TEMPERATURES AND TEMPERATURE DISTRIBUTION IN HOG HOUSE WITH SLATTED FLOOR OVER LAGOON

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ABSTRACT

TEMPERATURES AND TEMPERATURE DISTRIBUTION IN HOG HOUSE WITH SLATTED FLOOR OVER LAGOON

by Trygve Graee

The present work deals with the influence of temperature on growth, feed conversion ratio of growing-finishing hogs, temperature distribution in a prefabricated hoghouse with slatted floor over lagoon and some general performance characteristics of the same house.

Data from the literature indicates that inferior feed conversion of hogs at lower temperature not only is due to a greater heat loss, but also to a higher energy content being built up in the carcass. Although most experiments and investigations show a definite influence of high and low temperature there is no great consistency in the magnitude of the effect. This is found partly to be due to differences in test procedure and that the air temperature rather than the microenvironment is considered. Data is also assembled that indicates a greater effect of low temperature on hogs on slatted floors than in other hog housing systems.

The temperature recorded in the slatted floor house at the hog level in the wintertime is far below what climatic laboratory research results show to be optimal.

A vertical temperature gradient of up to 20°F was encountered in the house in the winter period. This gradient was only about 8°F for the spring and summer period under consideration. A lagoon temperature of about 40, 50 and 60°F was encountered for winter, spring and summer respectively. This was interpreted to affect the proper

room air temperature in winter compared to summer in the house. Research should be done to find methods of reducing the vertical temperature gradient in slatted floor swine buildings.

Calculations showed the heat generation in the house to be inadequate to maintain the desired climatic conditions in the house. Improved thermal insulation was found to be good economy at current prices.

Heat balance calculation should be based on 50 lb hogs as these may be the only heat source in the house at any time of the year.

The lagoon below the slatted floor removed moisture from the room air in the winter.

The bacterial activity in the lagoon was low in the winter months.

Serious condensation was observed in the attic of the house caused by moist air from the pen area. The ventilation system should be redesigned to prevent such occurrences.

Considerable wear of the oak slats was encountered after one year. Other materials as concrete are well worth considering as another choice.

Odor from the lagoon may limit the lagoon system to uninhabited areas if no economic way is found to exclude the odor generated.

The health condition in the house was poor with many losses of hogs. The deaths were diagnosed as being due to stomach ulcer, pneumonia and cannibalism with chewed out rectum or tailbiting, resulting in bleeding to death or infection.

To have a balanced economy for the house, both reduced losses of hogs and better feed conversion and a lower purchase price of pigs are necessary at the obtained selling prices.

Full scale experiments should be carried out to determine the optimal temperature for growing-finishing hogs on slatted floors.

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Approved for J S Boyd
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TEMPERATURES AND TEMPERATURE DISTRIBUTION IN HOG HOUSE WITH SLATTED FLOOR OVER LAGOON

By

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TABLE OF CONTENTS

TABLE OF CONTENTS - Continued

LIST OF TABLES

TABLE Page

LIST OF FIGURES

LIST OF FIGURES - Continued

FIGURE | Page

A. INTRODUCTION

Swine and poultry used to be the domestic animals requiring little care by farmers. They were carried along with other production to provide pork and eggs for the farm family. Commercial production of hogs and poultry more frequently was found on small holdings. The hogs and chickens had access to fields to scavenge for food in addition to waste from the household. The housing was a poor shelter, a condemned building or a straw stack if any housing at all was provided.

Today this situation is changed although the old management still is practiced. By far the major part of the poultry production is carried out on a factory scale and hog raising is turning rapidly in the same direction. Never before has there been such a high demand for knowledge and experiment in these fields and the results are rapidly applied.

The reason for this change is a pooled effect of different circumstances as better communications, more capital available for investment, a more stable market by utilizing conserving and storing techniques, better knowledge about feed and feeding, better knowledge about sanitary and veterinary questions and improved sanitary and veterinary remedies, improved housing and mechanical equipment and methods.

The profit margin has decreased considerable, but improved control of production and a more stable market have lessened the hazard so that a supply of good nourishing food is possible at reasonable prices.

As an example of what results can be obtained in a short period of time the following data is taken from Agricultural Statistics U.S.D.A. (1961). Broiler production in U.S.A. in 1947 was about 900 million pounds at an average price of 32.3 cents/pound. In 1960 the production was more than six fold, about 6 billion pounds at a price of 16.9 cents/pound. Poultry ration cost was $4.17 per 100 lb in 1947 and $3.33 in 1960. Allowing for the decreasing value of money these figures become farther apart indicating a more realistic increase in productivity.

Most experiments show a pronounced effect of environment on hog performance, rate of growth and feed efficiency. Feed is known to share a great part of production costs. This can be demonstrated by data from Agricultural Statistics (1961). In 1960 the average price of hogs was 15.3 cents/pound to farmers. Average hog size 236 lb. In the Lansing area (1963) an average feed price of 3.5 cents/pound is used for calculation. Assuming a feed efficiency of 3.5 lb of feed/lb of gain we get per hog:

Selling price	0.153 x 236	=	$36.10
Feed cost	0.035 x 3.5 x 236	=	$29.00
Difference			$ 7.10

The difference has to cover labor, housing, medicine, loss of hogs, the life value of the pigs etc. According to these figures the feed cost will contribute 2900/36.10 = 80 percent to the production cost when the operator has his costs covered without profit. These figures show the profit margin is small, and the farmers are eagerly looking for means to decrease production costs. Every effort in this direction is well worth considering. Agricultural Statistics give the number of hogs slaughtered in U.S.A. 1959 to be 87,607 millions. Average live weight 236 lb. The gross income $2,285,728,000 on an average price per 100 pounds received by farmers of $14.10. Only a small improvement in production efficiency will justify research.

