THE PHYSIOLOGICAL RESPONSE OF GROWING-FATTENING SWINE TO DIFFERENT HOUSING ENVIRONMENTS

by

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AN ABSTRACT

Submitted to the School of Graduate Studies of Michigan State University of Agriculture and Applied Science in partial fulfillment of the requirements for the degree of

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The physiological response of growing-fattening swine to different housing environments was studied in a series of seven trials conducted alternately in winter and summer. The first trial was conducted in the winter of 1952-1953, and the final trial in the winter of 1955-1956.

The housing environments were varied throughout the study. In the first trial, the performance of growing-fattening swine in different wings of a central swine barn was compared. In the succeeding trials, the performance of the swine in a conventional type of growing-fattening house was compared with that of swine confined to from one to four experimental test houses. The test houses used in the various trials included a house with double-pane windows and a southern exposure; a house with double-pane windows, and an eastern exposure; a house with one-half as much double-pane window area as the other test house; a house with single-pane windows; a house with no windows; an air-conditioned house; and a heated house.

The hogs were placed on trial at weights ranging from an average of 23.5 to 100 pounds, and removed at an average weight of 200 pounds. In the different trials, 6 to 10 animals were placed in each lot. The hogs were self-fed identical rations, and water was supplied _ad libitum_. The hogs were weighed at two-week intervals.

An automatic potentiometer was used to record hourly wet and dry bulb temperatures in the houses. Ventilation records were obtained by the use of operational recorders.

Random determinations were made of rectal temperature, respiration rate, and pulse rate in the summer of 1954; and of rectal temperature and respiration rate in the summer of 1955.

Data obtained from the study indicated that improved housing environments are conducive to higher rates of gain and better feed efficiencies. The use of supplemental temperature controls did not significantly affect the performance of the swine, but shade and moisture did. Increases in the ambient temperature were accompanied by increases in rectal temperature and respiration rate and decreases in pulse rate with varying zones of thermal neutrality for each response.

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INTRODUCTION

For generations livestock men have recognized the importance of environment in the production of all classes of hogs. However, the question of what conditions are most suitable has long been a controversial one. Up to the present time, most of the management practices employed to improve the environmental surroundings of swine are based on exchanges of experiences rather than research findings.

With continuing advancements in the fields of nutrition, breeding and disease control, and the subsequent increases in the amount and efficiency of production, the effects of environmental conditions on swine production have become more apparent. Consequently, more experiments are being conducted in which environmental influences are studied under controlled conditions.

The objective of the research reported here was to obtain data which would be useful in the evaluation of designs for housing and shelter for market hogs, and which would suggest improved management practices contributing to increases in the rate and efficiency of hog gains.

REVIEW OF LITERATURE

I. EFFECTS OF AMBIENT TEMPERATURE ON PRODUCTIVE PERFORMANCES

Shelton (1883) reported as early as 1883 that it required about 25 per cent more feed in winter for pigs kept in the open without protection, than for similar pigs housed in the basement of a warm barn.

In Ottawa, Canada, it cost 25 per cent more to house brood sows during the winter months in small single brood cabins than in the regular brood sow house (Grisdale, 1904). In a similar test with young pigs, those fed inside gained more rapidly, and the feed required for their gains was lower.

In the work of Heitman, et al. (1949), the effect of increasing air temperature on feed consumption was illustrated. Feed consumption decreased as the air temperature increased from 40 to 100 degrees F., and it appeared this decrease was more rapid at higher temperatures.

Average daily gain also varied with the changes in air temperature. Hogs weighing 166 to 260 pounds gained most rapidly in the neighborhood of 60 degrees F., while the lighter weight animals weighing 70 to 144 pounds gained most rapidly at approximately 75 degrees F.

The amount of feed required to produce 100 pounds of gain was at a minimum when the rate of gain was at a maximum. Both below and above the temperatures of approximately 60 degrees F. for the heavier weight pigs, and about 75 degrees F. for the lighter pigs, utilization of feed declined.

Water consumption was variable. In the three trials conducted with hogs weighing over 150 pounds, water consumption declined with increasing air temperatures in a manner similar to feed consumption. In the trial with light weight pigs, water consumption declined as the air temperature increased from 40 to 90 degrees F. However, from 90 to 115 degrees F., water consumption increased.

Similar observations have been made of the effect of temperature in dairy animals. A study of the data compiled by Regan and Richardson (1939) fails to substantiate the general belief that the water consumption of dairy cows is substantially increased in hot weather. Uniform constant values were obtained for temperatures ranging from 40 to 80 degrees F. The upper limit of heat regulation for producing Holstein cows is about 80 degrees F. when the room temperature is maintained above this point for more than 24 hours, the animals tend to be hyperthermic, coincident with a reduction of feed and water intake and the milk "flow". Instead of an increase, there is an actual decrease in the amount of water drunk at higher temperatures.

Heitman, et al. (1951) placed pregnant sows in a psychrometric chamber when the body weights ranged from 300 to 560 pounds. The temperature in the chamber varied from 70 degrees F., to the maximum the sows could withstand. During the period when the sows were in the experimental chamber, there was a general weight loss in all cases. At an average ambient temperature of about 88 degrees F., the respiratory rate showed a marked increase. At about 94 degrees F., on the average, the body temperature was markedly increased.

Part, if not all, of the weight loss probably was due to a lowered feed and water consumption which has been found under these conditions where ambient temperature is increased.

Results obtained from the sows that farrowed, as well as the one that died of heat prostration, indicate that in swine a high environmental temperature (and subsequent high body temperature) apparently will kill the dam before it will cause death of the litter and subsequent abortion.

In a review on pig housing, Inglis and Robertson (1949) state that they cannot recommend any definite optimum temperature for a house for baby pigs. They give a short account of the optimum temperature for a farrowing house suggested by various workers, the suggestions varying from 50 to 80 degrees F. From the results of the experiments of the Rowett Research Institute, it seems that the type of flooring provided for the pigs to lie on is of great importance, and if this is well insulated, good pigs can be reared in a house with an average air temperature of only 45 degrees F., although a higher temperature than this would be safer. It also seems clear that pigs kept under these conditions do better with an outdoor run.

In the absence of a specially designed chamber, McLagan and Thomas (1950) thought that it was best to estimate the "effective temperature" of the pigs' environment, and to study the effect of this temperature on the performance of baby pigs. The effective temperature of an environment is the temperature of still, saturated air, in which an equivalent sensation of warmth was experienced by human subjects.

The effective temperature was tested as a means of comparing different types of housing for pigs. Average and total weaning weights of litters showed that a hut with an outside run produced the best performances, a hut with an inside run produced the second best, and an open pen was the poorest. The differences in the effective temperature were not large.

The experiments described in the paper by McLagan and Thomas (1950) confirm the observations by Howie (1949), that it is impossible to rear good pigs in an open pen in a large, cold, and draughty building. In three experiments the pigs under this condition weaned at poor weights and were in a state of ill-health. In one case where the pigs were kept on after weaning in the same pen until they were 16 weeks of age, they showed no sign of catching up on pigs from the outside hut. That is what would be expected from observations made over a period of years; that the pigs from the open pen took months to become healthy, even if transferred after weaning to a warm environment--sometimes they never attained a reasonable condition.

McLagan and Thomas (1950) figures for food consumption confirm the previous observation that the pigs in the hut with an outdoor run had a better appetite before weaning. The figures seem to indicate that appetite decreases with a decrease in the average effective temperature of the environment, quite apart from the possible influence of an outdoor run.

It seems clear from the results, however, that it was possible to rear good pigs in a hut where the average effective temperature was as low as 44 degrees F., with a range of from 33 to 55 degrees F., and an average daily variation of 12 degrees F., where a warm bed was provided. From the results of the pigs in an open pen with a wooden sleeping platform in a second experiment, it seemed that good pigs could be reared in a piggery with an average effective temperature of only 38 degrees F., with a range from 26 to 50.5 degrees F., and an average daily variation of 10 degrees F., where a dry insulated bed was provided. On an uninsulated floor, however, pigs under the same, or even higher, effective temperatures did not thrive. In the same experiment, a litter of pigs did not thrive in the hut with an indoor run where the temperature was much the same, except that on one occasion, the effective temperature was as low as 22 degrees F.

From other figures, it is indicated that it is possible for baby pigs to be exposed to effective temperatures as low as 33 degrees F., during the first 48 hours and still grow well. This is related to the work by Newland (1952).

Horvath, and co-workers (1948), reported some observations on the survival time and body temperatures of various adult animals at an ambient temperature of 35 degrees C.

The data indicate that the adaptability to low environmental temperature varies considerably among species, as well as within species.

The observations are in accord with Giaja (1933), who found the lowest temperature at which the animal can maintain its body temperature for one hour to be: for the pigeon, -85 degrees C; for the chicken, -50 degrees C; for the rabbit, -45 degrees C; and for the white rat, -25 degrees C.

Giaja's experiment, in which environmental temperature was the variable, placed species in the same order in regard to the degree of their resistance to cold.

Studies conducted by Dice (1935), showed that the dairy cow withstands long periods of exposure to temperatures as low as zero degrees F., with little loss, either in production, or in the efficiency of food utilization.

Rhoad (1936) found that temperatures in excess of 85 degrees F. have, however, a marked detrimental effect on the milk production of the dairy cow.

In two experiments conducted with dairy bulls, Casady and co-workers (1956) found that gains in weight were maintained when a chamber temperature was 85 degrees F., or below, in both experiments; but daily losses occurred during exposure to 90 and 95 degrees F.

II. EFFECTS OF AMBIENT TEMPERATURE ON PHYSIOLOGICAL RESPONSES

It is quite evident that the heat regulating mechanism in the hog is a very poor one. Schroeder and Mohler (1906) call attention to the fact that the hog is an animal that is ordinarily incased in a thick layer of fat, which is a poor conductor of heat and in which the circulation of blood is very meager.

Palmer (1917) stated that there are several factors which can possibly account for the wide variations in the temperature of normal hogs: (1) the condition of the animal--that is, the amount of fat; and (2) the temperature of the atmosphere and the percentage of humidity. A fat hog would have a much higher body temperature on a hot, humid day than a lean hog, and even on a cool day, slight variation may occur. Schroeder and Mohler (1906) concluded that fat hogs have a higher temperature than lean ones, and that a higher temperature induced by exercise or some temporary cause persists longer in fat than in lean hogs.

Since environment can cause a marked variation in the temperature of man, with his excellent heat-regulating mechanism, we would expect that similar conditions would cause a greater variation in the case of the pig, with a poor heat regulating mechanism.

Dukes (1947), states that the average body temperature of the pig is 102.5 degrees F.

Critical Temperature in the Pig

Capstick and Wood (1922), studied the basal metabolism of the pig using a large calorimeter. They found the critical temperature of a one year old hog to be 21 degrees C., but this temperature was that of the water entering the calorimeter and may not have been the real average temperature of the hog's surroundings.

This conclusion agrees very well with Tangl (1912), who states that he found the critical temperature to be between 20 and 23 degrees C.

Capstick and Wood (1922) also found that the actual metabolism at the critical temperature (21 degrees C.) to be 1.50 calories per minute for a 300 pound hog, or 2160 calories per day.

The values of the basal metabolism at different temperatures have a special interest for they make it possible to calculate the maintenance ration at various temperatures. From the data presented, it was shown that the maintenance ration at zero degrees C. is more than double that at 22 degrees C., and both these temperatures are not infrequently met with on farms in this country.

Deighton (1929) has obtained indications of a much lower critical temperature (16 degrees C.) in a middle White pig than that measured by Capstick and Wood. Since the pig used in the latter study varied in weight from about 200 to 400 pounds during the period of observation, the calculated critical temperatures for pigs within this weight range may be more significant than those calculated for lighter or heavier pigs.

Effect of Ambient Temperature on Body Temperatures, Respiration Rates, and Pulse Rates

Heitman and co-workers (1949) have presented data to show the effect of ambient temperature on physiological responses in the pig. As the air temperature increased from 40 degrees F., the body temperature and respiration rates increased. The results of two trials illustrate the effect of difference in body weight on the reaction of the pigs; pigs weighing under 150 pounds were more comfortable at a given high temperature than the pigs weighing more than 150 pounds.

The lighter weight animals could be kept at a temperature of approximately 115 degrees F., whereas it was not possible to take the heavier hogs much beyond 100 degrees F.

Pulse rates decreased with increased room temperature.

Kelly *et al.* (1948), reported that the surface temperature of light-weight hogs is considerably higher than that of the heavy at lower environmental temperatures, but the difference between the two becomes steadily less as the air temperature is increased. No heat can be lost by convection or radiation, where the surface and the environmental temperatures are equal. The regression equation indicates that this point for the heavy hogs is 102 degrees F., and for the light hogs, 104 degrees F. Above these temperatures, heat will flow from the environment into the hog.

The lowering of surface temperature with increase in hog weight is considerable and was shown by Kelly *et al.* (1948), to have a marked effect on radiation and convection heat losses.

The average temperature responses of 25 baby pigs under barn conditions (environmental temperatures between 55 and 75 degrees F.), as studied by Newland *et al.* (1952), and Wallach *et al.* (1948), showed that the body temperature of a new-born pig drops by 3 to 12 degrees F. during the first hour after birth, with the average being about 4 degrees F.

Newland *et al.* (1952) also showed that the average body temperature-drop of 16 pigs with an average birth weight of

2.5 pounds, born in a warm room (between 55 and 75 degrees F.), was 3 degrees F., during the first half-hour after birth, the average at this age being 100 degrees F. At one hour old, they showed a gradual increase to 100.2 degrees. By the time the pigs were 48 hours old, the average body temperature was 102 degrees F., at 72 hours old, it was 102.2 degrees F., and at 96 hours old, it had reached 102.4 degrees F., or almost back to normal.

The body temperature of the 19 baby pigs with an average birth weight of 2.4 pounds, born and raised in the cold (between 25 and 35 degrees F.), dropped lower during the first half-hour of life, and the return to normal was at a slower rate than those born in the warm room. The average drop for this group was 7.3 degrees F., at one-half hour, down to a temperature of 95.7 degrees F. However, like those in the warm room, they showed a definite climb back toward normal. At one hour, the average was 96.2 degrees F., in 48 hours, 100.7 degrees F., in 72 hours, 101.4 degrees F., and in 96 hours, 101.6 degrees F.

At ten days old, the pigs raised in the warm room showed an average body temperature of 102.7 degrees F., while those raised in the cold averaged 102.1 degrees F.

The results of a study by Regan and Richardson (1938), show that as the room temperature increases, there is a rise in the respiration rate, and a fall in the pulse rate; the rectal temperature, however, remained constant at 101 degrees F., until a room temperature of 70 degrees F. was reached; after which, it also rises. The normal rectal temperature was between 101 and 102 degrees F.

Casady and co-workers (1956) conducted two experiments to determine the effect of air temperature on the physiological responses of dairy bulls. The results showed that, in the first experiment, increases in respiratory rate, pulse rate, skin temperature, and water consumption, preceded those of rectal temperatures. Pulse rate and water consumption showed a marked rise at chamber temperatures of 70 degrees F., and again at 95 degrees F., while respiratory rates showed marked increases at 70, 80, 90, and 95 degrees F. Rectal temperatures and rump skin temperatures, on the other hand, did not show marked responses to increased chamber temperature, until the latter reached 80 degrees F., above which there was a steady rise, with increasing ambient temperature through 95 degrees F.

During the second experiment, there was no marked response in either rectal temperature and respiration rate, until the chamber temperature reached 95 degrees F. This delay, or absence, of responses in rectal temperature may have been a reflection of the increased age of the bulls, since there is evidence that thermoregulation in young animals is not as efficient as in the adult. The second experimental animals were 3 years old, and 14 months older than the first.

Field studies by Johnson and Branton (1952), have indicated significant correlations between body temperature and ambient temperature of dairy animals, only when the ambient temperature was within 40 to 60 degrees F., and 70 to 80 degree F. intervals. Respiration rate was significantly correlated with ambient temperature and humidity, except maximum temperature within the 80 to 85 degree F., and 85 to 90 degree F., intervals. Pulse rate was significantly correlated with mean daily temperature within the 85 to 90 degree F. interval.

Later investigations by Johnson and Branton (1953), and Johnston _et al_. (1954), showed that only respiration rate was consistently related to climatic conditions, with absolute humidity and mean environmental temperature being most highly correlated with respiratory responses. Changes in respiratory rate, flank skin temperature and scrotal length on exposure to heat stress did not bear much relationship to "heat tolerance".

In addition, McDowell _et al_. (1953), in chamber studies on respiratory activity as an index of heat tolerance, concluded that it was not significantly correlated with rectal temperature under the conditions of their experiment. Similar conclusions are drawn by Blakley and Findlay (1955a, 1955b), from results of chamber experiments with young Ayrshire bulls.

III. EFFECTS OF RELATIVE HUMIDITY

In studies by Heitman *et al.* (1949), experiments, in which humidity was the variable, were run only at 90 and 96 degrees F. At 90 degrees F., the data indicated that there was not much difference in the response of hogs weighing over 200 pounds to relative humidities of 30 to 94 per cent, except that the respiratory rate is increased at the higher humidity. At 96 degrees F., and relative humidity of 30 per cent, swine weighing over 200 pounds lost weight, but survived for long periods. When the relative humidity was increased to 94 per cent, they were immediately increasingly distressed. Upon decreasing the relative humidity to 58 per cent, the respiratory rate and body temperature were back to that which existed at the 30 per cent level.

IV. EFFECTS OF EXPOSURE TO SUN

Experiments by Palmer (1917) clearly demonstrated the extreme variability in the temperature of pigs from handling and the direct rays of the sun. He found that the handling of, or working among, a group of pigs for only a few minutes can cause a marked increase in their body temperatures. Although it was not intended to see how high the temperature would go, the highest temperature after exercise was noted in a red female weighing 108 pounds. The animal was in very good condition. Before exercise, the sow showed a temperature of

102.4 degrees F. After exercising for one-half hour at a slow gait, the temperature was increased to 109.4 degrees F. If allowed to remain quiet, the temperature of the pig would return to normal in one-half to one hour.

Merely being in the direct rays of the sun caused a marked increase in the body temperature; the increase varying with the atmospheric pressure and the relative humidity. On a hot day, a normal pig exposed to the direct rays of the sun may show a temperature as high as 106 to 108 degrees F.

Tidwell and Fletcher (1951) presented data to indicate that there was no correlation between air temperature or relative humidity, and the initial body temperature of the pigs before being exposed to the sun.

However, the differences in body temperature rise on different days, following a 15 minute exposure to the sun, were statistically significant. There was a highly significant correlation between air temperature and increase in body temperature; that is, the higher the air temperature, the greater the increase in body temperature upon a 15 minute exposure to the sun.

A reverse relationship existed between relative humidity and body temperature change upon a 15 minute exposure to the sun.

On the days these observations were made, the air temperature ranged from 55 to 80 degrees F., and the relative humidity from 58 to 76 per cent. The average temperature and humidity was 87.6 degrees F., and 65.4 per cent, respectively.

The observations of the effect of a 30 minute exposure to the sun were made when the air temperature ranged from 85 to 91 degrees F., and the relative humidity from 58 to 75 per cent.

There was not a significant correlation between air temperature or relative humidity and the body temperature before exposure for 30 minute periods. However, the correlation between air temperature and body temperature rise upon exposure to the sun for 30 minutes did approach significance.

The average rise in body temperatures of all pigs during a 30 minute exposure was significantly greater than the rise for a 15 minute exposure. The average rise in body temperature of all pigs on all days of 30 minute exposure was more than 100 per cent greater than the average rise during a 15 minute exposure. The average temperature and relative humidity was 88.6 degrees F., and 65.4 per cent, respectively.

The average body temperature increases for 15 minute and 30 minute exposure were noted. An exposure of 15 minutes resulted in an average increase in body temperature of 0.92 degrees F. The differences between individuals in temperature rise during the 15 minute exposure were not significant.

