost of the materials used in the three houses were:

House F - $114.55

House G - $109.46

House H - $124.88

11. The weights of the houses at the end of the test period were:

House F - 1569 lbs.

House G - 1401 lbs.

House H - 1722 lbs.

12. Under conditions of normal operation, greater financial returns can be expected from houses F and H early in the brooding season, because it is during this cooler weather that ventilation is reduced to the point where it is used only to remove excess moisture.

VIII. SUMMARY

From previous work on project 562 of the Iowa Agricultural Experiment Station data have been accumulated that are related to heat flow through roof sections covered with sheet steel. From the eight roof sections comprising the original test house, three were selected for further study. It was decided to incorporate the insulation features of these three roof sections into poultry brooder houses and then study the performance of these houses under actual operating conditions.

A gothic-roof brooder house was designed, and three of the houses were constructed. The houses were identical except for their insulation features.

On March 28, 1945, two hundred day-old white leghorn chicks were placed in each house. The houses were given the same treatment for an eight-week testing period.

Readings were taken twice daily of the brooder thermometers and the watt-hour meters, which were used to record current consumptions. Records were also kept of the outside air temperatures and wind velocities.

By using a system of thermocouples attached to light wooden frames, readings were taken of temperatures in a vertical plane six inches from the rear wall of each house and in a horizontal plane eight inches above the floor in each house.

From the data collected on current consumptions and interior temperatures the houses were then compared as to their performance.

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