B. OBJECTIVE

By laboratory experiments data concerning the influence of environmental climate on hogs have been obtained. Field experiments have also been carried out under practical conditions to investigate the effect of environmental temperature and housing systems on swine.

Both of these methods have their limitation for general use. Many of the laboratory data are questionable because of test procedure and because test conditions are different from the practical situation. The field experiments often suffer from scarce or incomplete data about the real environment or microclimate the hogs have been exposed to.

The objective of the present investigation is to supply detailed climatic data for a new type of commercial hog house with a slatted floor and lagoon, to show the seasonal and general temperature evolution in such houses and to enable us to evaluate the effective environmental temperature to which the hogs are exposed in these houses. The investigation is also intended to provide information and direction for further investigation and experimental design and for improvement in the design of this housing system.

In the present house being investigated the principal difference from the traditional housing methods is the floor. We therefore intend to analyze and apply available experimental data to the effect this type of floor may have upon the hogs efficiency. As the cold rather than the heat stress probably is more pronounced in this area (Lansing) and also in the authors home country (Norway) the influence of low rather than high temperature will be dealt with more thoroughly.

C. FUNDAMENTALS AND REVIEW OF LITERATURE

1. Heat Balance of Hogs

Swine are like other higher mammals and birds, homeothermic. The average rectal temperature of healthy hogs is 102.5°F with a range from 101.6°F to 103.6°F, (Mitchell and Kelly, 1930). They can exist for prolonged periods of time only as long as their body temperature is within this range.

To maintain a constant body temperature swine have to exchange heat with the environment. This occurs according to the known principles of heat transfer. Within a certain range the hogs can adjust to ambient climate easily, but the further from the optimal condition the harder it is for the animal to adapt.

The homeothermic animals maintain their temperature and activity by tissue oxidation. The rate of metabolism is normally a function of body weight, growth, activity and feed consumption.

The ability of swine to adapt to the environmental temperature depends to a certain extent upon their body size and age. Brody (1945) has found the basal heat production in most homeotherms to follow the equation:

$$Q = KW^{3/4}$$

where Q = heat production in Btu/hr
K = coefficient
W = weight of animal in pounds

For basal conditions the value of K is 6.5. By feeding the value of K will increase to one-half times that of basal or more.

The basal energy metabolism for hogs occurs between 60-70°F given by Blaxter *et al.* (1959) quoting Capstic and Wood, Tangl and Deighton.

In cold weather the rate of heat generation raises through an increase in metabolic rate stimulated by secretion of throxine and adrenaline. In the Danish experiments on hogs (Korsgaard et al., 1960), in a climatic laboratory they found the thyroid secretion rate to increase at air temperatures below 15°C (59°F). The hogs also showed a definite difference between the microenvironments. Hogs kept in individual pens at 3°C without straw bedding and exposed to cold stress showed higher thyroid secretion than those kept in common pens with straw bedding at the same air temperature. The feed conversion ratio obtained in this research varied in accordance with the thyroid secretion. Regression quotient = 0.82.

As the heat increment of feeding is proportional to the feed consumption the heat generation also is increased by larger quantities of feed intake. The ratio of heat increment of feeding to metabolizable energy varies with the different feedstuffs, but the hogs can not take advantage of this as much as cattle because of their poor ability to digest roughage. The heat increment of feeding of ground corn which commonly makes up a large part of hog feed is given by Morrison (1956) as 552 kcal/lb (2070 btu/lb.). By muscular activity such as exercise and shivering the heat production also can be increased.

As swine are a nonsweating animal, no heat exchange can occur by evaporation of sweat. The amount of moisture given off by regular diffusion from the body surface is small. Swing utilize, however, the effect of moisture evaporation by wetting their body surface when possible. This is observed under high temperature experiments (Havskov-Sørensen, 1961; Heitman and Hughes, 1949; etc.) and there is also found positive effect on the hogs performance by providing access to water under high temperature. Mist sprayers are commonly applied in hog houses to cool the animals during hot weather.

Rate of respiration is also one means of adjustment. By respiration a direct exchange of heat by heating the air is obtained and in addition moisture is expelled as latent heat in the respired air. In experiments at Davis (Heitman and Hughes, 1949), the rate of respiration increased from 20 respiration pr. minute at 40°F to 135 at 85°F for 200 lb hogs.

Bond et al. (1957) have calculated the proportions of heat loss by radiation, convection, conduction and evaporation from hogs (Table 1). They found that the size of hogs has little effect on the proportion of heat lost by each method of heat transfer (Table 1). These data were calculated from experiments in psychrometric chambers. Animal management and conditions within the test chamber were said to be representative of normal farm conditions. The animals were tested in groups of four or five.

Table 1. Effect of air temperature on the percent of total heat lost by each of the four methods of heat transfer.

Air Temperature °F	Percent of Total Heat Loss			
	Radiation	Convection	Conduction	Evaporation
40	34.9	37.8	12.8	14.5
50	33.0	38.7	12.8	15.5
60	32.9	38.7	11.8	16.6
70	27.0	34.3	10.7	28.4
80	23.0	32.0	7.7	37.3
90	17.2	20.7	7.4	54.7
100	2.6	5.0	2.8	89.6

It is possible to observe the partial increase in heat loss by evaporation at high temperature on the expense of the other methods of heat transfer.

The temperature adjustment to environment can also be improved by reducing or increasing surface insulation accomplished by the amount of subcutaneous fat. In the Danish research protein deposition was lower and bacon quality inferior for hogs raised at the lower temperatures.

The animals can also regulate the heat loss by huddling together or by laying spread and thus exposing more or less of their surface to the environment. In the house for our measurements the hogs piled up to two or three deep when the new batch was put into the house in January. As they were exposed from all sides to the cold environment they found this a practical way to conserve heat.