The average rise in temperature during the 30 minute exposure period was 1.94 degrees F. This increase in body temperature was significantly greater than the rise of 0.92 degrees F., which occurred during the 15 minute exposure. Again it was found that the differences between individuals in temperature rise was not significant. The 0.29 degrees F. greater rise in temperature of the Poland China pigs during the 30 minute exposure was significant statistically.

In determining the effect of exposure to the sun on respiration rates, the same air temperatures and relative humidities were used as those for studying body temperature. The average initial respiration rate for all pigs on all days was increased 100 per cent when the pigs were exposed for 15 minutes. An air temperature of 85 degrees F., and a relative humidity of 73 per cent caused the least respiration increase. This difference between days in the average increase in respiration was highly significant.

The average initial respiration rate increased 150 per cent during 30 minute exposures.

The difference in increase in respiration rate on different days was statistically significant. The differences in increase in respiration when exposed for 15 and 30 minutes were highly significant. The average rise in respiration that followed a 15 minute exposure was 19.8 respirations per minute. The average rise that occurred during exposure for 30 minutes was 80.8. Exposure for 30 minutes increased the respiration rate approximately 30 respirations more per minute than the 15 minute exposure.

V. EFFECTS OF EXPOSURE TO WATER

Effect of Hog Wallows on Swine

Bray (1948) compared the average daily gains of pigs with no wallow, with those having access to a sanitary portable wallow and to pigs having access to a mud wallow. The difference in gains between the sanitary wallow, and the mud wallow was not significant, but the differences were quite marked between the pigs having wallows and those with none. The pigs with wallows ate more feed, leaving their shelters at intervals during the day, cooling off in the wallows, and then going to the self-feeders. Those with no wallow rarely came out between eight in the morning and five in the afternoon.

A report by Jackson (1938) indicated that hogs having access to a hog wallow when the atmospheric temperature averaged 83 degrees F., ate more feed, gained more rapidly, and were more economical users of feed than similar pigs without access to wallows.

Bray (1948) found that body temperatures on hot days for pigs without wallows sometimes reached temperatures of 105 to 106 degrees F. Hogs just out of the wallow had temperatures as low as 102 degrees F., while the average temperature of those in the lots with wallows ran around 104 degrees F. The maximum temperature in the shed in which the pigs were housed ran to 104 and 105 degrees F., on hot days.

Effect of Evaporating water on Gain, Respiration Rate, and Body Temperature

Heitman and co-workers (1949) studied hogs weighing around 250 pounds which were kept for a period at 90 degrees F. on a dry floor, with relative humidity of 35 per cent. Then the temperature was held constant and a trickle of water was run across the floor for a 7 day period. During the period with a wet floor, the rate of gain was markedly increased, the respiration rate was about 30 per cent of that during the period on the dry floor, and the body temperature was 1.5 degrees F. lower. The same comparison was made at 100 degrees F., with similar differences.

The cooling effect due to evaporation of water was very rapid. An experiment was run with three 240 pound hogs at a room temperature of 100 degrees F. All were distressed with a body temperature of 106.8 degrees F., and an average respiratory rate of 150 breaths per minute. Four liters of water were poured on the floor to make a wet area. The hogs began to roll in the water immediately. In twenty minutes, the body temperatures were lowered an average of 1.0 degree F., and the respiratory rate lowered by 50 per cent. In ninety minutes, the body temperature was lowered by 2.0 degrees F., and the respiratory rate by 80 per cent.

Effect of Sprinkling on Dairy Cattle

Miller (1951) found that during the summer months, a definite relationship between air temperature and time dairy cows spent under a water sprinkler. The time spent under the shower for all breeds more than doubled (122 per cent increase) when the maximum temperature increased from a range of 80 to 85 degrees F., to a range of 86 and 91 degrees F. The animals spent approximately three times (218 per cent increase) as much time under the shower when the temperature ranged from 92 to 97 degrees F., as they did when the temperature ranged from 80 to 85 degrees F. This difference in time was highly significant for both breeds. Holsteins used the shower more than the Jersey.

Respiration rates were taken on 10 relatively warm days (average maximum temperature, 93 degrees F., range, 88 to 97 degrees F.), in the pasture just before the animals departed for the milking barn, and again after they had walked one-quarter of a mile to the barn. While in the pasture, the respiration rates of the Holsteins and Jerseys having access to shade were 90 and 92 per minute, respectively. The respiration rates of the Holsteins and Jerseys having access to the shower were 74 and 80, or 18 per cent and 13 per cent lower, respectively, than those with shade.

The data indicated that sprinkling was effective in reducing respiration rate and was of the greatest value for the Holsteins.

After walking to the barn, the respiration rate of the Holsteins with shade increased from 90 to 98 respirations per minute, or 9.5 per cent, while those of the cows with the shower increased from 74 to 96 per minute, or 30.5 per cent.

After the same trip, the respiration rate of the Jerseys with shade increased from 92 to 105 per minute, or approximately 15 per cent and those of the Jerseys with the sprinkler increased from 80 to 98 per minute, or approximately 24 per cent. The cows that had access to the shower and shade had lower respiration rates than those with only shade when in the pasture, but this difference was largely overcome by the time they had made the trip to the barn.

VI. EFFECTS OF AIR MOVEMENT

In one experiment to determine the effect of air motion on hog performance, Heitman and co-workers (1949) studied three hogs weighing around 250 pounds on a wet floor at approximately 119 degrees F. Air motion in the chamber varied from 20 to 30 feet per minute at hog level. A fan was turned on, which increased the air motion to an estimated average of 175 feet per minute at hog level, but varying from 100 to 250 feet. In 30 minutes, the respiration was lowered by about 60 per cent, and the body temperature was reduced about 2.5 degrees F., on the average. In 80 minutes, the body temperatures were reduced an average of 3.0 degrees F.

In contrast to the results obtained on a wet floor, four pigs averaging about 100 pounds were on a dry floor at 113 degrees F. The fan was turned on, increasing the air velocity as before. The respiratory rate and body temperature decreased slightly at first, as it was not possible to have the floor completely dry and the hogs were slightly damp. As the floor and hogs dried, the respiratory rate and body temperature increased again to that at the start. After five hours with the accelerated air motion and a dry floor there was no apparent benefit to the comfort of the animals.

PROCEDURE AND TREATMENTS

I. PROCEDURE COMMON TO ALL TRIALS

Seven trials were conducted in this experiment. The first trial was made in the winter of 1952-1953, and the subsequent trials made in each summer and winter that followed through the winter of 1955-1956.

Table I shows the beginning and ending dates of each of the seven trials. The four winter trials were begun on dates ranging from November 14th to December 21st. The three summer trials were begun on dates ranging from May 27th to July 24th. Except for the summer of 1953, each of the trials were continued until the hogs reached market weight.

TABLE I

BEGINNING AND ENDING DATES OF EACH OF THE SEVEN TRIALS CONDUCTED

Trial No.	Season	Beginning Date	Ending Date
1	Winter	Nov. 14, 1952	March 12, 1953
2	Summer	July 24, 1953	Sept. 1, 1953
3	Winter	Dec. 15, 1953	April 6, 1954
4	Summer	June 3, 1954	Sept. 23, 1954
5	Winter	Dec. 17, 1954	April 11, 1955
6	Summer	May 27, 1955	Sept. 9, 1955
7	Winter	Dec. 21, 1955	Feb. 28, 1956

For each trial, healthy pigs were lotted into uniform lots according to standard procedure. The average initial weights of the pigs in each lot are shown in the results. The average weights in the lots varied from 23.5 pounds in one lot in the winter of 1952-1953, to 100 pounds in a lot in the summer of 1953.

The pigs for each trial were selected from the University herd. Sex, litter, and breed; as well as weight were taken into account in lotting the pigs. The breeds used were: Durocs, Chester Whites, Chester white Duroc first crosses, and Chester White Yorkshire first crosses.

The pigs in each lot of each trial were fed the same ration. An example of the type of ration is that used in the winter of 1955-1956, which is shown in Table II. The rations were slightly altered between trials to conform to the most recent recommendations of the animal husbandry department of the University. The high protein ration was used until the pigs reached an average weight of 125 pounds, at which time, the low protein ration was fed. All of the rations were self-fed, and water was supplied <u>ad</u> <u>libitum</u>.

The pigs were weighed at two-week intervals; at which time, feed consumption was also determined. In three trials, the summer of 1953, the winter of 1953-1954, and the summer of 1954, water consumption was also measured.

TABLE II

A TYPICAL RATION USED IN THE EXPERIMENT*

Ingredient	MIXTURE USED--IN POUNDS	
	When pig weights averaged up to 125 pounds	When pig weights averaged 125 pounds and over
Corn	805 pounds	865 pounds
Soybean Oil Meal	110	80
Meat Scraps	50	20
Alfalfa Meal	25	25
Dicalcium Phosphate	5	5
Trace Mineralized Salt	5	5
Aurofac 10	1	1
Merck Vitamix 58C	1	1
Vitamin A and D conc.	1/4	1/4
Total	1002 1/4 pounds	1002 1/4 pounds

*This is the ration actually used in the final trial, Winter, 1955-1956.

The houses were cleaned and bedded daily. Hourly records were made of the temperature and relative humidity in each of the houses, and in the atmosphere surrounding the houses. Summaries of the maximum, minimum, mean, and daily variations in temperature are recorded in reports by Hinkle (1953), Brandt (1954), and Kazarian (1956). Summaries of the daily mean relative humidity are also found in these reports. Solar radiation data, obtained from the Michigan Hydrologic Research Station, Michigan State University, was plotted by Brandt for the second and third trials. Instruments used for recording temperature and controlling ventilation are also described by Brandt (1954), and Kazarian (1956).

Physiological observations were made during the fourth and sixth trials (summer 1954, and summer, 1955). In the fourth trial, records were made of the rectal temperature, respiration rate, and pulse rate; and in the fifth trial, only rectal temperature and respiration rate were recorded.

The pulse rates were obtained by applying a stethoscope to the flank of the animals for a period of thirty seconds. Respiration rates were obtained by counting the flank movement for a period of from fifteen to thirty seconds. This was done when the hogs were lying down, and in a relaxed position.

Rectal temperatures were observed by the use of two different types of temperature-recorders. In the summer of

1954, clinical thermometers were used. These were placed in the rectum of the hog and allowed to remain approximately two minutes. In order to keep the thermometer in place, and to get an accurate recording, it was necessary for the animals to be relatively inactive during the two minute recording period. More rapid determination of rectal temperatures were made possible in the summer of 1955 by the use of a Swiftem instantaneous thermometer.

II. TREATMENTS USED IN EACH OF THE TRIALS

The housing treatments used in each of the seven trials conducted during the course of this study were by no means identical. After each trial, attempts were made to improve the treatments for the succeeding trial, in efforts to better determine the factors which might contribute to the efficiency of a house for hog production.

Except where noted, the overall procedure previously described was used in all of the trials. However, in a description of the treatments used, each trial is considered separately.

Trial I--Winter, 1952--1953

The housing treatments in the first trial differed from those used in all of the succeeding trials in that all of the pigs in the first trial were housed in the central farrowing and experimental swine barn on the Michigan State University Farm, as shown in Figure 1. Ten pigs were used in each of the two housing treatments.

Figure 1. A southeastern view of the central swine barn used in the first trial. A comparison was made between the performance of hogs grown in each of the two wings.

The first lot of pigs were placed in a wing of the house which had a double-paned insulated glass on the south side of the wing, and continuing along the entire length of the wing. The window area was 5 1/2 feet in height.

The second lot of pigs were housed in a second wing of the barn, which is of more conventional construction. In this wing, single-paned, conventional windows are on the east and west sides of the housing. The windows were 24 inches high, 22 inches wide, and placed 5 1/2 feet apart. Temperatures above freezing were maintained in each house by a central hot-air furnace.

Trial II--Summer, 1953

For the second, and succeeding trials, the central swine barn was no longer used. The pigs were housed in portable houses constructed according to plans presented by Brandt (1954). Figure 2, and Figure 3, page 31, show the

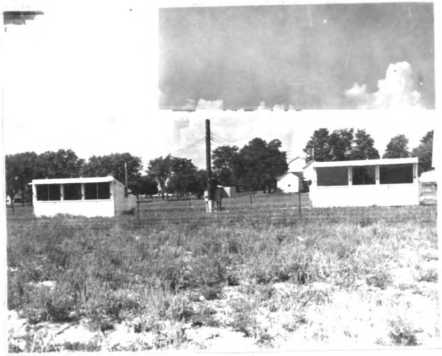

Figure 2. A view of the two experimental houses used in the second trial with instrument box. All of the experimental houses were equipped with plywood sun-shades for the summer studies. The single-pane house is on the left, and the double-pane house on the right.

houses used for this trial. There were three treatments, with 8 pigs in each treatment lot. The first treatment was replicated, for a total of 16 pigs.

Figure 3. The conventional house and concrete slab used in the second and third trials.

The type house used for each treatment was as follows:

1. A conventional, portable A type hog-house, with approximately 40 square feet of floor space. This house was placed on a concrete slab within a 16 foot by 24 foot area. An automatic waterer and a feeder was placed at the end of the slab opposite to the house.

2. An especially constructed house described by Brandt (1954). This house contained approximately 120 feet of floor space, and measured 6 feet high in front, and 4 feet high on the rear. A partition was placed in the middle of the house to separate the pigs into two groups. The window area of the house was all on the front (south side), and this measured approximately 38 square feet. This window area was covered by a double-pane insulated glass. The houses contained automatic waterers and self feeders, and were ventilated with electric fans.

3. The house used for the third treatment was identical in construction to that used in the second treatment, except that the window area was covered by single-pane glass.

Trial III--Winter, 1953-1954

In the third trial, four treatments were used. All of the treatments used in the second trial were repeated, but the conventional treatment was not replicated. The added treatment consisted of pigs housed in still another especially constructed house. In this case, the fourth treatment differed from the second and third, in that it contained double-paned insulated glass, but the window area was only one-half as large as the window areas for treatments two and three.

The test houses used are shown in Figure 4, page 33. Eight pigs were subjected to each treatment.

Trial IV--Summer, 1954

For the fourth trial, the house containing one-half double-pane windows was converted into a house with no glass area. This change eliminated the entrance of sunlight except through small ventilating openings. Electric light bulbs were used soon after the beginning of the trial. The change from one-half double-pane to a house with no window glass was suggested because the same results were obtained in both houses with varying amounts of double-pane glass, and because of the interest shown in the probable results obtained with

Figure 4. The three experimental houses used in the second trial. From left to right the houses are one-half double pane, single pane and double pane.

practically no sunlight. The dark house is shown in Figure 5. In this, and subsequent trials, six pigs were placed in each treatment.

Figure 5. The house with no glass area. This house, converted from the one-half double pane house, was used in the fourth and subsequent trials.

Trial V--Winter, 1954-1955

In the fifth trial, the same treatments were used as in the fourth, except that a larger conventional house replaced the one formerly used.

Trial VI--Summer, 1955

In the sixth trial, still another treatment was added. This made a total of five treatments, with six pigs in each treatment. For the fifth treatment, another house was constructed, which was identical to the second treatment, viz., with 38 square feet of double-paned, insulated glass window area. However, in the newly constructed house, an air conditioner unit, shown in Figure 6, with a cooling capacity of 10,000 BTU per hour was inserted. The unit which is described by Kazaran (1956), was also equipped with a four-way reversing valve, which enabled it to heat, as well as cool.

Figure 6. The air conditioner unit installed in an experimental house for the sixth trial.

Some changes were also made in the conventional treatment. A larger, shed-roofed house was used, and an 8 foot by 8 foot metal livestock shade was placed on the concrete slab. These changes are shown in Figure 7.

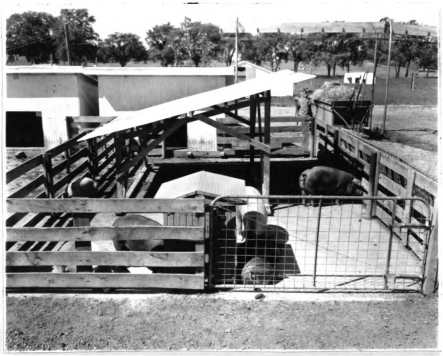

Figure 7. The conventional house used in the fifth, sixth, and seventh trials with the livestock shade used in the sixth and seventh trial.

Trial VII--Winter, 1955-1956

For the seventh, and final trial, two changes were made in the treatments used in the sixth trial. For the first change, six 375-watt infra-red heat bulbs were installed in the house with no glass area, and controlled by a thermostat.

For the second change, the air conditioner was removed from the house which contained it, and the house was rotated, so that the glass area had an eastern exposure. Prior to the latter change, all the test houses were orientated south, with only the conventional house orientated east.

RESULTS AND DISCUSSION

Trial I--Winter, 1952-1953

The gains and feed efficiency which occurred during this trial are shown in Table III. The pigs in the conventional wing of the barn gained faster and more efficiently than those in the double-pane wing. However, conditions other than those due to the effect of the glass may have been responsible for the results obtained. The data were not analyzed statistically.

TABLE III

PERFORMANCE OF THE HOGS IN TRIAL I, WINTER, 1952-1953

Comparisons	Conventional Wing	Double-Pane Wing
Number of pigs	9.	10.
Ave. initial weight (lb.). . . .	23.6	23.7
Ave. final weight (104 days; lb)	193.1	186.6
Average daily gain	1.54	1.47
Average daily feed (lb.)	5.32	5.32
Feed/pound gain (lb.)	3.46	3.63

Trial II--Summer, 1953

The summer study began on July 24, 1953, but due to a difficulty with the recording potentiometer, correct temperature recordings were not available until August 3, 1953.

The study was discontinued on September 2, 1953, when it was determined that sufficient data were available so that continuation of the study was unwarranted.

Temperature and relative humidity. The mean weekly temperatures for each of the houses are shown in Figure 8, page 40. The difference between the inside temperature in the single-pane and double-pane houses was not significant. There were slight temperature differences for short periods of time, but a definite trend was not noticeable.

The relative humidity in the conventional house varied daily between 50 per cent and 100 per cent. The relative humidity in the two test houses averaged 80 per cent, with a daily variation of about 20 per cent. The main factors contributing to the high relative humidity were the large amounts of water spilled from the waterer onto the floor, and insufficient ventilation.

Feeding trial. The results for the feeding trial of the summer study are shown in Table IV, page 41. The results from this trial show very little difference in the rate of growth, and the feed consumed per pound of gain, between the hogs in the test houses. There were, however, appreciable differences between the hogs in the test houses and those in the conventional house. The hogs in the conventional house made the better average daily gains of 1.90 pounds, and were also the most efficient gainers with 3.70 pounds of feed per pound of gain.