Surface losses by radiation, conduction and convection are adjusted by regulating the surface temperature through restriction of blood circulation in the subcutaneous tissue. The Danish investigators (Korsgaard et al., 1960), found these surface temperatures for hogs at different air temperatures.

Table 2. Surface temperatures of hogs measured at different air temperatures.

Air Temperature	Skin Temperature °C	Rectal Temperature °C
24	36.2 ± 0.19	38.6 ± 0.05
23	36.5 ± 0.06	38.6 ± 0.08
15	34.9 ± 0.26	38.7 ± 0.08
8	30.7 ± 0.26	38.6 ± 0.06
3	27.0 ± 1.02	38.8 ± 0.10

Irving (1956) found large topographic variation of skin temperature on hogs exposed to cold environment. At air temperatures of -12°C he observed skin temperatures as low as 10°C (50°F). From the figure in his article higher temperatures were observed on the belly than was found on the back.

Kelly *et al.* (1963) found that by regulating the floor temperature the rate of heat loss to the slab was increased slightly by an increase in slab surface temperature. This they concluded may be explained by the fact that heat transfer within the animal body mainly is due to blood circulation which is lowered by vascular constriction on the cooler slab.

Blaxter *et al.* (1959) deducted from experiments on closely clipped sheep that at a level of feeding which results in a heat production of 1500 $kcal/m^2/24$ hr there would be no increase in metabolism of the pigs until environmental temperature fell below 0°C possibly - 5°C. These theoretical data imply that the heat increment of feeding should be sufficient to cover the heat expenditure in heat transfer from growing-finishing hogs under normal conditions down to the suggested temperatures. The heat increment of feeding is not expelled at a constant rate, however, but can be evened out. By increased feeding, the skin temperature increases and consequently the heat transfer from the body. Havskov-Sørensen (1961) found an increase of skin temperature of approximately 5°C (9°F) by feeding a full ration and about 3°C (5.4°F) with a one-half ration. The increased temperature lasted only half as long with a half ration compared to full ration. This undoubtedly effects the hogs heat performance both in cold and hot environment. Frequently feeding should possess potential to even out the heat loss and therefore the temperature stresses. The probable effect can only be determined by applied experiments.

The Danish experiments (Korsgaard *et al.*, 1960) imply that there is a higher energy content in the hogs reared at lower temperature.

Some of the hogs raised at the different temperatures were run through an overall composition analysis. If the energy content is calculated based upon protein and fat using 5600 kcal/kg and 9500 kcal/kg for protein and fat respectively we obtain an energy content of 3287 kcal/kg for those raised at 15°C and 4274 kcal/kg for those kept at 3°C in single pens or a difference of 992 kcal/kg. The feed conversion ratio was 3.4 and 5.9 respectively, with a difference of 2.5 F.U./kg gain. Each F.U. has a net energy of about 1600 kcal. In this example 25 percent of the extra net energy in feed is spent in a higher specific energy content in carcasses of low temperature raised hogs.

Another experiment by Havskov-Sørensen (1961) gives body composition of 200 lb hogs reared at cycling (4-14°C) and constant air temperature (14°C). The hogs raised at cycling temperature based upon same procedure as above had an energy content of 4142 kcal/kg and those kept at constant temperature 3975 kcal/kg a difference of 167 kcal/kg. Difference in net energy in feed kg/gain in this case was 450 kcal/kg. This makes 37 percent of net energy difference spent in higher specific energy content in hogs.

We know from experiments on farm animals that they usually digest a larger percentage of their feed when fed a scanty ration than when they receive a full ration. Three to nine and five-tenths percent differences are obtained on sheep and cattle (Morrison, 1956). There is even a greater difference in the percentage utilization in the body of the nutrients from scanty compared to liberal rations. Twenty percent differences is obtained between steers fed on 2.5 times and 1.5 times maintenance ration (Morrison, 1956). This may also affect hogs on self feeding as their apetite increases at lower temperature.

The feed conversion ratio is defined as pound of feed (or F.U.) required per pound (or kg) of gain. The inferior feed conversion of hogs at lower temperature seems ultimately to depend on the heat balance of the hogs. Cold stress seems to lead to physiological changes with a lower protein deposit and higher fat deposit. The higher energy requirement seems partly to cover higher energy content per pound of hog and a greater heat loss and perhaps some inferior basic feed utilization.

2. Growth Rate of Hogs

The growth rate relative to body weight decreases from a short period after birth. The absolute growth rate increases with age to a certain point which changes for different breeds or final weight. For the hogs referred to in Table 4 the growth rate is maximum at 250 lb. The energy content per pound of gain is steadily increasing as shown by the following table.

Table 3. Estimated energy content of a pound of gain by pigs of increasing body weight (Mitchell and Kelly, 1938).

Body Weight (pounds)	Energy Content of Gain Per Pound (calories)
2.5	500
5.0	750
10.0	1000
50.0	1500
100.0	1750
150.0	2025
200.0	2400
250.0	2850
600.0	4050

As the energy content per pound of gain increases also the energy requirement or pounds of feed per pound of gain increases. This is well demonstrated in Table 4. It is necessary to take these facts into consideration when comparing test results on rate of gain and feed conversion.

By general experience it is accepted that retarded hogs grow slower and need more feed. Catron (1959) reports on some English research which shows that the heaviest pigs at eight weeks of age gain faster on less feed and hang up better carcasses than slow growing pigs. It should, therefore, be important to determine the optimal condition at the different stages throughout the growth period for hogs.

At the Ohio Swine Evaluation Station (Bruner, 1958) they have found that meat hogs are better feed converters than fat hogs. In the example given a feed-conversion of 3.37 for meat hogs compared to 3.56 for fat hogs. The fat hogs in this experiment were not real fat and all would grade U.S. No. 2.

3. Temperature Experiments on Hogs

In Norway farmers long experienced in hog raising have recognized a higher feed consumption and slower growth of hogs in winter than in summertime. This is especially true in the colder regions and under poor housing conditions. Many farmers in the past therefore raised their hogs only in summertime.

Series of temperature experiments are carried out to find the optimal environmental condition for hograising, both laboratory and field experiments. Most of the research shows the temperature to have a significant influence upon growth rate, feed conversion ratio and carcass quality, but there is no great consistency in the results of temperature effect upon these responses. This probably is due to the

Table 4. Daily food requirements, heat production, and geseous exchange of growing and fattening female and castrated male pigs, according to American feeding practice (Mitchell and Kelly, 1938).

							Water Vaporized	
Body weight (pounds)	Average daily gain (pounds)	Total net energy required (calories)	Metabolizable energy required (calories)	Dry matter required (calories)	Feed economy of gains (pounds)	Total heat produced (calories)	Under ordinary conditions (grams)	At 103°F and above (grams)
2.5	0.20	250	330	99	1.2	200	86	345
5	0.30	450	610	182	1.5	380	164	655
10	0.40	820	1,100	328	2.0	800	483	1,379
50	0.85	2,400	3,200	955	2.8	1,980	854	3,414
75	1.02	3,200	4,500	1,343	3.3	2,550	1,099	4,397
100	1.20	4,000	5,600	1,672	3.5	3,050	1,315	5,259
150	1.55	5,500	7,600	2,269	3.7	4,000	1,724	6,897
200	1.78	6,900	9,500	2,836	4.0	4,940	2,129	8,517
250	1.85	8,300	11,300	3,373	4.6	5,700	2,457	9,828
300	1.80	9,250	12,700	2,791	5.3	6,200	2,673	10,690
400	1.60	9,200	12,500	3,731	5.8	6,500	2,802	11,207
600	1.00	8,000	10,700	3,194	8.0	6,700	2,888	11,552

variable test procedures used and to the fact that in most cases only the air temperature is considered and not the microclimate or the actual environment to which the animals have been exposed.

Kelly et al. (1948) report that swine in confinement in a pen or shelter spend from 80-90 percent of the time lying down. Kraggerud (1962) reports from an experiment in Norway with hogs housed in different systems that growing-finishing hogs in a traditional type of house (confinement with solid concrete floor) lied down 77.5 percent of the time and the remaining 22.5 percent was used as follows: eating 7.4, drinking 0.9, excreting 0.6, and standing up or walking around 13.6 percent. The temperature in the house was 16°C (61°F). Approximately the same activity distribution was observed on groups housed in open shelter with deep litter and a daily mean air temperature varying from 9 to 15°C. These figures indicate that finishing hogs lie down more than 75 percent of their time. Studies at Davis (Kelly et al., 1948) show that the contact area between the hogs and the floor is about 20 percent of their surface area.

Irving (1956) shows in his article that the hogs are able to reduce their surface temperature on their back more than on their belly. A cross-section of the hog carcass showing the distribution of subcutaneous fat supports this. From observations of swine behavior it is recognized that hogs expose preferably their back to cold environment. In hot environment they spread out and expose readily their belly. Heitman and Hughes (1949) shows photographs giving a good illustration of this. On slatted floors the hogs can not protect their belly with a warm or insulating bedding and this may be an important factor.

In Denmark experiments are being conducted in a new climatic laboratory fo find the influence of environmental temperature and humidity on growth, feed conversion and bacon quality of hogs (Korsgaard et al., 1960). In these tests the temperature has been maintained constant throughout the growing-finishing period of hogs in well insulated air conditioned rooms. They used common pens with 5-8 hogs in each group and in addition some hogs were kept in individual pens. In some tests straw bedding was used in others no bedding. The air and enclosure temperatures presumably were about equal. They used two different compositions of feed (protein content). In the following only the tests with ration of lowest protein content are referred to because these are more complete. The feed conversion, however, did not show much difference between rations.

In Table 5 are the feed conversion ratios for hogs raised in common pens.

Table 5. Feed conversion ratios in hogs from 40 (88) to 90 kg (200 lb.) body weight as influenced by ambient temperature and humidity, no straw bedding, common pens.

Air temperature °C (°F.)	Relative humidity percent	Feed conversion F.U./kg gain	Number hogs in group	Rate of gain kg/day
24 (75.2)	90	3.6 ± 0.16	8	0.70 ± 0.048
23 (73.4)	50	3.4 ± 0.11	8	0.78 ± 0.024
15 (59.0)	70	3.4 ± 0.08	8	0.78 ± 0.006
8 (46.4)	70	3.7 ± 0.20	8	0.71 ± 0.030
3 (37.4)	70	4.3 ± 0.20	5	0.63 ± 0.034

For moderate relative humidities feed conversion ratios were similar at 15 and 23°C. Inferior feed conversion occurred at lower temperatures.

By using straw bedding in a common pen with five hogs and an air temperature of 3°C showed a feed conversion of 3.7° ± 0.05 compared to 4.3 ± 0.20 without bedding other conditions being the same. The decrease of 0.6 F.U. was attributed to the bedding.

By keeping the hogs in individual pens without straw bedding a poor feed-conversion of 5.9 ± 0.02 was obtained on three hogs at an air temperature of 3°C compared to the feed conversion of 3.7 for a group of hogs in straw bedded pen with other conditions being the same. The difference of 2.2 F.U. or 60 percent inferior feed conversion may express the combined effect of huddling together and the benefit of straw bedding.

The Danish investigators drew the following conclusion. "The optimal air temperature in well ventilated and insulated swine building is between 11-12°C and 18-20°C (51.8-53.6°F and 64.4-68°F) provided there is plenty of straw bedding in the lowest range and ample space for the hogs to lie spread out in the highest range."