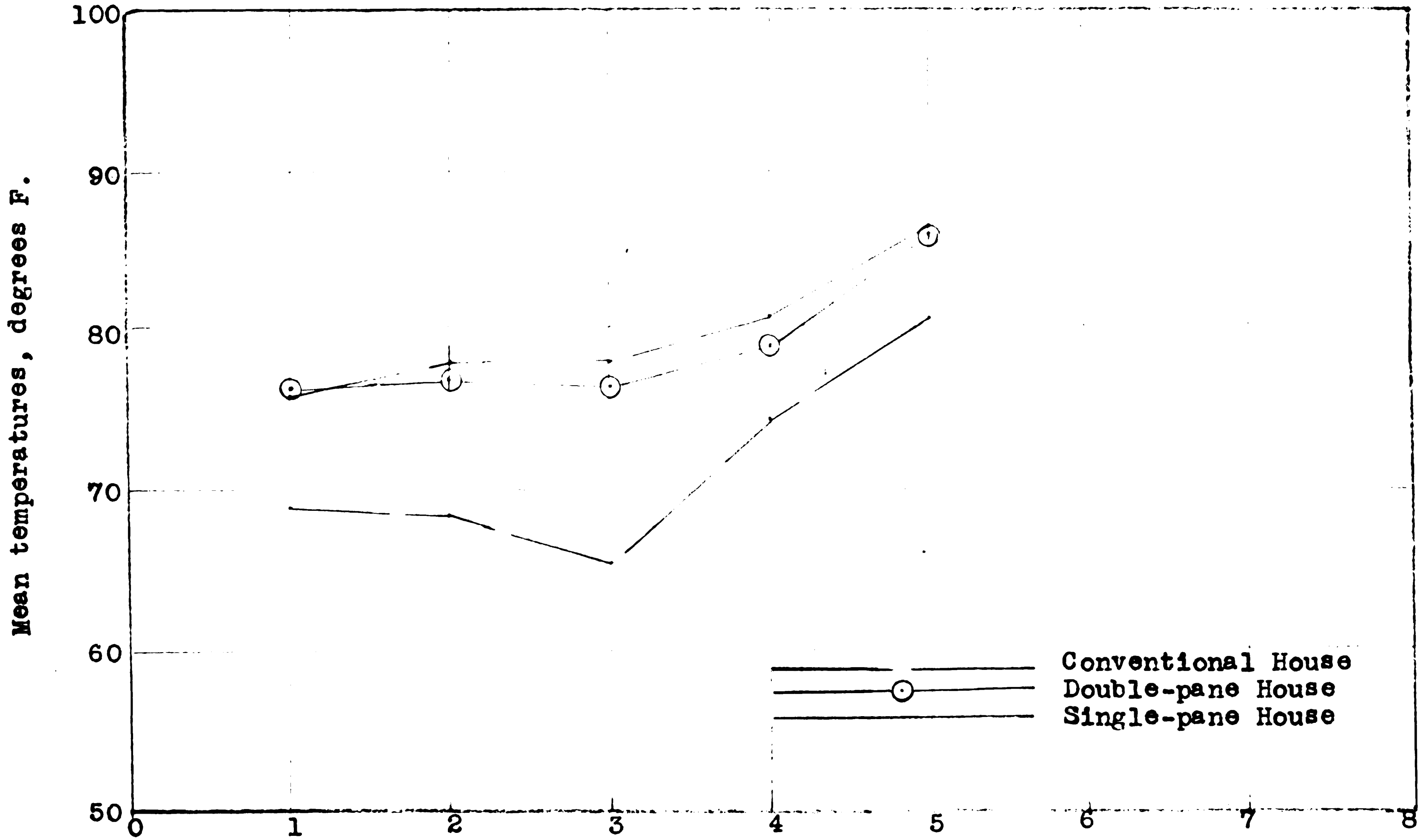

Figure 8. The mean weekly temperatures in each of the houses during Trial II, Summer, 1953.

The water consumption data were not reliable because large amounts of water were spilled on the floor by the hogs. Water consumption data was not obtained for the hogs in the conventional house.

TABLE IV

PERFORMANCE OF THE HOGS IN
TRIAL II, SUMMER, 1953

Comparisons	Conventional House	Double-Pane House	Single-Pane House
Number of pigs	16.	8.	8.
Ave. initial wt. (lb.)	98.7	95.9	95.7
Ave. final wt. (lb.)	171.4	155.5	158.4
Ave. daily gain (lb.)	1.90	1.55	1.65
Ave. daily feed (lb.)	7.00	6.40	6.15
Feed/pound gain (lb.)	3.70	4.15	3.85
Total water consumed (gal.)	----	900.	825.
Ave. daily water (gal.	----	2.88	2.64
Water/pound gain (gal.	----	1.89	1.65
Water/pound feed (gal.	----	.45	.43

Trial III--Winter, 1953-1954

In the third trial, four treatments were used as described in the previous chapter. Each treatment contained eight pigs.

Temperature and relative humidity. The mean temperature for each house is shown in Figure 9, page 42. The

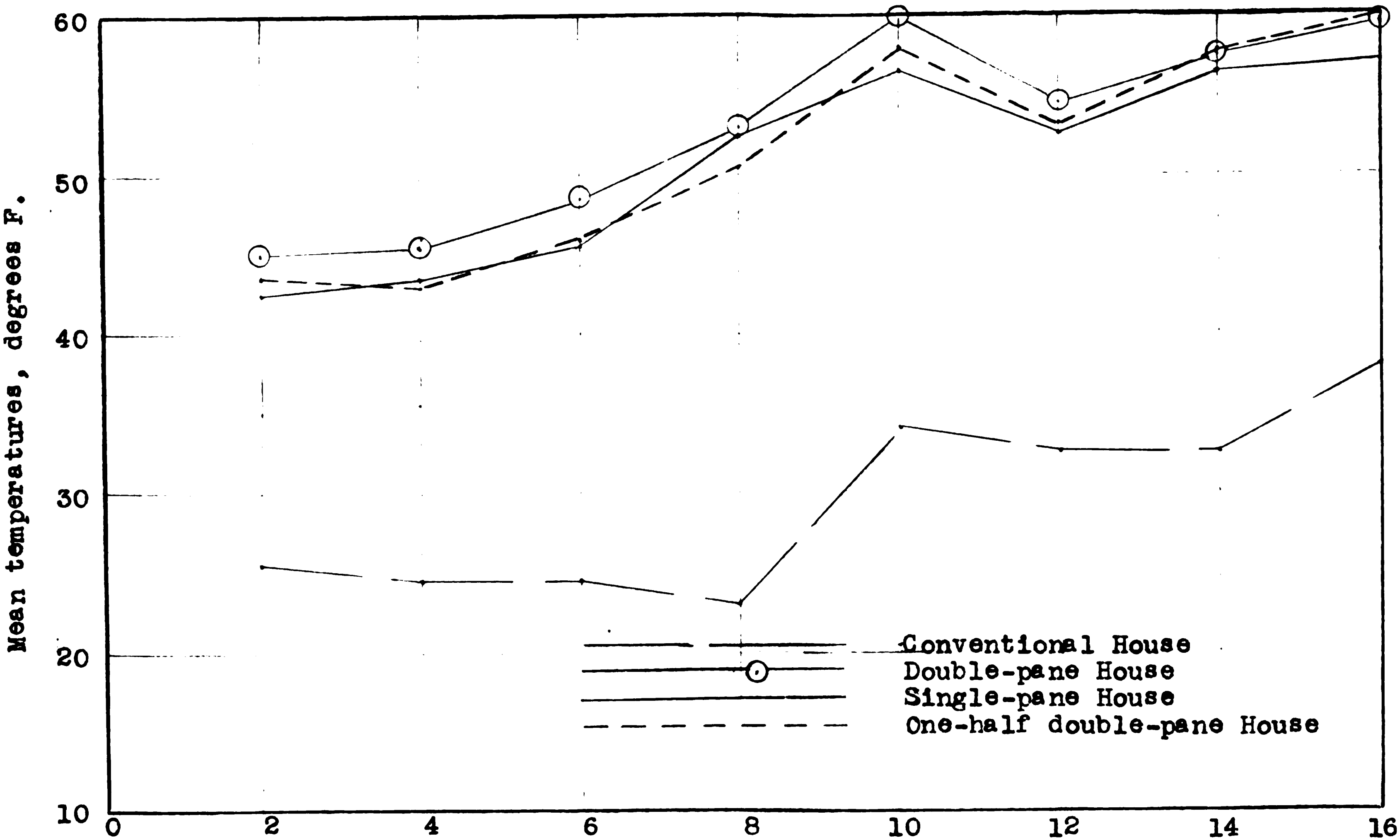

Figure 9. The mean biweekly temperatures in each of the houses during Trial III, Winter, 1953-1954.

inside temperature of the double-pane, single-pane, and one-half double-pane house showed definite patterns during this trial.

On the days on which there was a large amount of solar radiation, the variation in the daily temperature in the single-pane house was greater than in either of the other two test houses. This greater range between the maximum and minimum temperature in the house with single-pane glass was caused by the ability of the single-pane windows to transmit greater quantities of both short wave-length radiation, and heat energy through the glass. However, when the source of incoming radiation was eliminated, the heat losses through the single-pane windows caused the temperature to be lower in this house. The daily temperature variation was greater in the double-pane house than in the one-half double-pane house. With the smaller glass area the temperature in the house with the one-half double pane window was more uniform than in any of the other treatments.

There was a difference of about 20 degrees F., between the mean temperatures of the conventional house and those of all of the test houses. The mean temperatures of the double-pane house were slightly higher than those of the other test houses.

During the day, the relative humidity in the test houses was not apparently different. Lower daytime temperatures in the one-half double-pane house did not permit as much evaporation of the moisture from the floor and litter as in the other test houses, and caused a higher relative humidity than in the other test houses. Lower night-time temperatures in the single-pane house caused the relative humidity to be higher than in the double-pane house.

The double-pane window had a definite advantage under the conditions of high moisture which prevailed. It was an effective means of preventing the accumulation of condensation and frost on the windows of the houses, as shown in Figure 10.

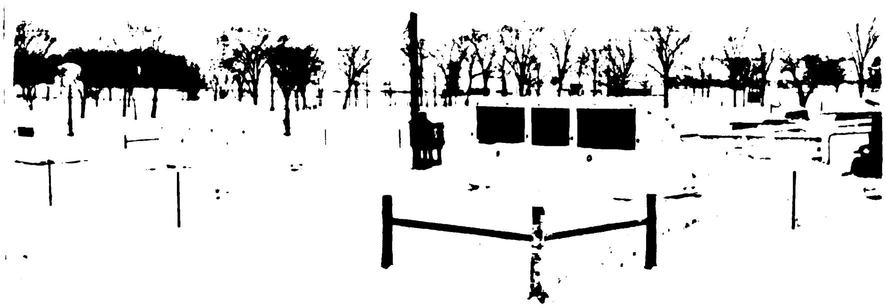

Figure 10. The two houses with equal glass area showing the relative amounts of condensation formed on the windows. The single-pane house is on the left and the double-pane house on the right.

This capacity of the double-pane windows to reduce condensation on the windows is due to an increase of the temperature on the inside surface of the glass by a few degrees.

Feeding trial. The results of the feeding trial for the third study are shown in Table V.

TABLE V

PERFORMANCE OF THE HOGS IN TRIAL III, WINTER, 1953-1954

Comparisons	Conventional House	Double Pane House	Single Pane House	1/2 Double Pane House
No. of pigs	8.	8.	8.	8.
Ave. initial wt. (lb.). .	34.2	34.6	34.6	34.6
Ave. final wt. (112 days) (lb.)	175.5	202.4	177.1	199.6
Ave. daily gain (lb.) . .	1.26	1.50	1.25	1.48
Ave. daily feed (lb.) . .	5.33	6.00	5.11	5.84
Feed/pound gain (lb.) . .	4.23	4.01	4.09	3.97
Ave. daily water (gal.) .	----	1.68	1.36	1.54
Water/pound gain (gal.) .	----	1.13	1.08	1.04
Water/pound feed (gal.) .	----	.28	.26	.27

The hogs in both houses with double-pane glass made faster gains than those in either of the other two types of housing. The difference between the hogs housed in the houses with double-pane windows and the others amounted to about 25 pounds, or about two week's growth.

The final weights were analyzed statistically by analysis of covariance, as shown in Table VI, page 47. There was a significant difference between the means of the weights of the hogs in the double-pane houses and those in both the single-pane and the conventional houses. This difference was significant at the 5 per cent level. There was no significance between the hogs in the double-pane house and in the one-half double-pane house. Likewise, there was no significant difference between the hogs in the single-pane house and those in the conventional house.

The feed consumption per pound of gain, as shown in Table V, page 45, did not follow any certain trend. The higher amount of feed consumed per pound of gain by the hogs in the conventional house was probably due to the increase in the amount of feed necessary to maintain a normal body temperature under the colder conditions, which existed in this house.

The hogs that made the greatest gains consumed the greatest quantities of water. The average amount of water consumed per pound of feed was practically the same for the hogs in each of the test houses. This indicates a direct relationship between the amount of water consumed and the amount of feed consumed. No water consumption records were made for the hogs in the conventional house.

TABLE VI

CO-VARIANT ANALYSIS OF THE INITIAL AND FINAL WEIGHTS OF THE HOGS IN TRIAL III, WINTER 1953-1954

	Observed				Adjusted		
Source	Degrees of Freedom	Sum of Squares of Initial Wts.	Sum of Products of Initial and Final Wts.	Sum of Squares of Final Wts.	Sum of Squares of Final Wts.	Degrees of Freedom	Mean Square
Total	31	660.0	1946.4	21777.5			
Treatment	3	0.9	39.4	4894.8			
Error	28	659.1	1907.0	16882.7	11371.5	27	421.2
Treatment plus Error	31	660.0	1946.4	21777.5	16035.6	30	
Treatment					4664.1	3	1554.7
F value					Significant at the 5% level		3.69

Trial IV--Summer, 1954

In the fourth trial, the one-half double-pane house was converted into a house which contained no glass area. In this trial, six pigs were subjected to each of the four treatments.

Temperature and relative humidity. The summer study of 1954 began on June 3, 1954, and ended on September 23, 1954. Missing temperature and humidity data were due to operational failure of the potentiometer or the wet bulb apparatus.

The mean biweekly temperatures in each of the houses are shown in Figure 11, page 49. The temperature in the conventional house followed closely the outside temperature. The mean daily temperature in the test houses were slightly higher than the outside temperature throughout the entire study. Daily maximum temperatures in the test houses approximated the outside maximum temperatures, but the daily minimum temperatures in the test houses were considerably higher than the outside minimum temperatures.

The mean temperatures in the double-pane and single-pane houses were almost identical throughout the trial, and only slightly higher than those in the conventional house. In the house with no glass, temperatures were generally lower than those in the houses with glass, but the differences were small.

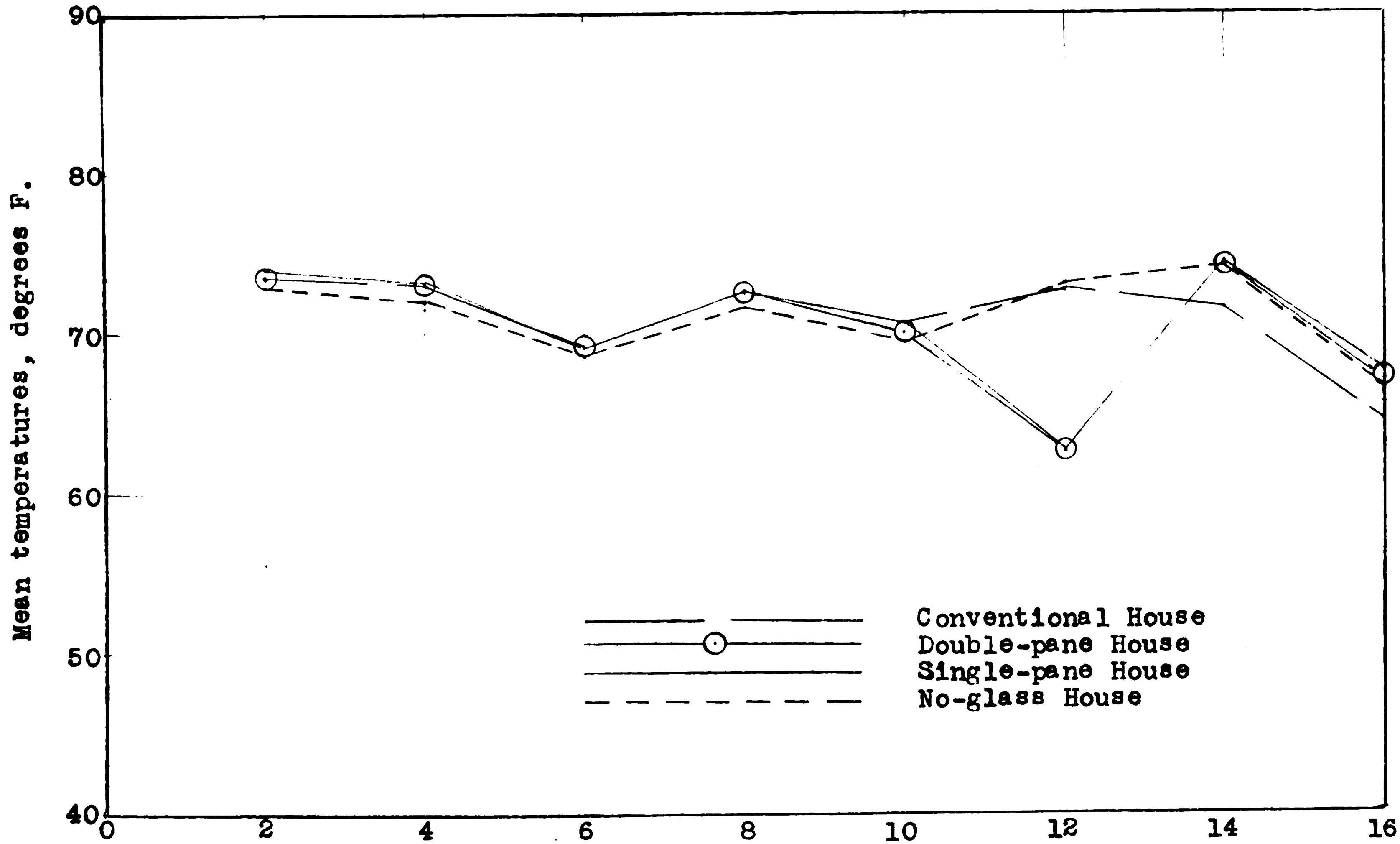

Figure 11. The mean biweekly temperatures in each of the houses in Trial IV, Summer, 1954.

Figure 12, page 51, shows that the relative humidity in the conventional house varied widely during the trial, while the humidity in the three test houses were very similar, and no definite trend was noticed.

Feeding trial. Results of the feeding trial are summarized in Table VII. The highest daily gain of 1.53 pounds was made by the hogs in the double-pane house, while the lowest daily gain of 1.39 pounds was made by the hogs in the conventional house. The hogs in the single-pane and no-glass houses made daily gains of 1.47 and 1.49 pounds, respectively.