In continued Danish investigations (Havskov-Sørensen, 1960), the response of hogs to a variably air temperature is compared to constant air temperature for different systems of management (Table 6).

Table 6. Daily gain in weight and feed conversion ratio in growing pigs (20-90 kg) (44-200 lb) at cycling (48 hour cycles) ambient temperature compared to constant temperature.

Conditions	Feed conver. F.U./kg gain	Gain of weight kg/day
Varying temperature (4-14°C)		
Group (3 hogs) litter	3.3 ± 0.02	0.68 ± 0.01
Group (3 hogs) no litter	3.5 ± 0.07	0.64 ± 0.02
Individual pens, no litter	3.8 ± 0.13	0.58 ± 0.02
Constant temperature 14°C		
Group (3 hogs) litter	3.2 ± 0.06	0.69 ± 0.01
Group (3 hogs) no litter	3.3 ± 0.11	0.66 ± 0.03

The conclusion drawn upon these figures indicates that "The effects on hogs of diurnally varying air temperature between 4°C and 14°C appeared to be approximately the same as the effect at constant air temperature which is close to the mean temperature of the diurnal temperature cycle."

At Davis, California (Bond, 1959; Bond et al., 1957; Kelly et al., 1948 and 1963) a series of experiments were carried out in a climatic laboratory to determine the influence of temperature on growth, health and wellbeing of hogs. As in the Danish experiments, air conditioned, well-insulated rooms were used. The floor was made of concrete over cork insulation and no bedding used. The hogs were tested in small groups (2-5 hogs).

The performance of hogs at different stages and different temperatures are given as rate of gain in Table 7.

Table 7. Effect of ambient air temperature and mean liveweight on rate of gain of swine.

Mean live-weight, lbs.	Average daily gain in pounds per pig. Air temperature °F.							
	40	50	60	70	80	90	100	110
100		1.37	1.58	2.00	1.97	1.40	0.39	-1.32
150	1.27	1.47	1.75	2.16	1.82	1.14	-0.19	-2.60
200	1.19	1.57	1.91	2.22	1.67	0.88	-0.77	
250	1.10	1.67	2.08	2.14	1.51	0.62	-1.36	
300	1.02	1.77	2.24	2.06	1.36	0.36	-1.95	
350	0.94	1.87	2.41	1.98	1.21	0.10	-2.53	

Feed conversion ratio is a better measure for economic evaluation and comparison than the rate of growth. Rate of growth and feed conversion do not always coincide. Feed makes up about 80 percent of the production costs. In the present house the feed costs run to $15,000 a year while the house costs run to $1,200 a year, which should express the advantage.

Bond and Petterson (1958) present figures for feed conversion versus temperature as follows.

Table 8. Effect of temperature on production efficiency of swine.

Temperature	Feed conversion ratio lb feed/lb gain	
	Hog weight 100 lb	Hog weight 200 lb
100	7.5	
90	4.7	11.0
80	3.1	5.0
70	2.5	4.0
60	3.2	3.6
50	4.1	5.0
40	5.3	11.0

The difference in feed conversion between 60°F and 40°F is 2.1 lb for 100 lb hogs and 7.4 lb for 200 lb hogs compared to 0.9 F.U. in the Danish experiments for the whole growing-finishing period. The temperature stresses should be comparable except that smaller groups of hogs were used in the American tests.

The optimal temperature seems to coincide fairly well, but the effect of temperatures different from the optimal conditions disagree considerably. This most likely is due to the difference in test procedure. The test periods in the experiments at Davis lasted usually one week and any aclimatization period before the individual tests is not identifiable in the reports. This can explain the disagreement.

In Norway an experiment comparing different housing system was carried out by Kraggerud (1962) and Lyso (1962). Some groups of animals were kept in an insulated house and some in a shelter with open front. In the insulated house three different floor systems were tried: solid floor, partially solid and partially slatted floor, and all slatted floor. All the flooring material was concrete, both for the solid floor and for the slats. Sawdust was used to keep the floor dry. All three groups in the insulated house were on limited feeding. Deep litter was used for the groups housed in the open shelter. Two groups were on self feeding the other two on limited feeding, the same as those in the insulated house. Ten tests or replications were made for each housing condition using eight hogs per group. The test periods comprised an average hog weight from 24 kg (53 lb) to 90 kg (198 lb).

The temperature in the deep litter in the open shelter was measured regularly throughout the winter periods. The temperature varied according to location and time between 15°C and 45°C. The predominant part of the temperature observations ranged from 30-35°C (86-95°F). The average feed conversion on ten tests was as follows:

Table 9. Feed conversion ratios (Scand. F.U./kg gain) in different housing of growing-finishing hogs (24-90 kg).

Housing System	Rate of gain kg/day	Feed conv. F.U./kg gain	Diff. F.U./ kg gain	Diff. %
1. Solid floor, insul. house, ltd. feeding	0.59	3.49		
2. Part. solid and part. slatted floor, insul. house, ltd. feeding	0.58	3.58	+0.09	2.6
3. All slatted floor, insul. house, ltd. feeding	0.57	3.63	+0.14	4.0
4. Open shelter, deep litter, ltd. feeding	0.53	3.83	+0.34	9.7
5. Open shelter, deep litter, self feeding	0.72	3.90	+0.41	11.7

The difference between 1 and 3, 1 and 4, 1 and 5 are all statistically significant. This table shows comparable figures for the different systems and the traditional one with solid floor appears most efficient. The report contains also data for individual tests and information on air temperature.

A low outside temperature will be accompanied by a lower inside air temperature and presumably a still lower temperature in the pit or cellar below, in summertime a more uniform temperature prevails.

Table 10. Comparison between feed conversion of hogs on solid floor and hogs on all slatted floor in tests carried out in wintertime.

Test No.	Feed conversion. Scand. F.U./kg gain			Average room air temp. ca. °C (°F)	Temperature change trends °C
	Solid floor	Slatted floor	Difference		
1	3.36	3.54	+0.18	13.5 (56)	15→ 16→ 11
2	3.40	3.61	+0.21	13.0 (55)	15→ 16→ 10
7	3.76	4.07	+0.31	12.0 (54)	11→ 13
8	3.67	3.88	+0.21	13.0 (55)	12→ 16
Average winter tests	3.55	3.78	+0.23 (6.5%)		
Average all tests	3.49	3.63	+0.14		

In the winter tests 0.23 F.U. or 6.5 percent inferior feed conversion was obtained for hogs on slatted floor compared to a solid floor. The efficiency of feed is highest at higher temperatures and decreases with a decrease in temperature. Small hogs suffer more from cold than do larger ones..

Table 11 summarizes tests carried out in the warm weather.

Table 11. Comparison between feed conversion of hogs on solid floor and hogs on all slatted floor in tests carried out in the spring, summer and fall period of the year.

Test No.	Feed conversion. Scand. F.U./kg gain Solid floor	Slatted floor	Difference	Average room air temperature °C(°F)(ca.)	Temperature change trend °C
3	3.33	3.43	+0.10	16.0 (61)	11 ⟶ 22
4	3.42	3.57	+0.15	21.0 (70)	15 ⟶ 22
5	3.51	3.58	+0.07	18.5 (65)	22 ⟶ 12
6	3.45	3.47	+0.02	15.0 (48)	22 ⟶ 11
9	3.61	3.63	+0.02	20.0 (69)	14 ⟶ 21
10	3.41	3.56	+0.15	20.0 (68)	16 ⟶ 22 ⟶ 20
Average summer tests	3.46	3.54	+0.08(2.3%)		
Average all tests	3.49	3.63	+0.14		

All the trials in the warmer periods of the year with these two systems show a good and more uniform feed conversion ratio and better than in the winter period. The difference between the winter and summer tests is 0.09 F.U./kg gain for the hogs on solid floor and 0.24 F.U./kg gain for those on slatted floor in favor of the summer period. If we ascribe these differences to the influence of temperature we could conclude that the hogs in both systems are affected by the cold but those on slatted floor are affected the most. This is consistent with what could be expected as hogs on slatted floors are more exposed to the environment. A similar comparison will be made for the hogs in open shelter.

Table 12. Feed conversion of hogs reared in open shelter with deep litter, winter tests.

Test No.	Feed conversion. F.U./kg gain Limited feeding	Self feeding	Average air temp. ca. °C (°F).	Temperature change trends °C
1	3.56	3.83	-2 (28)	2→ -6→ 4
2	3.70	3.80	0 (32)	2→ -6→ 8
7	4.27	4.19	-2 (28)	0→ -6→4→-8
8	4.09	4.16	0 (32)	2→ -8→ 6
Average winter tests	3.90	4.00		
Average all tests	3.83	3.90		

The Danish experiments (Korsgaard _et al._, 1960), gained considerable positive effect of bedding and there is no doubt that the same factors are involved in the good feed conversions obtained in these tests, also.

The tests with limited feeding show a difference in feed conversion ratio of 3.90-3.78 = 0.12 F.U. in favor of the summer tests. This is about the same difference (0.09) as on solid floor in an insulated house for winter and summer tests. This may also show the hogs ability to improve its environment when necessary as the temperature variation and temperature stresses in winter should be far more pronounced in the open shelter than in the insulated house.

The hogs on self feeding show some greater difference which partially may be due to higher energy content in carcasses as the fat deposition was greater for this group.

Table 13. Feed conversion of hogs in open shelters with deep litter, summer tests.

Test No.	Feed conversion F.U./kg gain Limited feeding	Self feeding	Average air temp. ca. °C (°F)	Temperature change trends °C
3	3.83	3.81	10 (50)	4 ⟶ 16
4	3.77	3.86	14 (57)	9 ⟶ 16
5	3.86	3.60	10 (50)	16 ⟶ 0
6	3.70	3.93	6 (43)	15 ⟶ 4
9	3.80	3.89	8 (46)	1 ⟶ 14
10	3.73	3.91	11 (52)	6 → 14 → 10
Average summer tests	3.78	3.83		
Average all tests	3.83	3.90		

Altogether the hogs in the open shelter on deep litter have been able to provide a favorable microclimate, but an inferior feed conversion can be expected under those conditions.

The hogs on self feeding gained 0.74 kg/day in the winter tests compared to 0.70 kg/day in the summer tests. The feed conversion at the same groups were 4.00 F.U./kg gain for winter and 3.83 F.U./kg gain for summer which show feed conversion ratio to be a better measure than the rate of growth.

4. Influence of Relative Humidity

There is very limited data available on how relative humidity affects the rate of growth and feed conversion of swine. The general belief is that high relative humidity decreases the feed utilization, health and wellbeing of swine. Research experiments do not confirm this belief and imply that relative humidity affects the swine's heat exchange with the environment especially at higher temperatures.

Heitman and Hughes (1949) ran experiments with relative humidity as a variable at 90°F and 96°F. At 90°F the data did not indicate much difference in the response of hogs weighing over 200 lb with relative humidities of 30 or 94 percent except that the respiratory rate is increased at the higher humidity. At 96°F and high relative humidity they found an increase in rectal temperature of 2.5°F on the hogs and the respiration rate more than doubled. They deemed it unadvisable to hold the hogs under these conditions. These are tests of short duration.

In some Danish experiments (Korsgaard et al., 1960), high humidity was shown to affect hogs considerably at an air temperature of 24°C (75°F). Protein deposition and growth rate decreased and more fat was deposited in the body resulting in a poor bacon quality. This is a long run test.