TABLE VII

PERFORMANCE OF THE HOGS IN TRIAL IV, SUMMER, 1954

Comparisons	Conventional House	Double Pane House	Single Pane House	No-glass House
No. of pigs	6.	6.	6.	6.
Ave. initial wt. (lb.) . .	39.5	39.5	39.8	39.8
Ave. final wt. (112 days) (lb.)	194.8	209.9	204.5	206.5
Ave. daily gain (lb.) . . .	1.39	1.53	1.47	1.49
Ave. daily feed (lb.) . . .	5.59	5.77	5.59	5.86
Feed/pound gain (lb.) . . .	4.03	3.79	3.81	3.94
Ave. daily water (gal.) . .	----	1.49	1.39	1.59
Water/pound gain (gal.) . .	----	.97	.95	1.07
Water/pound feed (gal.) . .	----	.26	.25	.27

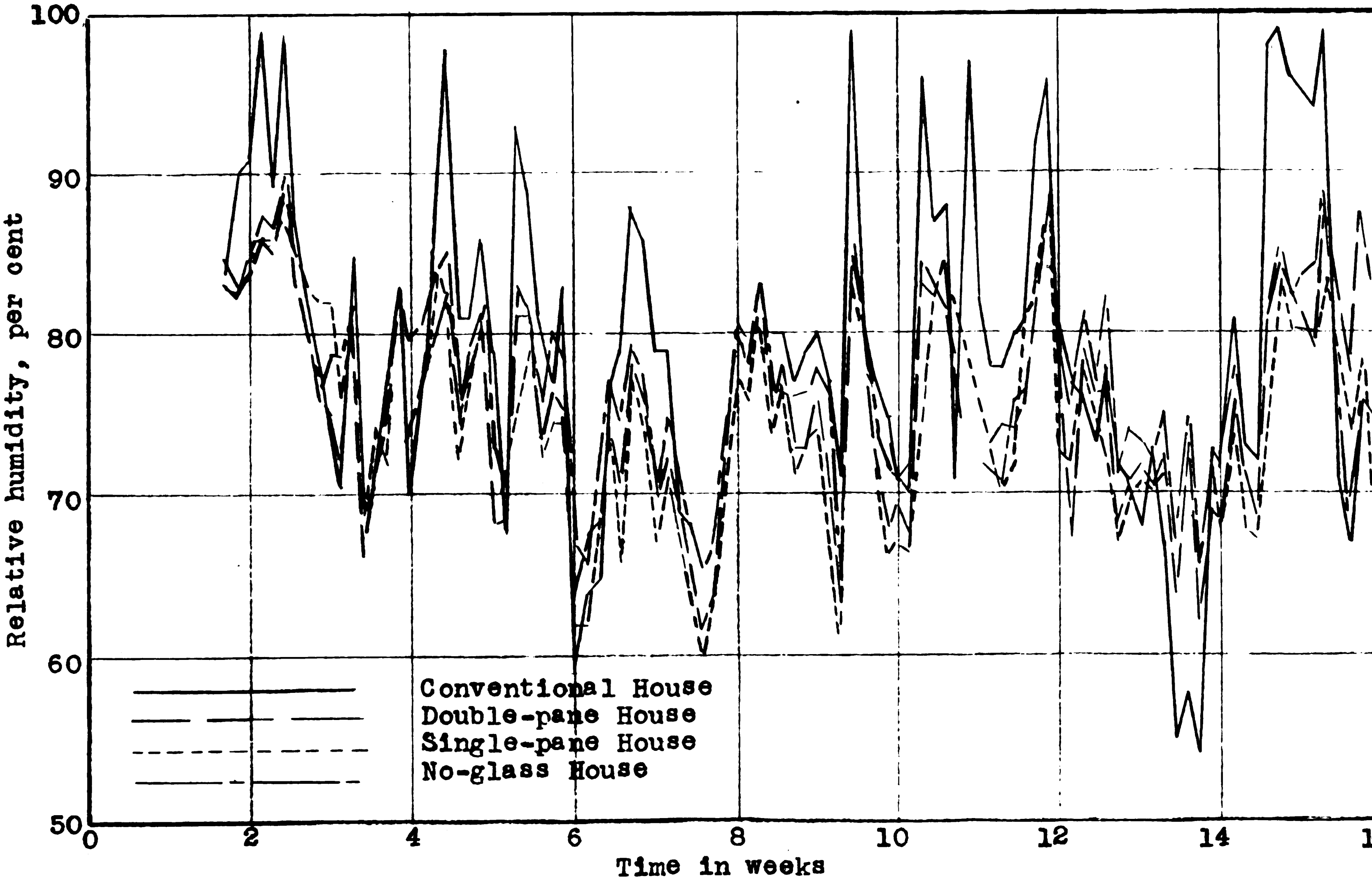

Figure 12. The mean relative humidities in each of the houses in Trial IV, Summer, 1954.

An analysis of the data by co-variants is shown in Table VIII, page 53. The differences between the averages of the final weights were not statistically significant.

The best feed efficiency was also made by the hogs in the double-pane house, with 3.79 pounds, per pound of gain. Following, in order were the single-pane house, 3.81; the no-glass house, with 3.94; and the conventional house, with 4.03 pounds of feed, per pound of gain.

Physiological responses. The effects of the immediate environment of the hogs on their rectal temperature, respiration rate and pulse rate were studied. A total of 272 observations were made on the pigs.

The effects of the environment were considered in terms of the effects of the temperature of the atmosphere immediately surrounding the hogs; that is, the ambient temperature. The graphs and explanations of the effect of ambient temperature on physiological reactions are summaries of the responses observed among all of the hogs without regard, except where noted, to any particular treatment.

Figure 13, page 54, shows the observed effects of ambient temperature on the rectal temperature of the hogs. A total of 228 rectal temperature observations were made on days and hours selected at random.

The temperature at which the observations were made varied from 61 to 93 degrees F., and the rectal temperatures

TABLE VIII

CO-VARIANT ANALYSIS OF THE INITIAL AND FINAL WEIGHTS
OF THE HOGS ON TRIAL IV, SUMMER, 1954

	Observed				Adjusted		
Source	Degrees of Freedom	Sum of Squares Initial Wts.	Sum of Products of Initial and Final Wts.	Sum of Squares Final Wts.	Sum of Squares of Final Wts.	Degrees of Freedom	Mean Square
Total	23.	573.3	1324.3	27730.3			
Treatment	3.	0.6	6.3	7471.6			
Error	20.	572.7	1318.0	20258.7	16953.7	19	892.3
Treatment plus Error	23.	573.3	1324.3	27730.3	24406.3	22	
Treatment					7452.6	3	2484.2
F value					Not significant		2.78

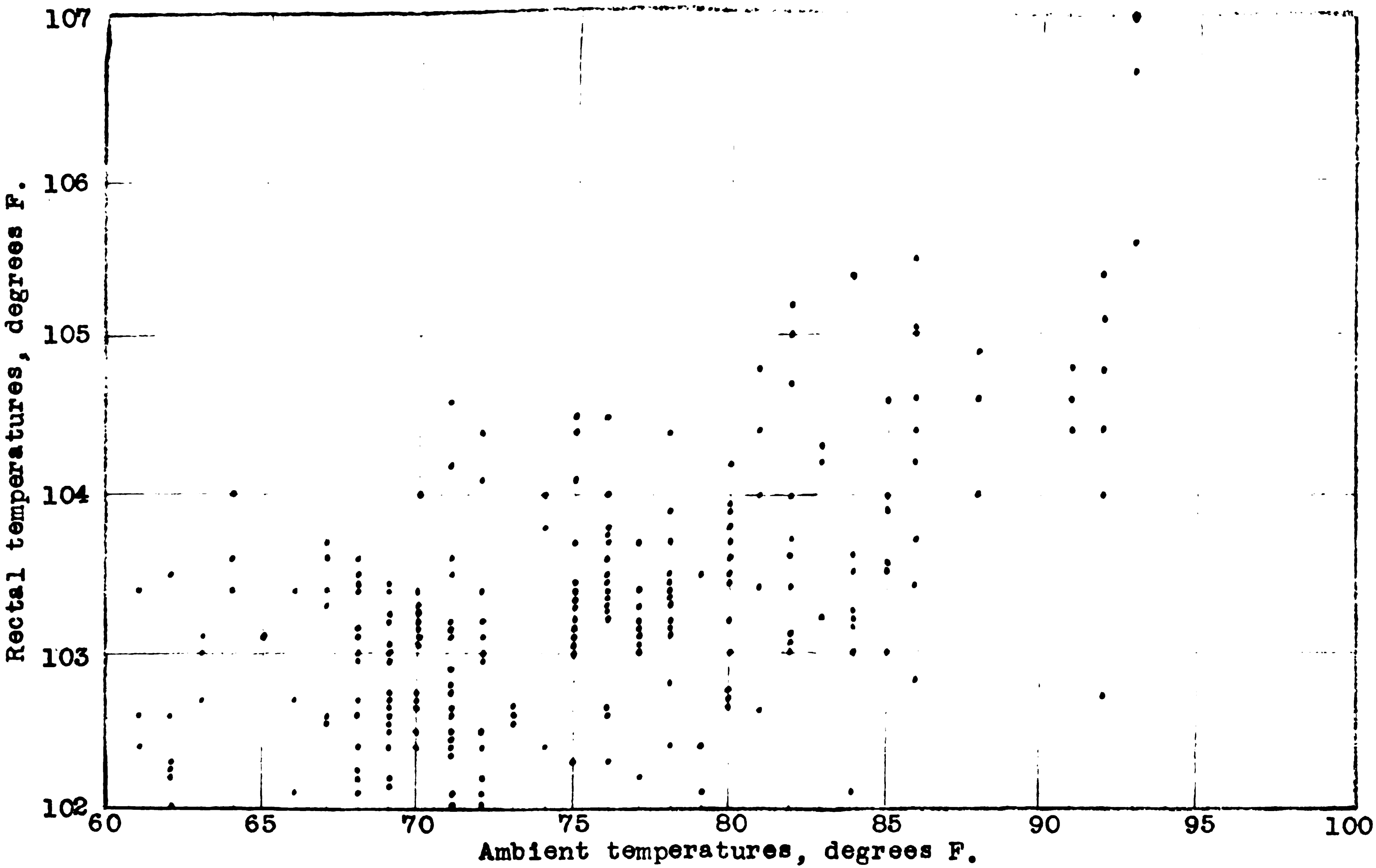

Figure 13. The effect of ambient temperature on the body temperature of the hogs in Trial IV, Summer, 1954.

observed varied from 101.4 to 107 degrees F. The rectal temperatures plotted in Figure 13, page 54, are the rectal temperatures observed at the ambient temperature indicated.

The data indicate that the average body temperature of the hogs was 103.2 degrees F., and that the hogs were able to maintain this body temperature in an ambient temperature range of, from 68 to 80 degrees F. Any decrease in the ambient temperature below 68 degrees F. brought about a corresponding decrease in the rectal temperatures of the hogs. Any increase in ambient temperature above 80 degrees F., caused a rapid increase in the rectal temperature of the hogs. Inspection of the graph indicates that at an ambient temperature of 61 degrees F., a hog in this trial would be expected to have a rectal temperature of 102.5 degrees F., and at an ambient temperature of 93 degrees F., a hog would have a rectal temperature of 105.5 degrees F.

In Figure 14, page 56, the effect of ambient temperature on the respiration rates of the hogs in this trial is shown. With respiration rates, there were apparently two ranges of ambient temperatures within which, a change of temperature did not affect the respiration rate. When the ambient temperature was between 61 and 69 degrees F., the hogs maintained a respiration rate of approximately 25 respirations per minute. From 69 to 74 degrees F., the respiration rate increased with the temperature up to a respiration rate of 55.

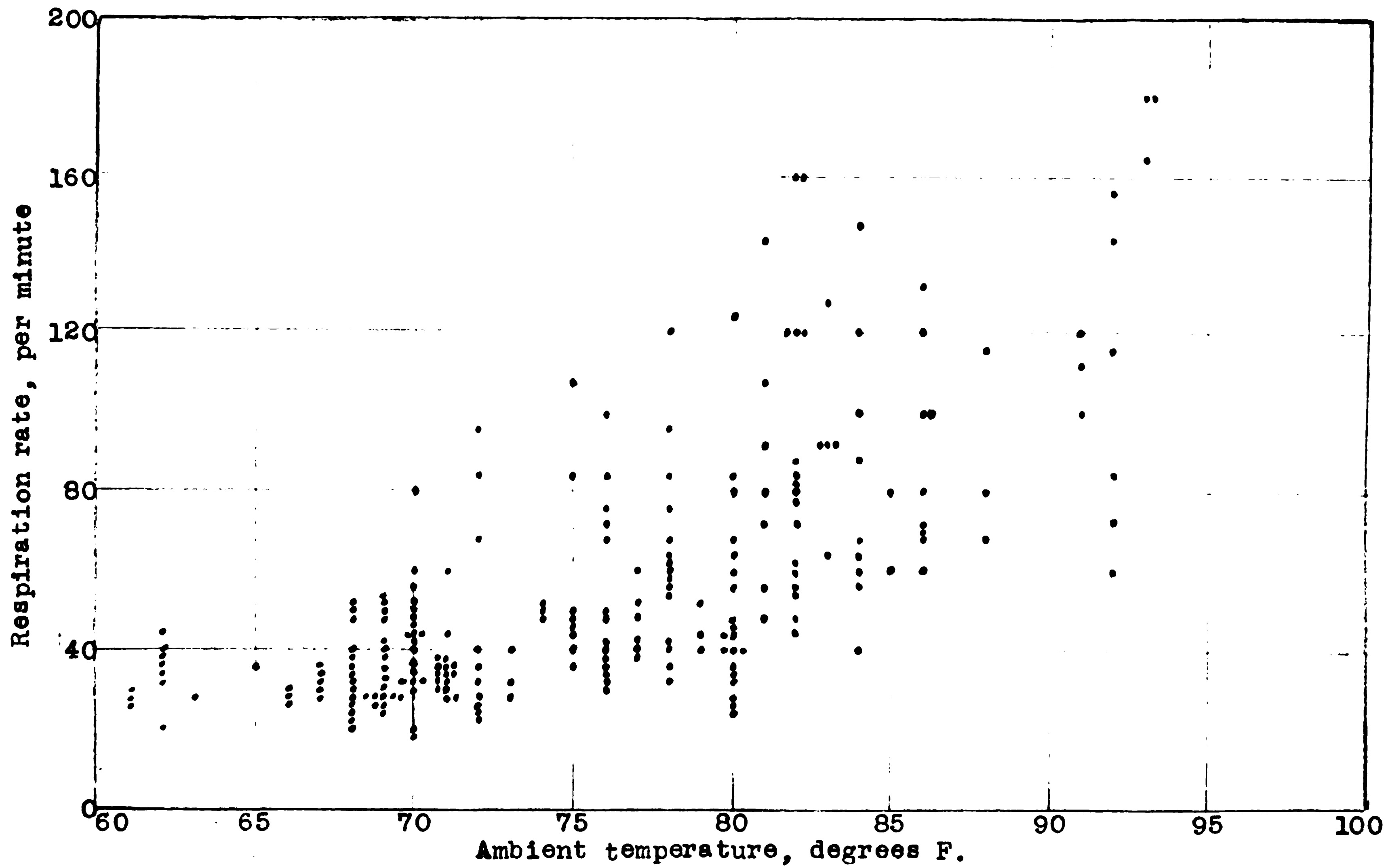

Figure 14. The effect of ambient temperature on the respiration rate of the hogs in Trial IV, Summer, 1954.

This rate was maintained up to an ambient temperature of 81 degrees F., above which temperature, the respiration rate increased with the increase in ambient temperature. The slowest rate observed was 20, and the fastest was 180 respirations per minute. A total of 232 respiration rate observations were made.

In Figure 15, page 58, the effect of ambient temperature on pulse rate is shown. The slowest pulse rate observed was 80 and the highest was 160 beats per minute. According to the data, the pulse rate was unaffected by ambient temperatures ranging from 62 to 82 degrees F., with a pulse rate of 132 beats per minute indicated as average. When the temperature increased above 82 degrees F., the pulse rates decreased to an indicated average of 122 beats per minute, at 93 degrees F. The pulse rate figures were compiled as a result of 146 observations.

Figures 16, 17, and 18, pages 59, 60, and 61, show the physiological responses in relation to each other, when the responses are observed at approximately the same time. The pulse rates first increased, and then decreased with increasing rectal temperatures, and showed a maximum rate of increase when the rectal temperatures reached 103.5 to 104 degrees F. With an increase in respiration a general decrease in pulse rate was observed, but the trend was not very definite.

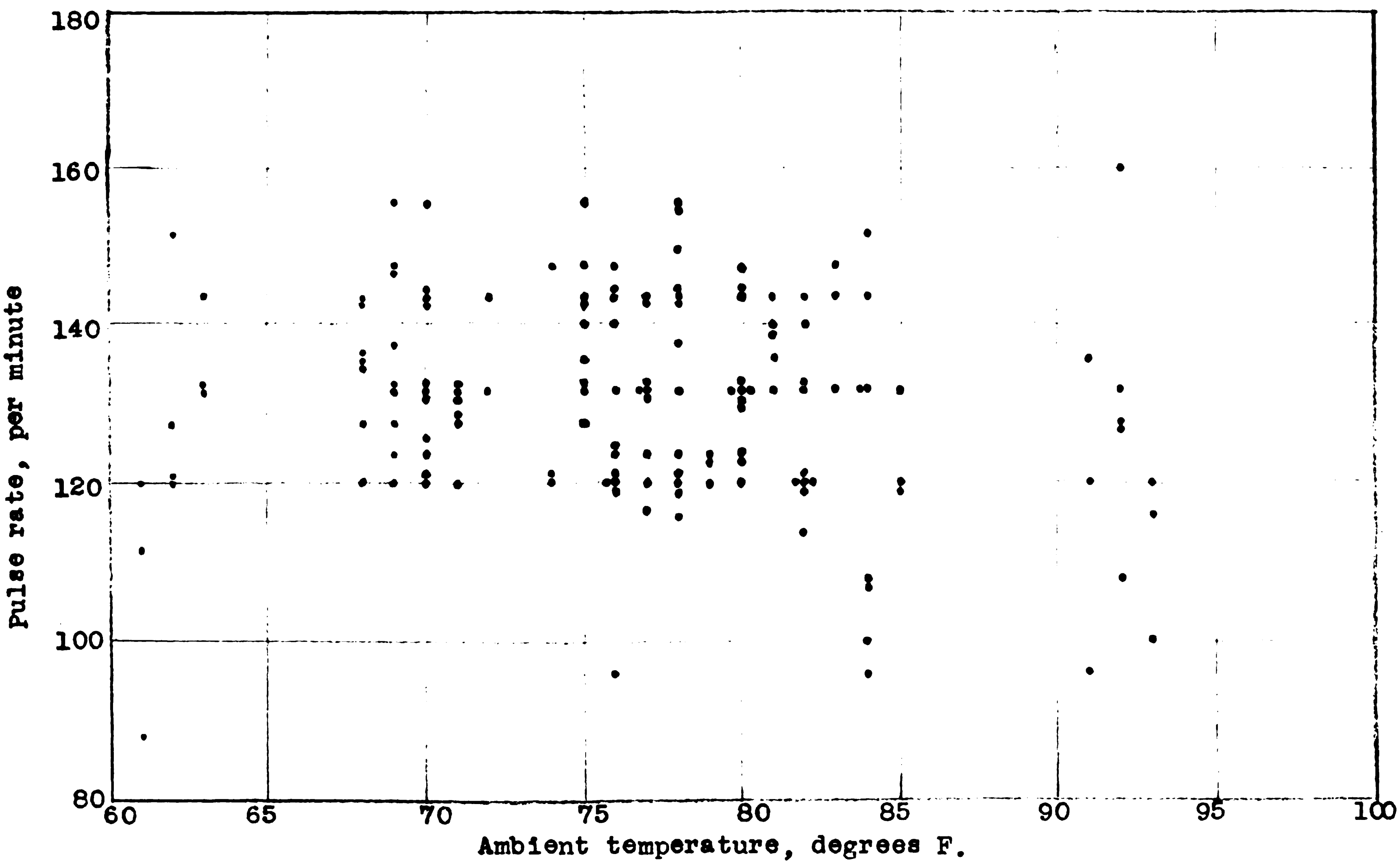

Figure 15. The effect of ambient temperature on the pulse rate of the hogs in Trial IV, Summer, 1954.