In practice high air temperature and high relative humidity seldom occur simultaneously. In cold weather with poor ventilation the room air temperature falls and the air relative humidity will be controlled by the surface temperature of the enclosure which determines the dew point. In surveys (Graee, 1957, 1962) of animal houses in Norway during the coldest winter months the relative humidity seldom passed 90% in spite of the heat balance which only allowed limited ventilation. High relative humidity usually occurred in cold rooms where there were small differences between outside and inside temperatures.

Relative humidity influences the dryness of the bedding area which may be of importance at low temperatures.

5. Pork Quality

The carcass quality of hogs is variable to the consumers taste and to the marketing policies. Because of scarcity of food in Norway during the war premium prices were paid for higher weight grades. The higher weight grades contain according to Table 3 more specific energy and this energy in pork is produced with less feed expense at the higher weight grades (Table 3 and 4). Today with the abundance of food the price grades are reversed, premium prices are paid for lean and smaller hogs.

The deposit of subcutaneous fat is one way for the hogs to provide protection against cold environment, but undesirable as far as carcass quality and market price is concerned. In the Danish research (Korsgaard et al., 1960), a noticeable effect of low temperature upon fat deposition and carcass quality is observed as the following table shows. The fat content is higher at lower temperature while the protein content decreased which resulted in a poorer bacon quality on hogs raised at low temperature. All hogs raised at 23°C and 15°C were classified as first grade while 11 out of 17 reared at 24° and 4 out of 10 at 3°C were first grade. Harskov-Sørensen (1961) gives body composition of hogs reared under different temperatures which show the same tendency (Table 15). Hazen and Mangold (1960) quote Clausen that carcass value declines with low temperature because the swine can convert proteins into heat much more easily than carbohydrates. Both theory and practice therefore indicate a definite negative effect of cold stress upon carcass quality.

Table 14. Chemical composition of 90 kg (200 lb) hogs reared at different environmental conditions.

Climate		Relative comp. of	
°C (°F)	Relative humidity (percent)	Crude protein (percent)	Crude fat
24 (75.2)	90	14.9	33.7
		14.3	34.2
23 (73.4)	50	14.4	29.5
		16.2	24.5
15 (59)	70	16.4	24.7
		17.2	24.6
8 (46.4)	70	15.1	25.6
		15.0	25.5
3 (37.4)	70	13.8	35.5
		14.2	37.6
		14.2	37.1

Table 15. Body composition of 90 kg (200 lb) hogs reared at cycling temperature and at constant air temperature.

	Cycling air temp. 4-14°C	Constant air temp. 4°C
Water	48.7	49.1
Dry matter	51.3	50.9
Protein	11.7	12.8
Crude fat	36.7	34.3

6. <u>Slatted Floors</u>

Slatted floors have only been used for hogs for about 10 years. The first experiments were mostly concerned with the operating capability of the system, type of material for slats, spacing between slats, floor space per hog. Only in very recent years have tests been run to evaluate the economic efficiency of the system, with feed conversion as the dominant figure as the feed makes up the largest part of production costs.

Hogs on slatted floors may perform different from other floor systems with regard to disease control, air temperature, air movement and draft, fluctuating temperature, and general wellbeing. No definite answers are given to any of these questions. In the meantime one must rely on his own judgment and try to transfer other experimental data.

There is reason to believe that hogs on slatted floors are more exposed to the general temperature environment than in other systems. The slats when in contact with the body surface of the hogs increase their body surface by acting as fins rather than giving them protection against cold environment. The hogs are also subjected to cold drafts from beneath by the air pressure difference between inside and outside existing at this level in cold weather.

In hot environments the slats will improve the heat transfer, but there will be little moisture accumulation on the floor on which hogs can lay on to keep cool (evaporation).

Because of the lower heat capacity of the floor and the exposure to environment there is reason to believe that cycling or diurnaly varying temperature will affect hogs on slatted floors more than in the traditional hog housing systems.

Slatted floors may affect hogs physically and psychologically (tailbiting). Lyso (1962) asserts that hogs on slatted floors (concrete slats) attained an unnormal pace. Jensen (1961) reports that pigs on floor of "Quarrey Screen" developed bruises and injuries on the pods of their feet, knees, and hams as they increased in weight, but pigs on concrete slats and wood slats showed no ill affects from flooring. Hoefer and Harmon (1961) say in their report on slatted floors that no lameness or leg difficulties were encountered.

On the other side the slatted floors possess possibilities for a more close or scientific control of the microenvironment. In a confinement system space is a limiting factor. The hogs have no choice where to lay down. On slatted floors, however, a more complete control on all sides is possible. The sanitary condition on slatted floors appears more favorable.

Jensen (1961) concluded after 14 tests with young hogs from two to three weeks of age that the pigs on expanded metal flooring gained 19.5 percent faster than pigs on concrete floor. The flooring, however, had no consistent effect on the amount of feed required per pound of gain. The test period was mostly 4 weeks.

Madsen (1962) reports some preliminary results from a research project on hogs raised on conventional floors compared to slatted floors (concrete slats). They used 8 hogs in each pen of 6 m^2. There is no information about temperature. The results to date show no significant difference between the two systems as far as gain in weight, feed conversion or carcass quality is concerned. He mentioned tailbiting tended to be more frequent for hogs on slatted floor.

Hoefer and Harmon (1961) report on an experiment with hogs in groups of five on solid concrete floors and on slatted wood floors. They found no significant differences between these floors. Average gains and daily feed consumption were highest for the pigs on concrete. On the average, pigs on slats used their feed more efficiently than did those on concrete. There is no temperature information given nor any information about management and construction.

Many tests show nearly equal performance of hogs on slatted floors and solid concrete floors. This may indicate no difference in the well-being as long as there is no unfavorable temperature. Norwegian research shows there is an influence of environmental temperature when the systems are compared.