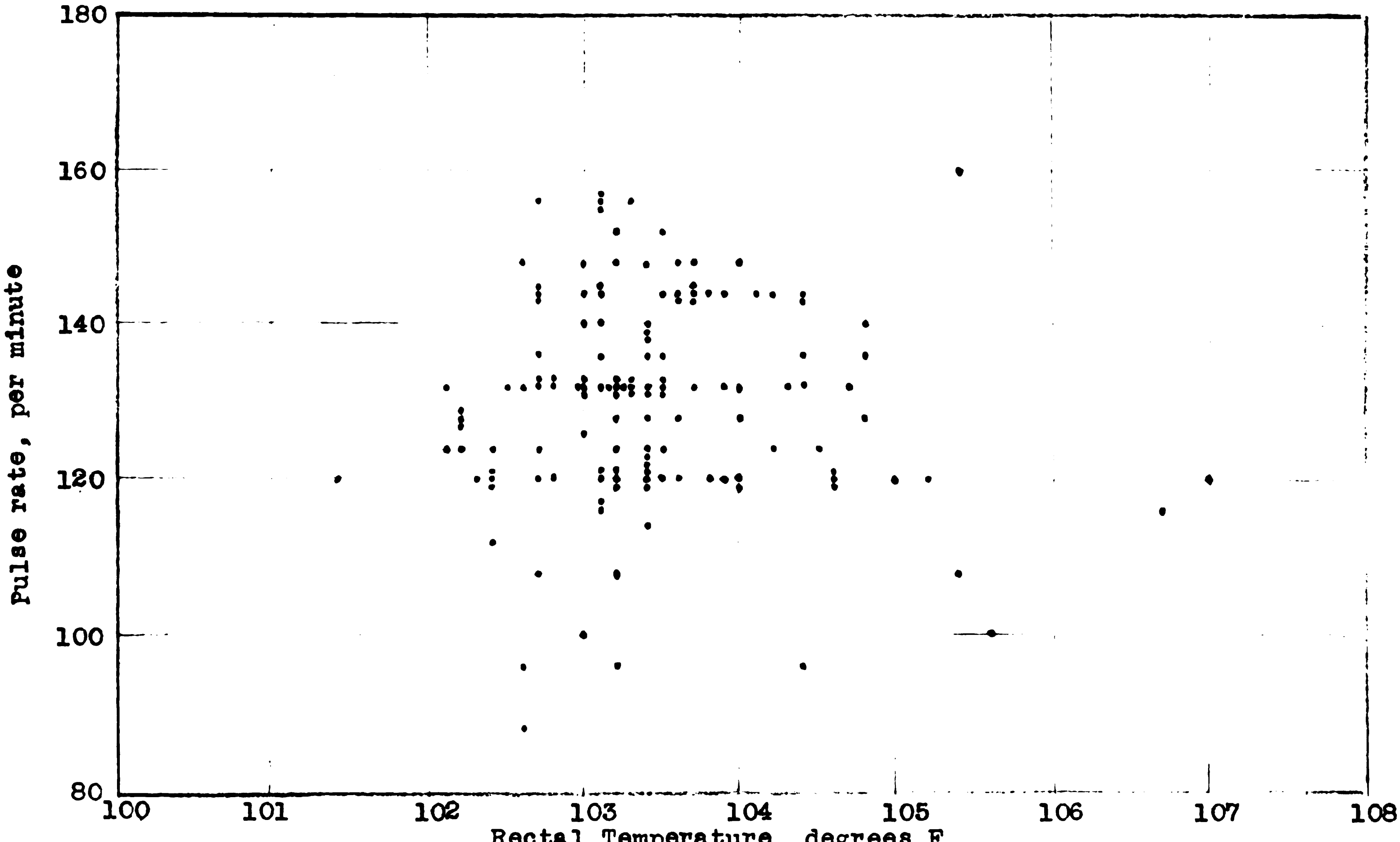

Figure 16. The relation between the pulse rate and rectal temperature of the hogs in Trial IV, Summer, 1954.

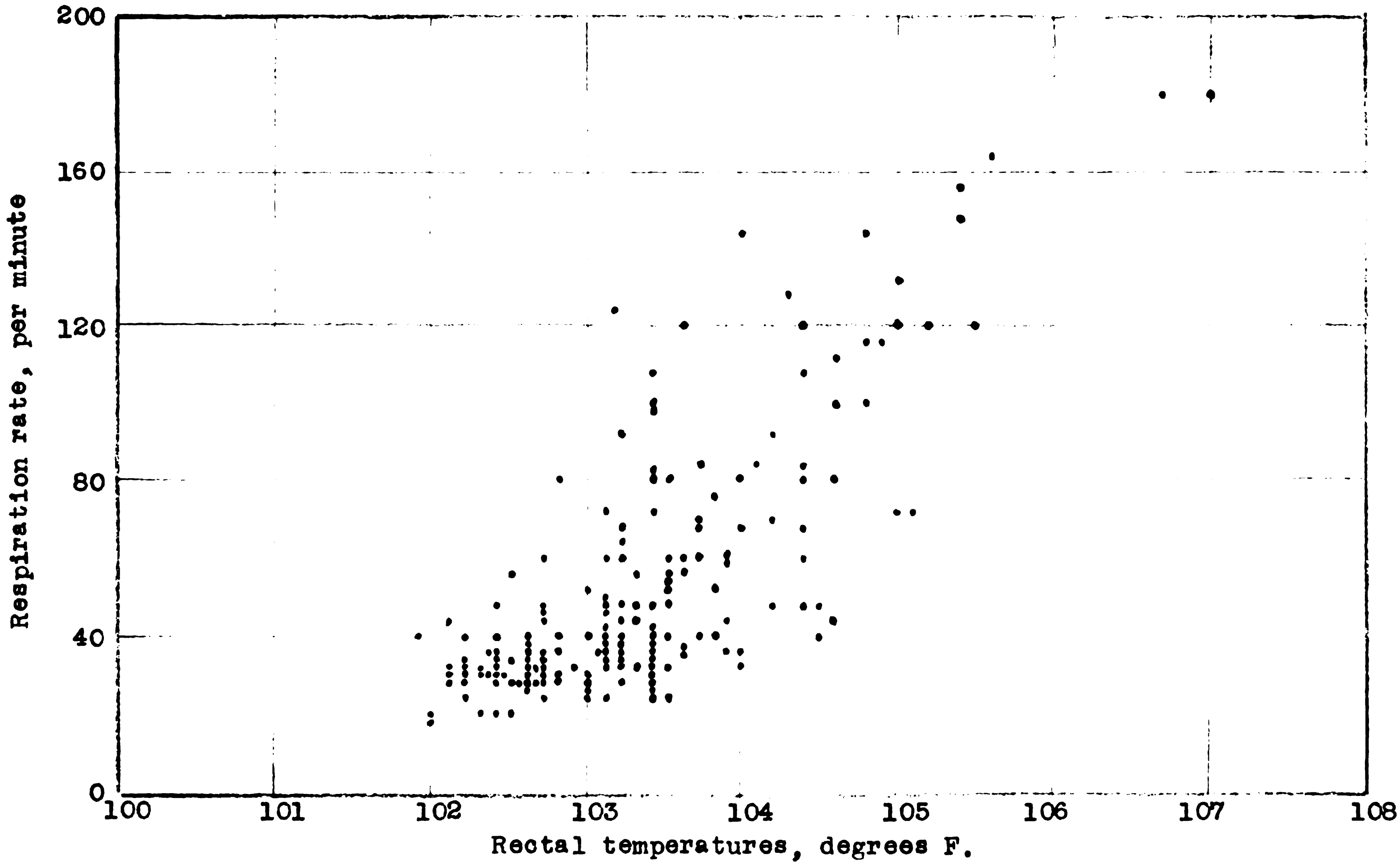

Figure 17. The relation between the respiration rate and the body temperature of the hogs in Trial IV, Summer, 1954.

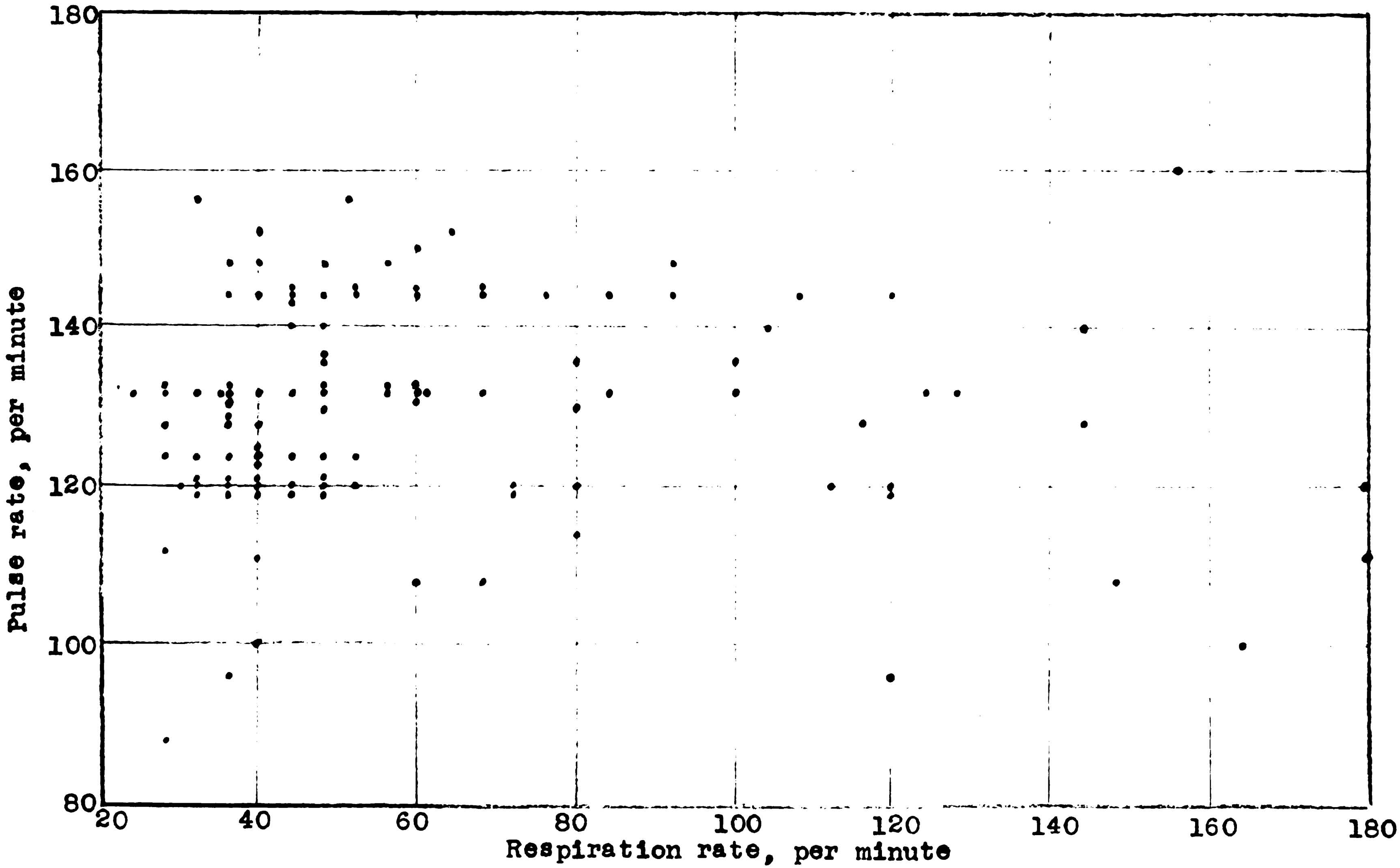

Figure 18. The relation between the respiration rate and pulse rate of the hogs in Trial IV, Summer, 1954.

Data collected in the summer of 1954 clearly substantiate the observations made by Palmer (1917), and Tidwell and Fletcher (1951) on the effects of exposure to the sun on body temperature and respiration rates of hogs.

In Figure 19, page 63, the differences in body temperature of hogs in the sun, as compared with those in the shade with similar ambient temperatures is illustrated. The hogs in the conventional house were exposed to the direct rays of the sun for the entire day, August 23, 1954, on which these observations were made. Inadequate shade was provided by the small portable house provided them.

Body temperature measurements were made at 8:30 A.M., 2:30 P.M., and 7:15 P.M. At the 8:30 A.M. observation, the recorded ambient temperatures in the double-pane house, the house with no glass, the single-pane house, and the conventional house were 77, 76, 78, and 79 degrees F., respectively. At the same time, the average body temperatures of three hogs in each of these treatments were--in the same order, 102.9, 103, 102.9, and 102.7 degrees F. At 2:30 P.M., the ambient temperatures in the four treatments were 92 degrees F. in the double-pane house, 91 degrees F. in the house with no glass, 92 degrees F. in the single-pane house, and 93 degrees F. in the conventional house. At the same time, the average body temperatures of the same three hogs observed in the morning were 104.1, 104.6, 104.7, and 106.4 degrees F., respectively.

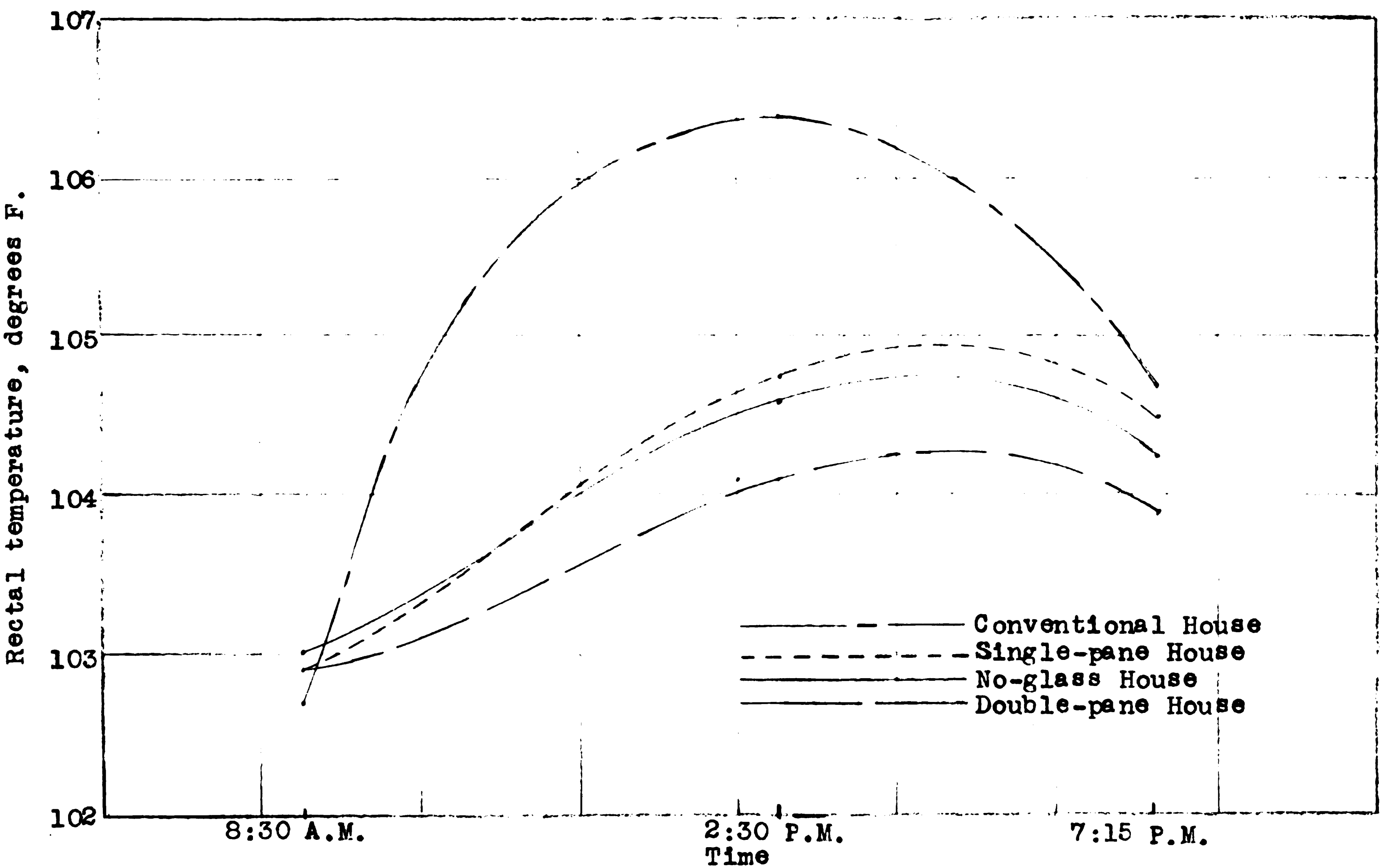

Figure 19. A comparison of the average body temperatures of three hogs in each of the houses on August 23, 1954.

At 7:15 P.M., the ambient temperatures were 86, 86, 88, and 86 degrees F., while the average body temperatures were 103.9, 104.3, 104.5, and 104.7 degrees F., for the four respective houses.

It may be noted that, while the air temperatures in the various houses varied, the body temperatures of the hogs showed greater variations than would be expected from the differences in air temperatures. The high body temperatures of the pigs in the conventional house were probably due to effects of the direct exposure to the sun, and the radiation of heat from the concrete slab to the hogs, as well as the slightly higher ambient temperatures to which they were exposed.

In Figure 20, page 65, the average respiration rates exhibited by the same pigs at the same time that the body temperature observations were made is shown. As with the body temperatures, the respiration rates between treatments show differences which cannot be accounted for on the basis of the differences in ambient temperatures in the different houses. The greatest differences in respiration rates occurred during the time when the animals were most exposed to the sun. At 2:30 P.M., when the temperatures were the same as those noted in the discussion of Figure 19, the average respiration rates were 72 per minute for the hogs in the double-pane house, 111 per minute in the house with no glass, 139 per minute in the single-pane house, and 175 per minute in the conventional house.

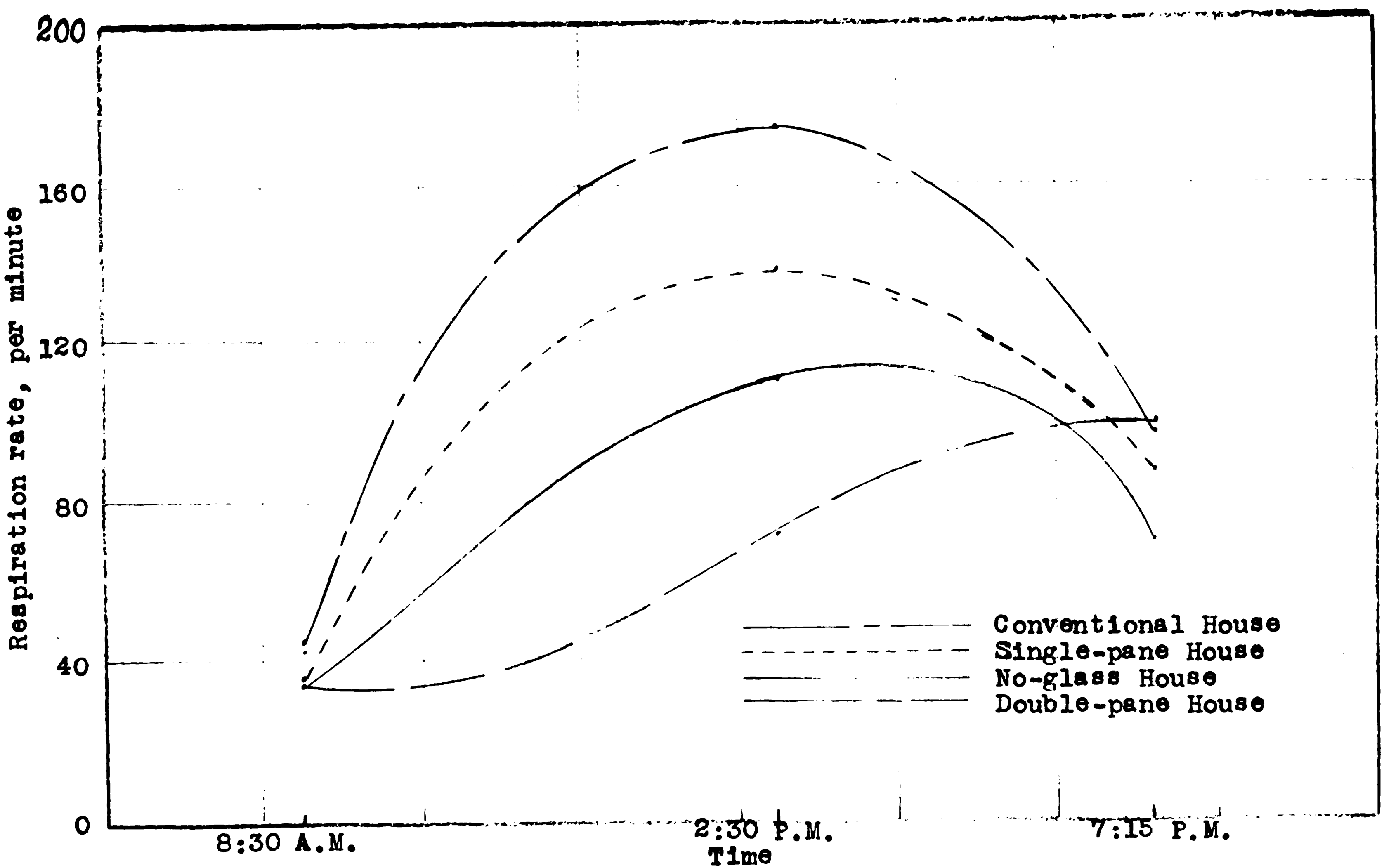

Figure 20. A comparison of the average respiration rates of three hogs in each of the houses on August 23, 1954.

Trial V--Winter, 1954-1955

The fifth trial was begun on December 17, 1954, and ended on April 8, 1955. The treatments were the same as that used in the fourth study, with six hogs in each treatment.

Temperature and relative humidity. The mean biweekly temperatures in all of the houses are shown in Figure 21, page 67. The temperatures in the conventional house were slightly higher than the outside temperature.

The mean temperatures in the single-pane house were higher than those in the double-pane house because the maximum temperatures in the single-pane house were higher. The maximum temperatures in the house with no glass were considerably lower than those in either of the other houses of similar structure, due to the lower amount of heat gain in the building. The double-pane house and the house with no glass maintained the most constant temperature throughout the trial.

The mean daily relative humidities are shown in Figure 22, page 68. As in the previous study, the relative humidity in the conventional house varied widely, while that in the other three houses had a much narrower range. The mean relative humidity in the dark house was considerably higher than in either the double-pane or single-pane houses. The humidities in the double-pane and single-pane houses were quite similar.

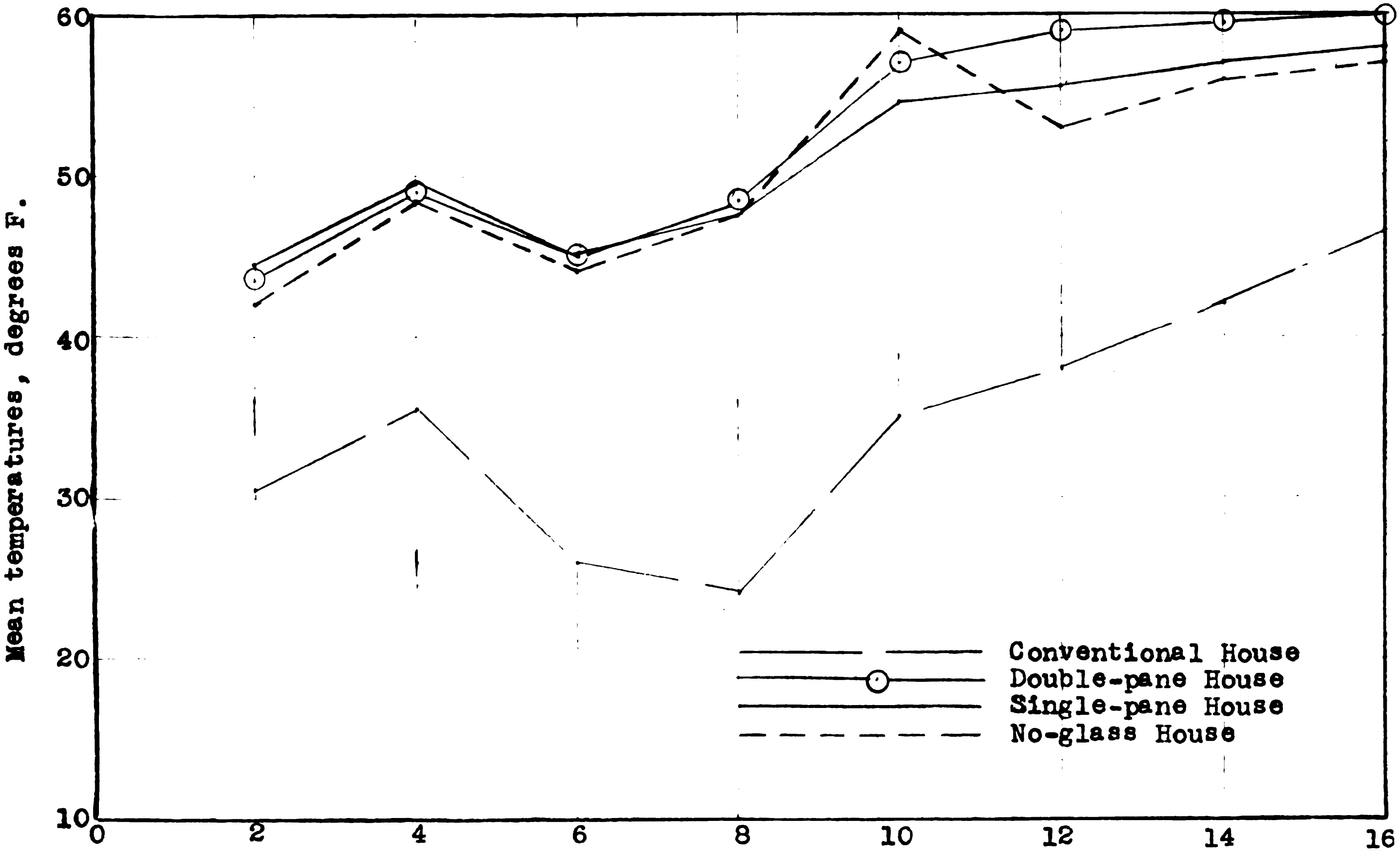

Figure 21. The mean biweekly temperatures in each of the houses in Trial V, winter, 1954-1955.

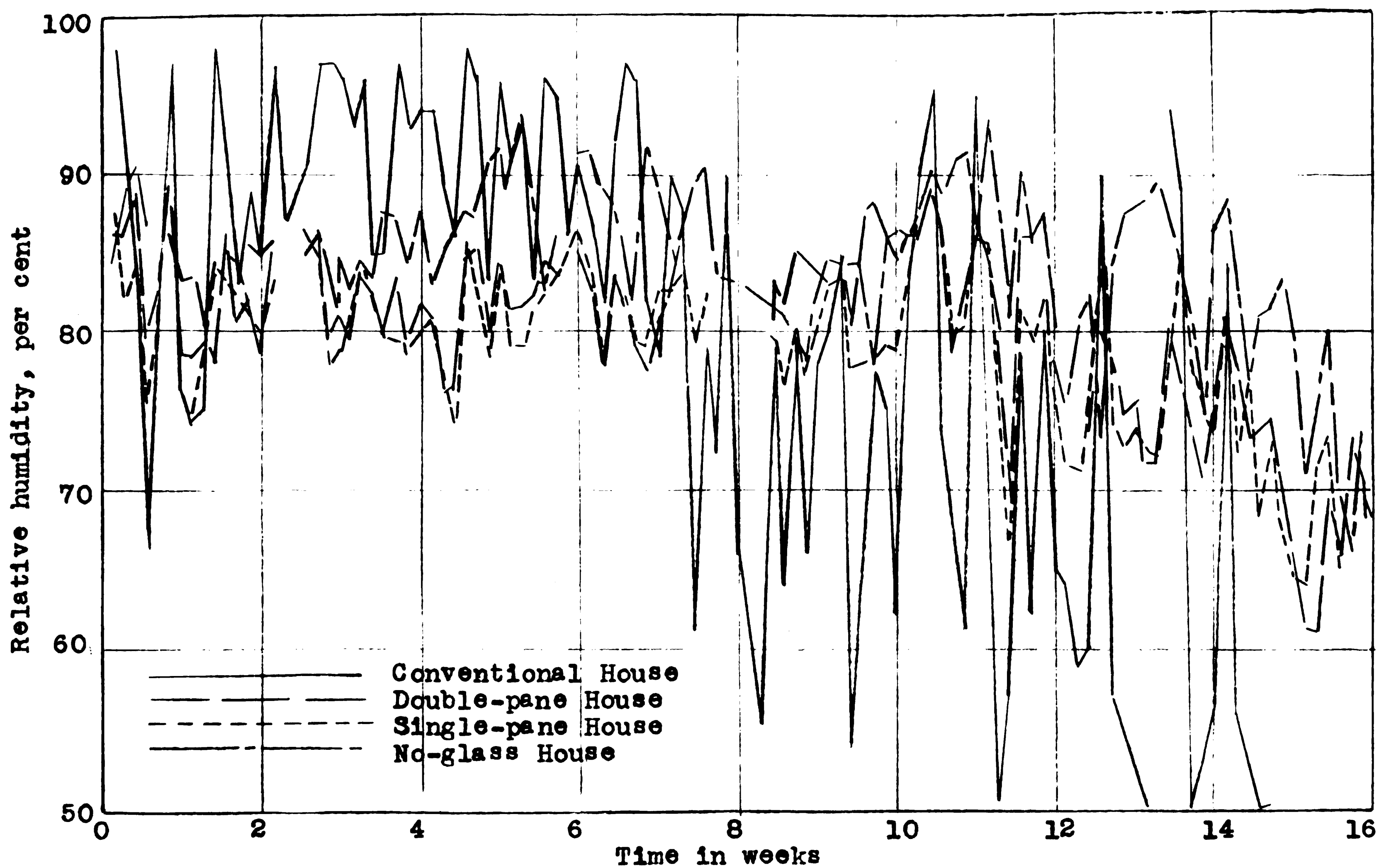

Figure 22. The mean daily relative humidity in each of the houses in Trial V, winter, 1954-1955.

__Feeding trial__. The results of the feeding trial are summarized in Table IX. An epidemic of dermatosis necessitated the removal of two pigs from the conventional house, and one from the single-pane house. One ruptured pig was removed from the house with no glass. For these reasons, no attempt was made to analyze the data statistically.

TABLE IX

PERFORMANCE OF THE HOGS IN
TRIAL V, WINTER, 1954-1955

Comparisons	Conventional House	Double Pane House	Single Pane House	No-glass House
No. of pigs	6 to 4*	6.	6 to 5*	6 to 5*
Ave. initial wt.* (lb.)	34.	36.5	36.4	36.4
Ave. final wt.* (lb.)	206.8	202.5	201.4	183.8
Ave. daily gain* (lb.)	1.50	1.45	1.43	1.28
Ave. daily feed** (lb.)	5.18	5.73	5.35	5.10
Feed/pound gain** (lb.)	4.07	3.97	3.96	4.01

*Computed only for pigs completing the experiment.

**Computed for all pigs while on the experiment.

Results of the trial show that the hogs in the conventional house made the highest average daily gains of 1.50 pounds, and those in the house with no glass made the lowest daily gains of 1.28 pounds. The hogs in the double-pane house and the single-pane house had gains of 1.45 and 1.44 pounds, respectively. The differences in feed efficiency were minor.

Trial VI--Summer, 1955

This trial began on May 27, and ended on September 2. An additional treatment was added to those used in the two previous trials in the form of a double-pane house with an air conditioner installed. Attempts were made to maintain a temperature of 75 degrees F., in the air conditioned house. A portable livestock shade was provided for the hogs in the conventional house.

Temperature and relative humidity. The biweekly mean temperatures in all houses are shown in Figure 23, page 71. As in the previous summer study, the mean temperatures in the conventional house were slightly higher than outside temperatures. The hourly recorded temperatures in the double-pane, single-pane, and no-glass houses did not vary appreciably.

The temperatures in the air conditioned house varied from approximately 69 degrees to 79 degrees F., except for a few days when the air conditioning unit was not functioning properly. Attainment of a constant temperature environment was best approached by the air conditioned house.

The mean daily relative humidities are shown in Figure 24, page 72. The greatest variation in relative humidity occurred in the conventional house. The air conditioned house

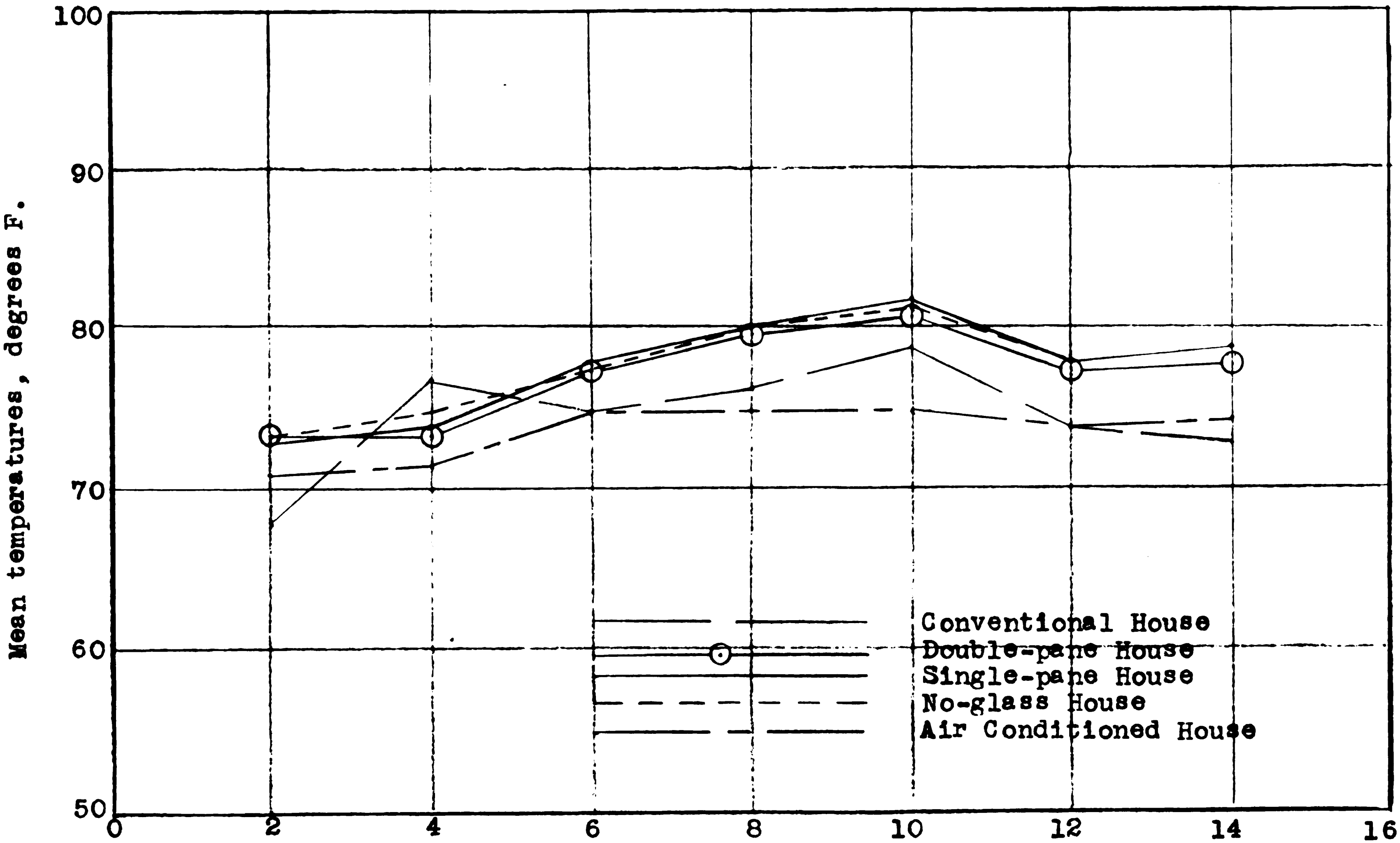

Figure 23. The mean biweekly temperatures in each of the houses in Trial V, Summer, 1955.

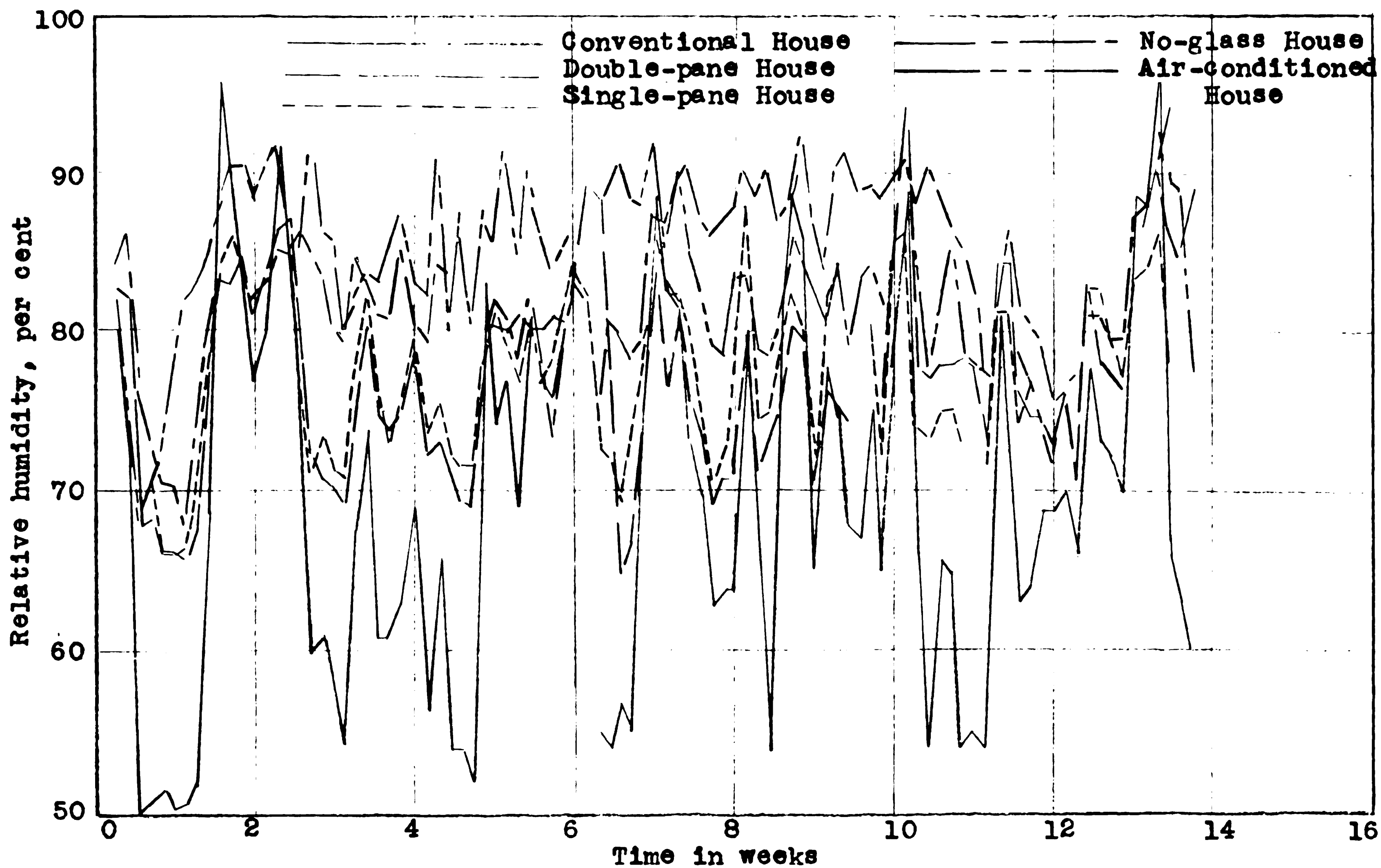

Figure 24. The mean daily relative humidities in each of the houses in Trial VI, Summer, 1955.

had the highest humidity values in the first half of the trial, and the house with no glass had the highest values in the second half.

Feeding trial. Results of the sixth feeding trial are shown in Table X. The hogs in the no-glass house made the highest average daily gains of 1.66 pounds, followed closely by the hogs in the double-pane and single-pane house, with 1.63 pounds and by those in the air conditioned house with 1.61 pounds. The lowest daily gain of 1.48 pounds was made by the hogs in the conventional house.

TABLE X

PERFORMANCE OF THE HOGS IN TRIAL VI, SUMMER, 1955

Comparisons	Conventional House	Double Pane House	Air Conditioned House	Single Pane House	No-glass House
No. of pigs . . .	6	6	6	6	6
Ave. initial wt. (lb.)	36.2	35.8	36.2	35.5	36.2
Ave. final wt. (98 days) (lb.)	181.3	195.9	193.3	195.2	198.5
Ave. daily gain (lb.)	1.48	1.63	1.61	1.63	1.66
Ave. daily feed (lb.)	5.61	5.72	5.50	5.78	5.84
Feed/pound gain (lb.)	3.79	3.49	3.42	3.55	3.53

The hogs in the air conditioned house were most efficient in the conversion of feed to gain, with 3.42 pounds of feed, per pound of gain. The hogs in the conventional house were least efficient, with a figure of 3.79 pounds of feed, per pound of gain.

An analysis of co-variance, as shown in Table XI, page 75, indicates that the differences in the average final weights of the hogs were not statistically significant.

A comparison of the performance results obtained in the summer of 1954 and of 1955 does not confirm the suggestions of Palmer (1917), and Tidwell and Fletcher (1951), on the detrimental effects of exposure to the direct rays of the sun, and of Bray (1948), and Heitman (1949) on the benefits derived when animals are exposed to evaporating water.

In the summer of 1954, the hogs in the conventional house were provided very little protection from the direct rays of the sun, and no attempts were made to enhance evaporative cooling. In this trial, the hogs in the conventional house had an average daily gain which was 7.3 per cent less than the average of the hogs in the experimental houses. The following summer, the hogs were provided with a livestock shade and the concrete slabs were sprayed with a hose on warmer days. However, in this trial, the average daily gains of the pigs in the conventional house was 9.8 per cent less than those in all of the experimental houses. These results were obtained des-

TABLE XI

CO-VARIANT ANALYSIS OF THE INITIAL AND FINAL WEIGHTS OF THE HOGS IN TRIAL VI, SUMMER, 1955

	Observed				Adjusted		
Source	Degrees of Freedom	Sum of Squares of Initial Wts.	Sum of Products of Initial and Final Wts.	Sum of Squares of Final Wt.	Sum of Squares of Final Wt.	Degrees of Freedom	Mean Square
Total	29	575.0	1501.8	13458.2			
Treatment	4	2.1	- 15.3	1017.3			
Error	25	572.9	1527.3	12440.9	8363.3	24	348.5
Treatment Plus Error	29	575.0	1501.8	13458.2	9538.4	28	
Treatment	4				1175.1	4	293.8
F value					Not Significant		1.18

pite the fact that a more adequate conventional house was provided for the 1955 trial than for the one in 1954.

Physiological responses. The effect of the immediate environment of the hogs on their rectal temperature and respiration rate was observed. In this trial, 339 observations were made and these most frequently involved both physiological responses.

Figure 25, page 77, shows the observed effects of ambient temperature on rectal temperature of the hogs. A total of 294 rectal temperature observations were made in ambient temperatures, ranging from 69 to 94 degrees F. Individual rectal temperature measurements ranged from a low of 101.2 to a high of 105.8 degrees F. Averages of the rectal temperatures at the various ambient temperatures indicates an average rectal temperature of 103.4 and the maintenance of this level at ambient temperatures of between 82 and 94 degrees F. At ambient temperatures increasing from 69 to 82 degrees F., the rectal temperature increased from an average of 102.4 to 103.4 degrees F. In contrast to the previous summer study, high ambient temperatures--up to 94 degrees F., did not cause rapid increases in rectal temperatures.

In Figure 26, page 78, ambient temperatures are plotted with the respiration rates of the hogs. A total of 246 observations were made in the temperature ranges existing during the time the hogs were on trial. The data indicate that the res-

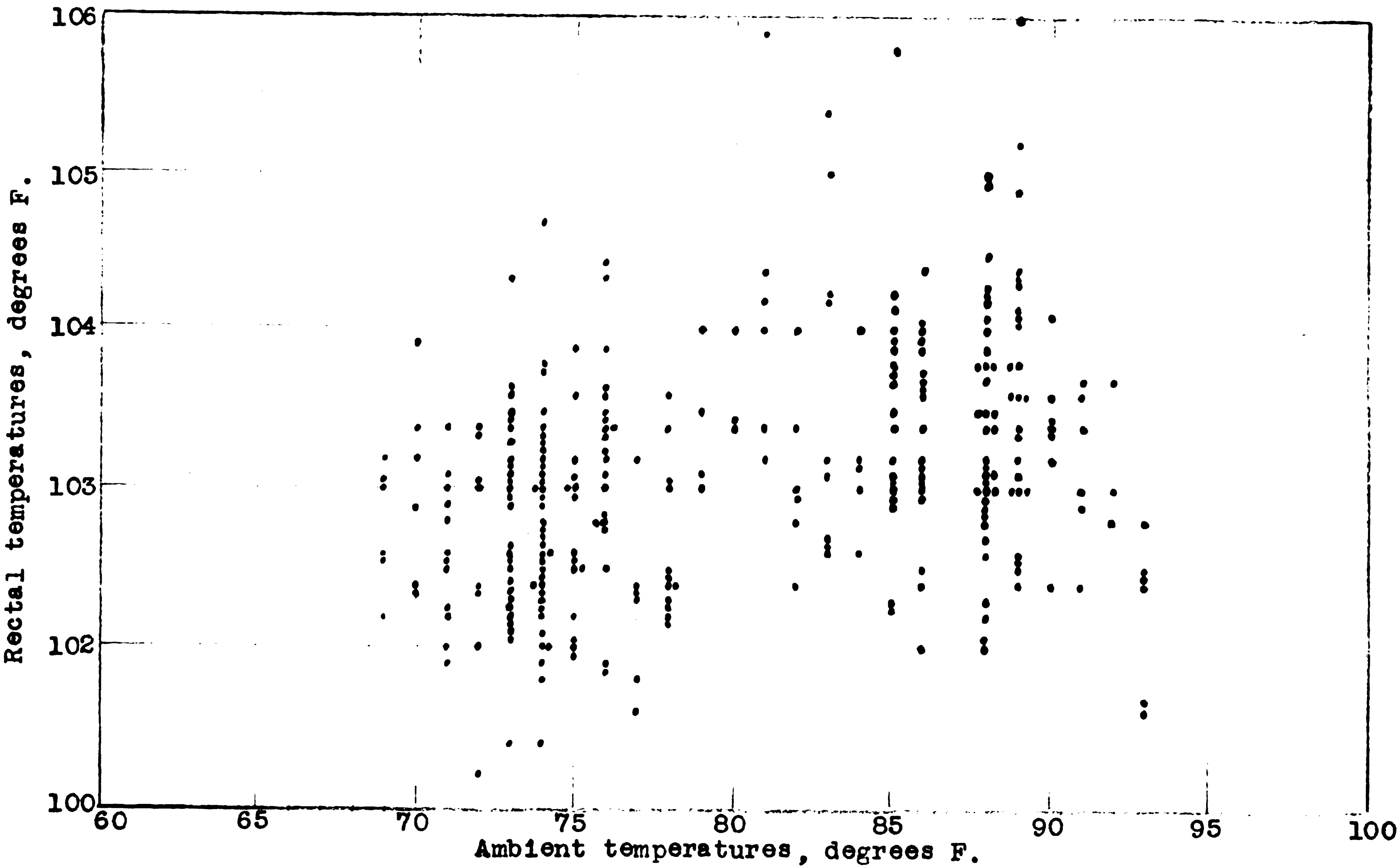

Figure 25. The effect of ambient temperature on body temperature of the hogs in Trial VI, Summer. 1955.

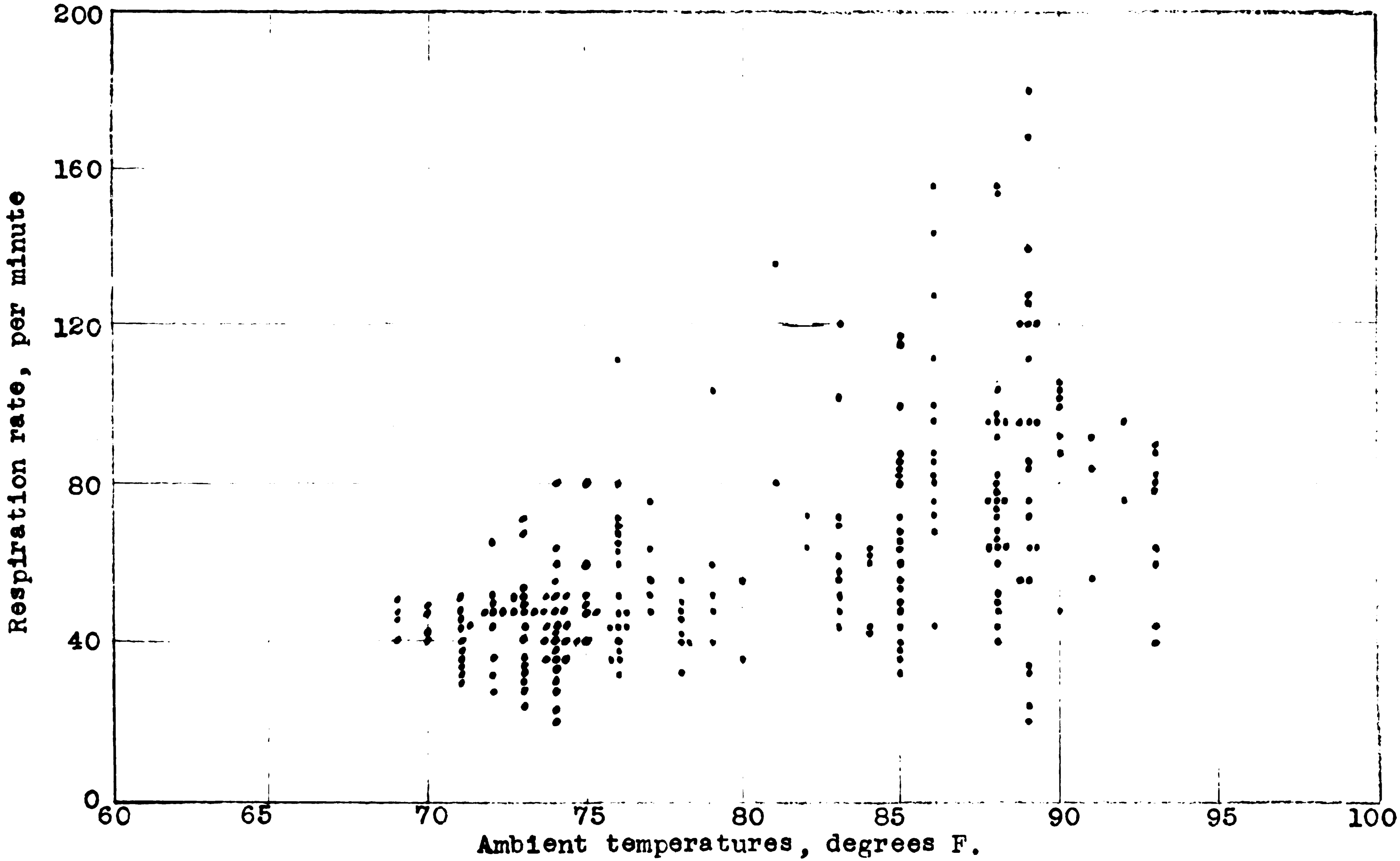

Figure 26. The effect of ambient temperature on respiration rate of the hogs in Trial VI, Summer, 1955.

piration rates increased from an average of 39 to 97 respirations per minute as the ambient temperature increased from 69 to 94 degrees F. Individual respiration rate observations varied from 20 to 168 respirations per minute.

As shown in Figure 27, page 80, a curvilinear relationship existed between the rectal temperatures, and respiration rates of the hogs. At a rectal temperature of 101 degrees F., a respiration rate of 40 is indicated, and with a rectal temperature of 106 degrees F., a respiration rate of 148 would be expected. The chart is a result of 207 observations of respiration rates and ambient temperatures made on the same hogs at approximately the same time.

A further indication of the effect of exposure to the sun on physiological responses is found in the differences in responses of the hogs in the summers of 1954 and 1955. In 1955, the hogs were protected from the direct rays of the sun by the placement of a livestock shade on the concrete slab surrounding the conventional house, and by the use of a larger conventional house. The data collected in the summer of 1954 indicate that at an ambient temperature of 94 degrees F., the rectal temperatures of the hogs averaged 105.7 degrees F., and the respiration rate averaged 154 respirations per minute. On the other hand, the data collected in the summer of 1955 indicate that at an ambient temperature of 94 degrees F., the rectal temperature of the hogs averaged 103.3 degrees F., and

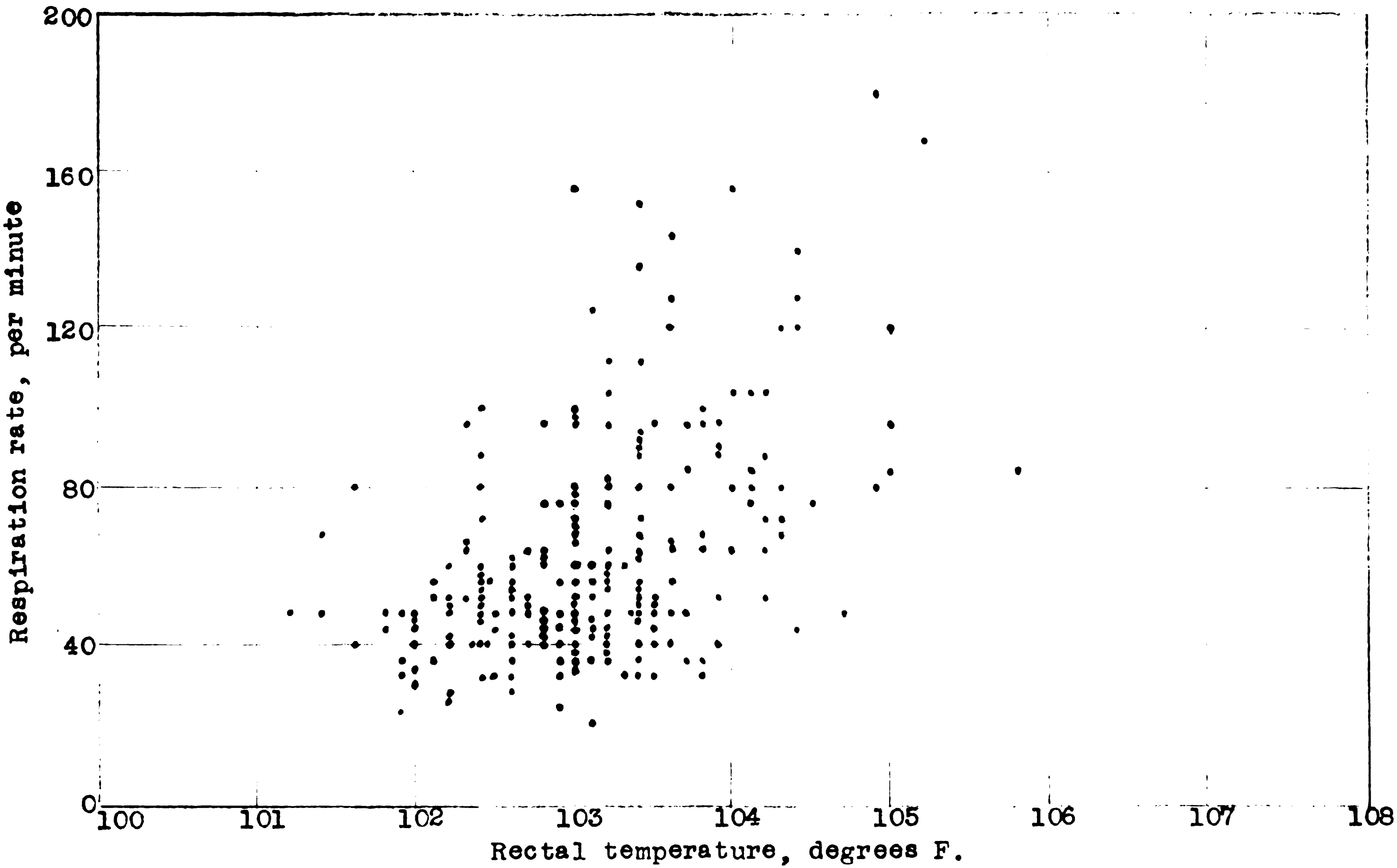

Figure 27. The relation between body temperature and respiration rate of the hogs in Trial VI, Summer, 1955.

the respiration rate averaged 91 respirations per minute. These observations were in agreement with the work by Palmer (1917) and Tidwell and Fletcher (1951).

One of the factors contributing to the differences in the physiological responses may well have been the addition of the livestock shade during the summer of 1955.

Another factor which probably contributed to the differences in the physiological responses from the summer of 1954 to 1955, is the way in which the hogs were managed. When the atmospheric temperatures reached a point of approximately 85 degrees F., the concrete slab of the conventional house was sprayed with a water hose, and the pigs laid in the moisture provided.

According to the studies made by Bray (1948) and Heitman and co-workers (1949) with swine, and Miller (1951) with dairy cattle, the use of wallows, evaporating water on the floor, or water sprinkled over the animals brings about a depression of body temperature and respiration rate at elevated ambient temperatures. In the trial conducted in the summer of 1955, there was no way to separate the effects of ambient temperature, exposure to the sun, and spraying of the slab on the physiological responses observed.

The absence of exaggerated physiological responses to high ambient temperatures in the summer of 1955 may also have been partly due to an adaptation of the hogs in the latter summer trial to higher temperatures than those produced in the summer of 1954. In the summer of 1955, the mean daily temperatures frequently exceeded 80 degrees F. in all of the houses; whereas, in 1954, the mean daily temperature reached 80 degrees F. only twice in the single-pane house, and not once in any of the others.

According to explanations by Lee (1948a), an acclimatization process could have enabled the hogs raised in the summer of 1955 to maintain normal physiological responses at the elevated temperatures occurring at this time. The marked displacement of the zone of thermal neutrality from the summer of 1954 to the summer of 1955, is further indication that an acclimatization process had occurred.

The range of thermal neutrality found in the summer of 1954 agrees quite closely with the findings of Heitman et al. (1949), who reported optimum temperatures of from 66 to 75 degrees F. The lower range of thermal neutrality found in the same trial agrees remarkably well with the reports of Tangl (1912), and Capstick and Wood (1922), who observed that the critical temperature of the pig was 68 degrees F.

Trial VII--Winter, 1955-1956

The final trial was begun on December 21, 1955, and ended on February 28, 1956. For this trial, the house with no glass was equipped with five heat lamps, with thermostatic controls set at 60 degrees F. After the removal of the air conditioner, the double-pane house was rotated so that the glass area faced east, instead of south.

Temperature and relative humidity. The biweekly mean temperatures are shown in Figure 28, page 84. The mean temperatures in the double-pane housing, facing east, were usually 3 to 8 degrees F., higher than those in the double-pane house, facing south. Mean temperatures in the south-facing double-pane house, and the single-pane house were 10 to 20 degrees F. higher than those in the conventional house.

The temperatures in the heated house averaged 58 degrees F., for most of the trial, and was more constant than in any of the other houses.

As shown in Figure 29, page 85, the mean relative humidity in the conventional house was consistently higher than in any of the test houses. No other marked trend was noticeable.

Feeding trial. Results of the seventh feeding trial are shown in Table XII, page 86. The statistical analysis, shown in Table XIII, page 87, indicates that the differences in the final weights of the hogs in this trial were not significant.

The hogs in the double-pane house, facing east, made the highest average daily gains of 1.94 pounds, and those in

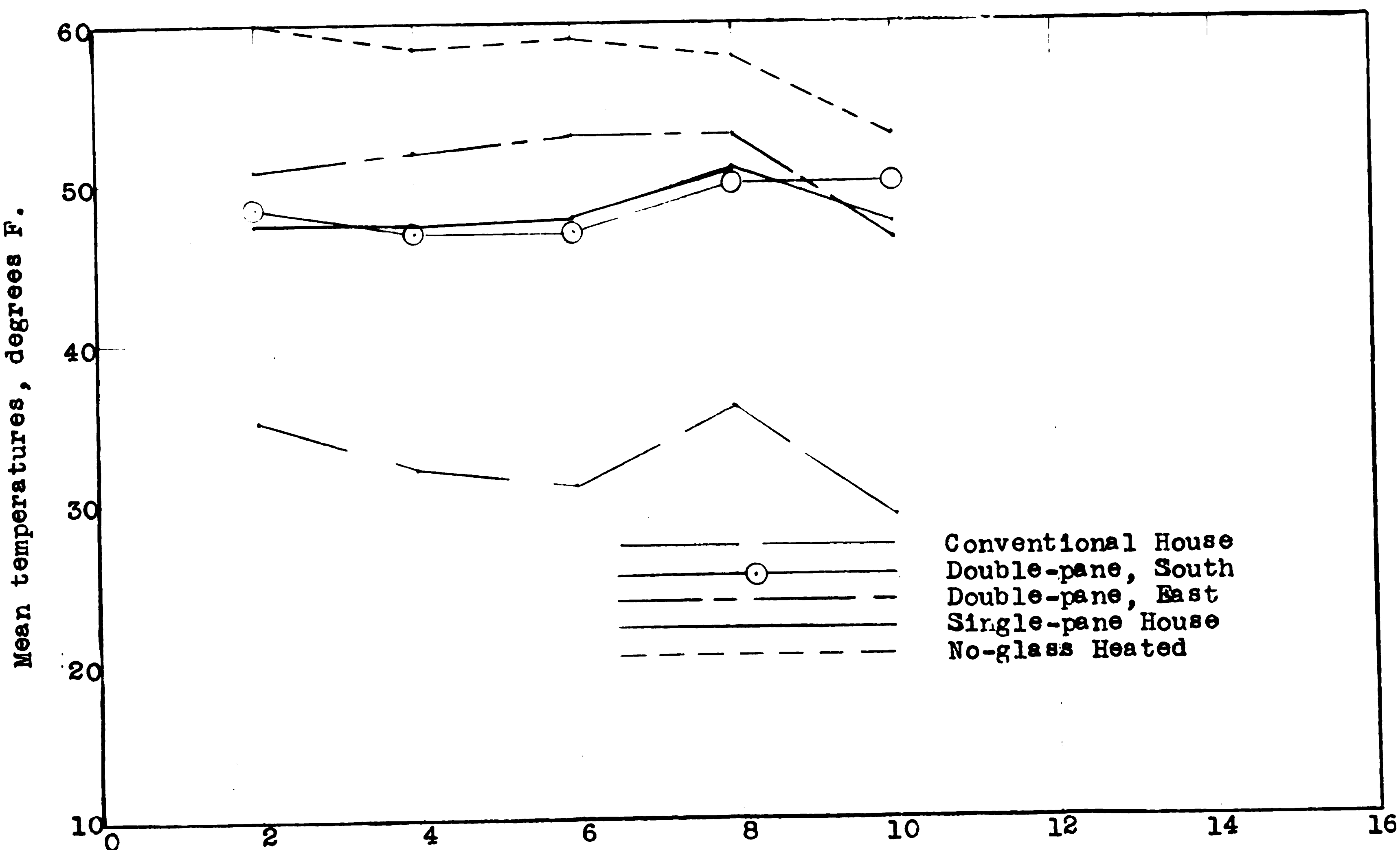

Figure 28. The biweekly mean temperatures in each of the houses in Trial VII, winter, 1955-1956.

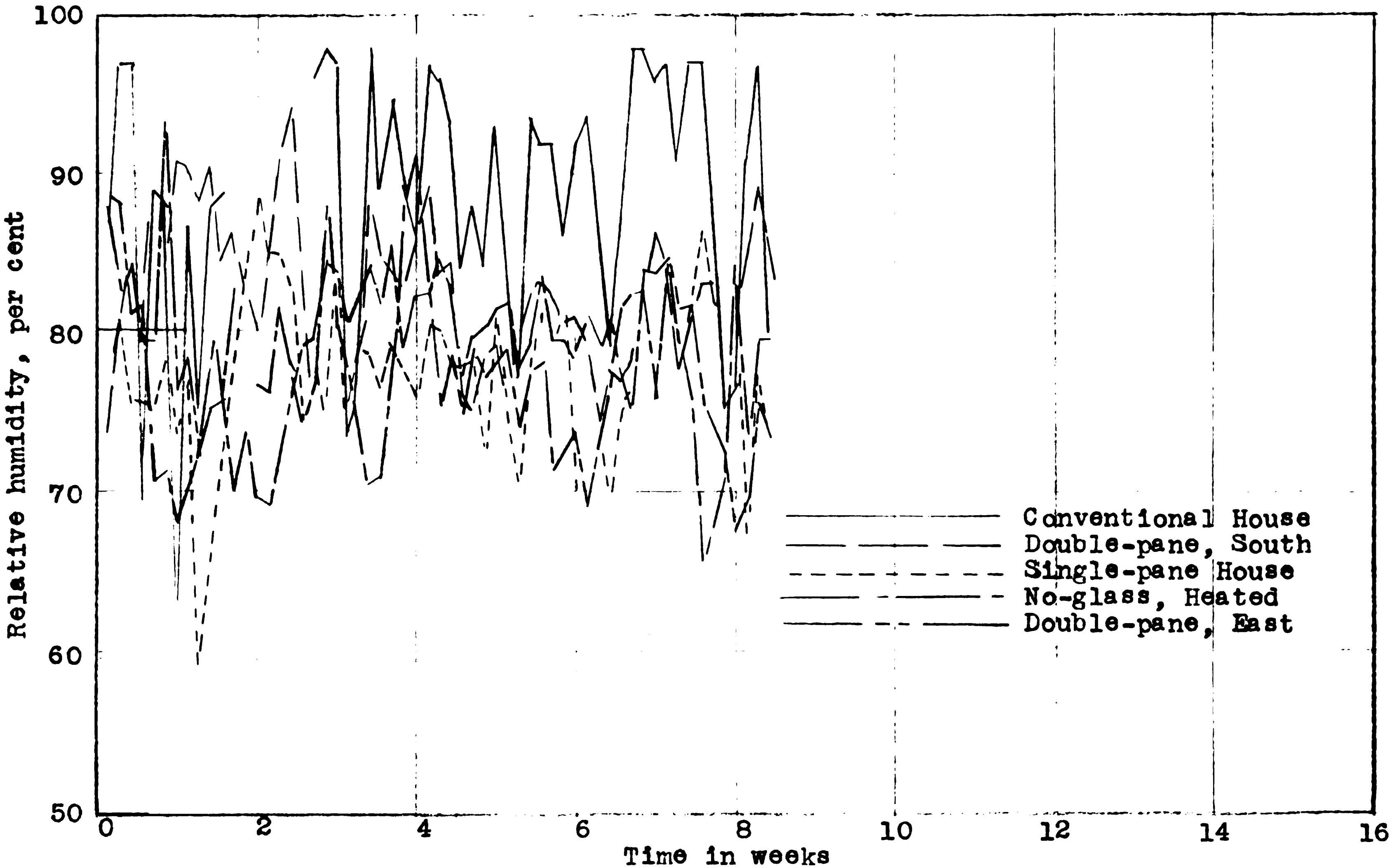

Figure 29. The daily mean relative humidities in each of the houses in Trial VII, Winter, 1955-1956.

the conventional house made the lowest, of 1.77 pounds, per day. Hogs in the double-pane house, facing south, the single-pane house, and the heated house with no glass, made similar daily gains of 1.88, 1.87, and 1.85 pounds, respectively.

TABLE XII

PERFORMANCE OF THE HOGS IN TRIAL VII, WINTER, 1955-1956

Comparisons	Conventional House	Double-pane House South Side	Double-pane House East Side	Single Pane House	No-glass House, Heated
No. of pigs . .	6	6	6	6	6
Ave. initial wt. (lb.)	81.2	81.4	81.3	81.4	81.3
Ave. final wt. (69 days) (lb.)	203.3	210.7	215.4	209.9	208.7
Ave. daily gain (lb.)	1.77	1.88	1.94	1.87	1.85
Ave. daily feed (lb.)	7.91	7.32	7.29	7.25	7.00
Feed/pound gain (lb.)	4.47	3.91	3.76	3.90	3.79

The hogs in the double-pane house also made the most efficient gains in consuming 3.76 pounds of feed, per pound of gain. The efficiency of the hogs in all of the houses followed in the same order as the average daily gains.

In the sixth and seventh trials, an attempt was made to maintain an "optimum temperature" for the hogs. However,

TABLE XIII

CO-VARIANT ANALYSIS OF THE INITIAL AND FINAL WEIGHTS OF THE HOGS IN TRIAL VII, WINTER, 1955-1956

	Observed				Adjusted		
Source	Degrees of Freedom	Sum of Squares of Initial Wts.	Sum of Products of Initial and Final Wts.	Sum of Squares of Final Wts.	Sum of Squares of Final Wts.	Degrees of Freedom	Mean Square
Total	29	1846.3	949.9	5937.4			
Treatment	4	0.1	6.2	445.2			
Error	25	1846.2	943.7	5492.2	5010.9	24	208.8
Treatment plus Error	29	1846.3	949.9	5937.4	5453.0	28	
Treatment					442.1	4	105.3
F value					Not Significant		1.98

the question of "optimum temperature" for hog growth requires still further study. The studies of Lee (1948a, 1948b), regarding acclimalization, are supported by the work reported here. The effects of any normally encountered temperature on the productive performances of hogs will, to a large extent, be affected by the previous temperatures to which the animals have been exposed. Inglis and Robertson (1949), and McLagan and Thompson (1950) state that young pigs can be subjected to a rather wide range of temperatures and still make good growth. The results of the trials conducted here also support the contention of these authors that the construction of pig houses and pens may affect pig growth through means other than the regulation of ambient temperature.

Beoause of the lack of control of ambient temperature in the houses used in this study, it was found difficult to correlate different ambient temperatures with the productive performances of the hogs. However, in Figures 30 and 31, pages 89 and 90, the relationship between the biweekly mean temperatures and biweekly average daily gain in a conventional house for both a winter and summer trial are shown.

In the summer trial, Figure 30, page 89, it may be noted that increases in the biweekly mean temperatures are accompanied by decreases in the average daily rate of gain in the same two-week period, or the two-week period following the increase in temperature. Even slight decreases in the biweekly

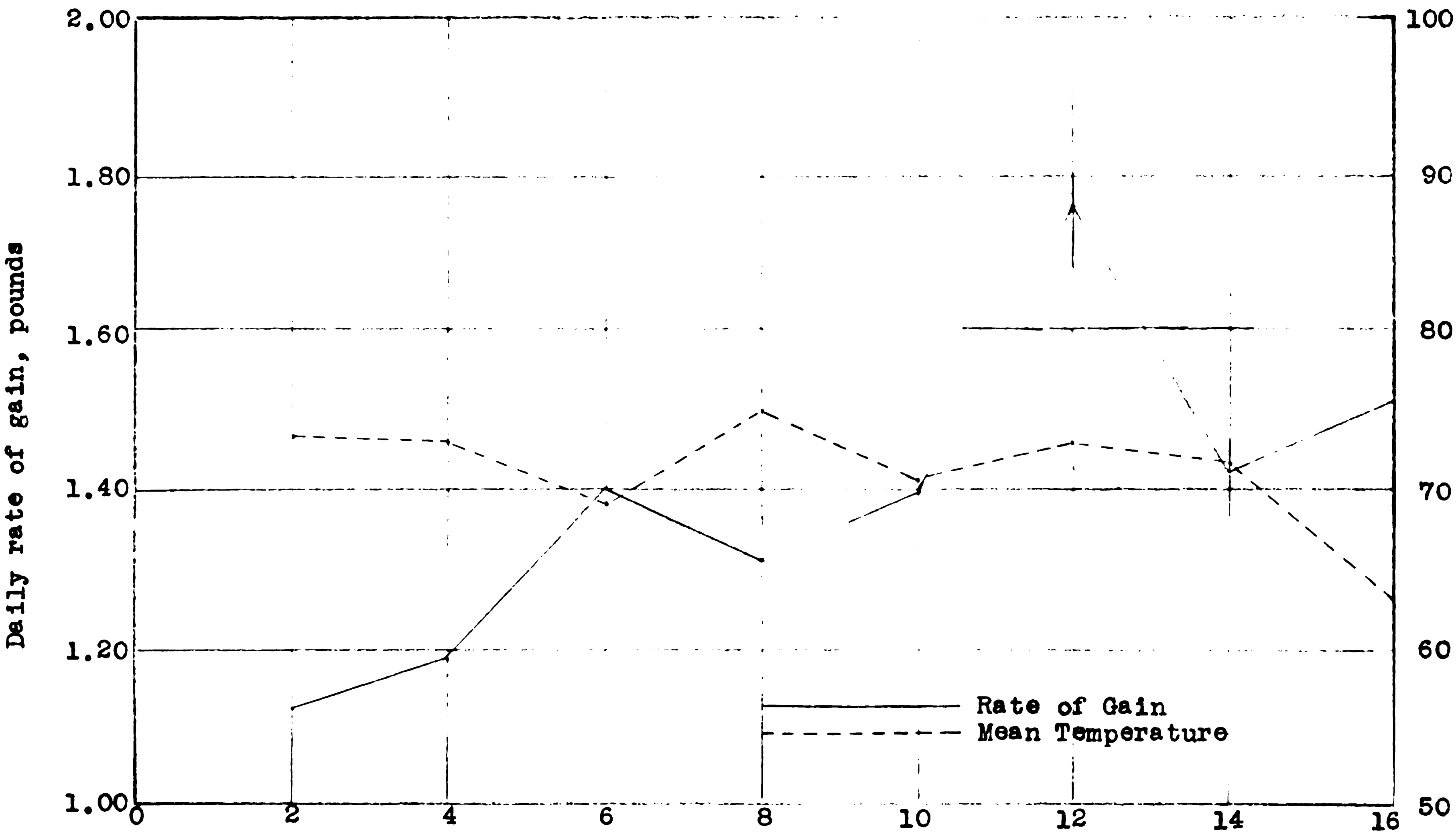

Figure 30. A comparison between the biweekly mean temperatures and the biweekly average rate of gain for the pigs in the conventional house in the summer of 1954.

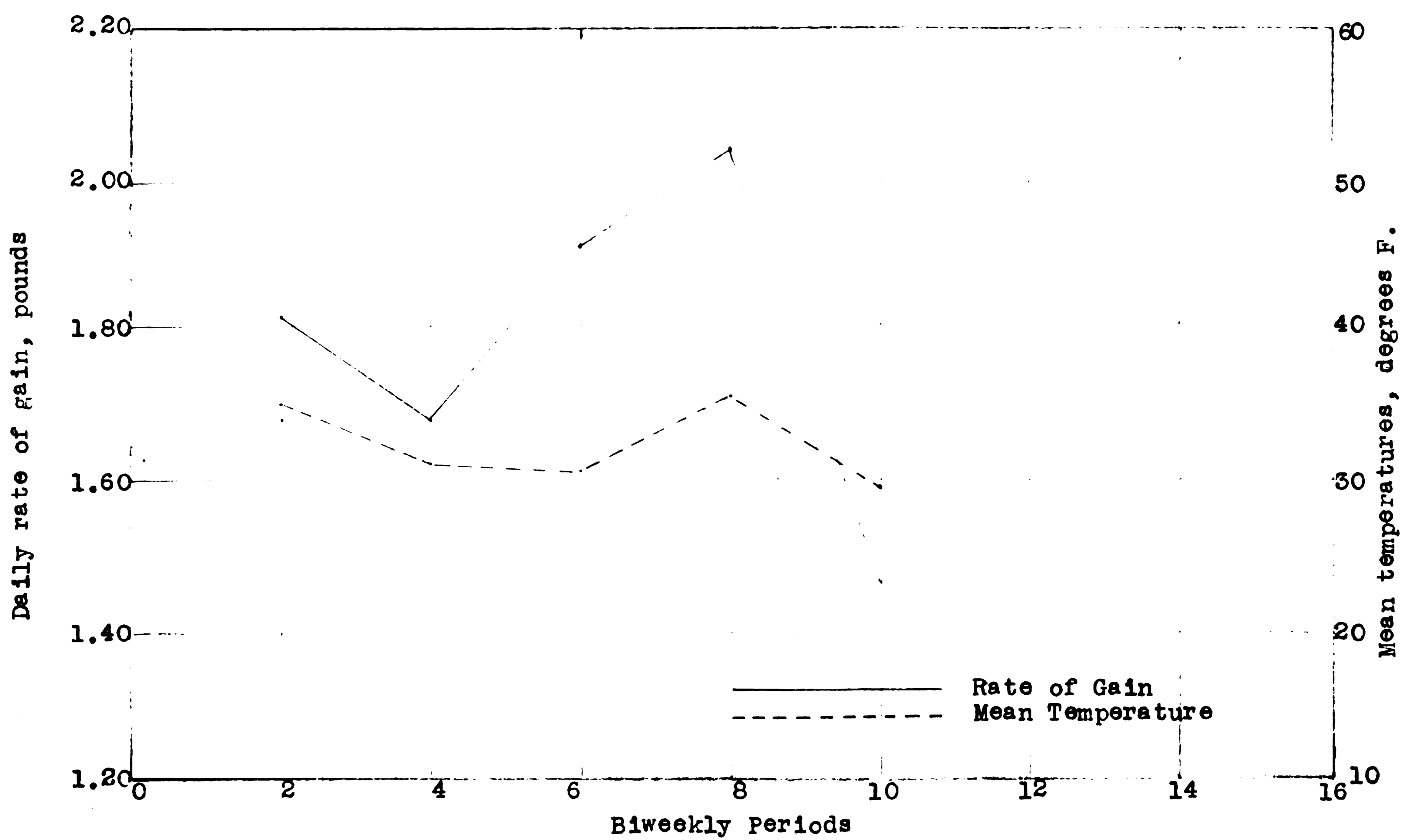

Figure 31. A comparison between the biweekly mean temperatures and the biweekly average rate of gain for the pigs in the conventional house in the winter of 1955-1956.

mean ambient temperatures are accompanied by increases in the rate of gain in the same, or following two-week period.

In the winter trial, Figure 31, page 90, increases in, or maintenance of, the biweekly mean temperatures are attended by increases in the average rate of gain. Conversely, decreases in the mean temperatures co-exist with decreases in the average rate of gain.

SUMMARY AND CONCLUSIONS

The physiological response of growing-fattening swine to different housing environments was studied in seven trials. The trials were begun in the winter of 1952-1953, and were continued alternately through winter and summer through the winter of 1955-1956.

The animals were placed in the trials at average weights ranging from 23.5 to 100 pounds, and continued on trial until they reached market weight. The hogs were weighed at two-week intervals, and the feed and water consumptions were computed.

Random determinations were made of rectal temperature, respiration rate, and pulse rate in the summer of 1954, and of rectal temperature and respiration rate, in the summer of 1955. The temperatures and relative humidities in each house, and in the surrounding atmosphere were recorded at one hour intervals.

From an examination of the results obtained under the conditions of this study, the following conclusions are made:

1. Improved housing environments are conducive to better growth and feed efficiency by growing-fattening swine.

2. The growth-promoting effect of the improved houses are attributed to the more moderate and constant temperatures maintained within these houses.

3. Lower daily mean temperatures in summer, and higher mean daily temperatures in winter are accompanied by faster rates of gain and better feed efficiencies.

4. The exclusion of natural sunlight from a swine house does not materially affect the performance of the hogs fed an adaquately supplemented diet.

5. The use of supplemental temperature controls for hogs does not bring about any improvement in the performance above that obtained in a well-constructed house without supplemental heating or cooling.

6. Increases in the ambient temperature of swine are accompanied by increases in rectal temperature, increases in respiration rate, and decreases in pulse rate with varying zones of thermal neutrality in each response.

7. The physiological response of growing-fattening swine to different ambient temperature may be altered by shade and moisture, and by the acclimatization of the animals.

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