Comparing all the experimental data indicates a logic result of providing bedding for hogs exposed to cold environment. Deep litter gives the hogs very good protection against low air temperature. Bedding shows a definite effect compared to no bedding on solid concrete floors and slatted floors with no bedding is the inferior one.

D. CONSTRUCTION AND MANAGEMENT OF THE HOG HOUSE

The investigations were carried out in a commercial hog house of prefabricated type, brand name "Easy Way Pork Factory". The house was built in 1962, at the farm of Otis and Loren van Ostran, Bath, Michigan. The house consists of three rooms or units all resting on oak wood poles (Figure 2). Each unit is designed for one hundred hogs divided into two pens with an automatic feeder as the partition. The layout is presented on Figure 1.

There are no transparent windows for daylight to enter, only shutters for ventilation in the summertime. Both doors, window-shutters and walls are built up of wood frame construction sheathed on both sides with corrugated aluminum and with 2 in. of polystyren as insulation. The lower part of the walls inside is protected with plywood covered with galvanized steel to stand the stresses of the hogs (Figure 2).

The slatted floor is made of oak slats with a trapesoidal cross-section 7/8 in. at bottom 1 3/8 in. at top and 3 1/4 in. deep tied together in sections each covering 22.5 in. x 5 ft 9 in. of the floor. The slats are spaced 3/4 in. apart and kept in place by steel frames (Figure 20).

The ventilation is provided with two reversible fans in each room, one for each pen (see Figures 1, 14 and 18 for location). For winter ventilation the fan blows outward and for summer ventilation inward. In wintertime the fresh air is designed to enter the room from the attic through air inlets in the ceiling (see Figure 2). The fans are controlled by individual thermostats located close to the fans (Figure 18). The operator has upon advise aimed to keep the room air temperature at 60°F throughout the entire growing-finishing period in wintertime.

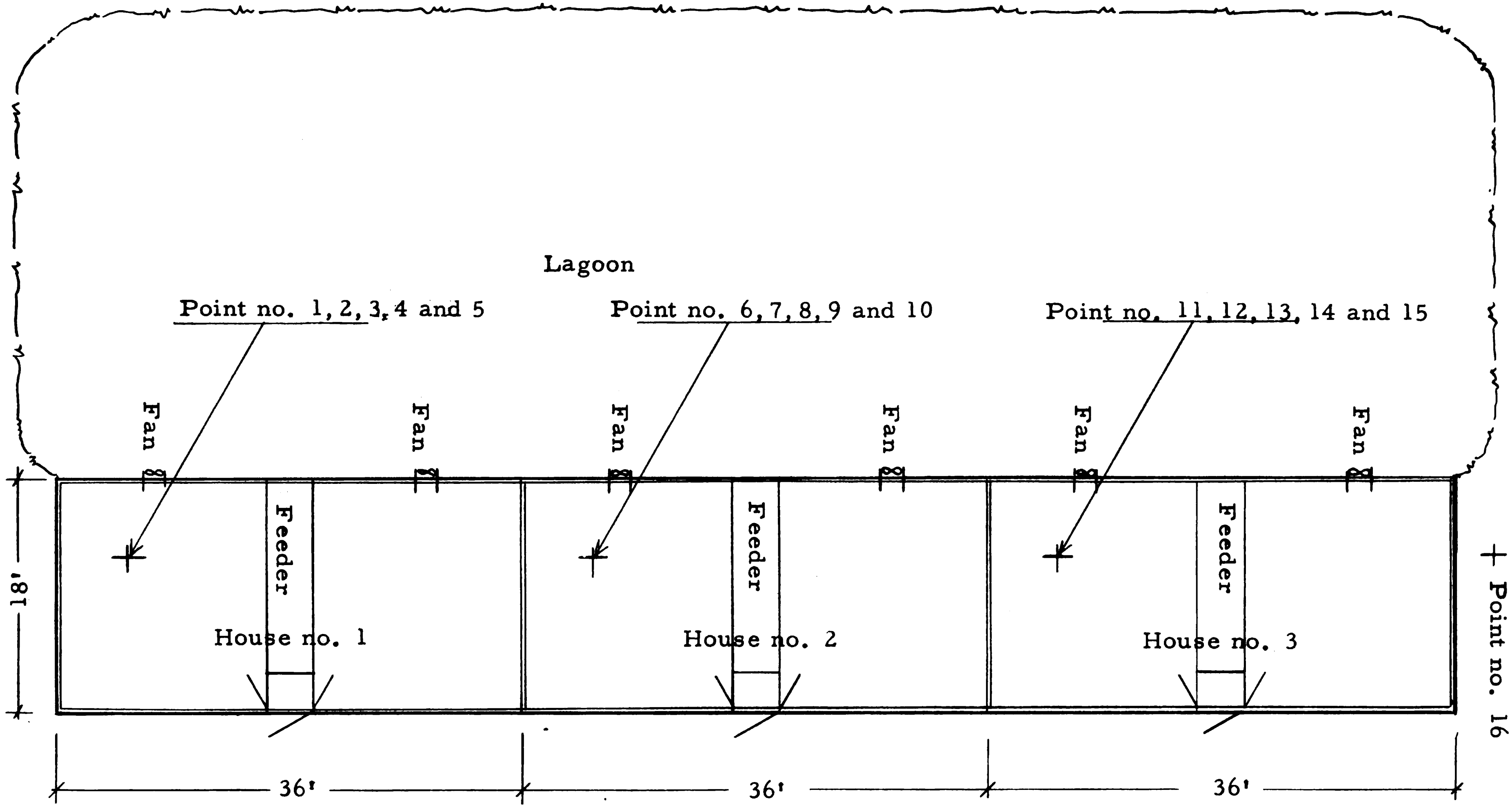


Figure 1. The house layout consists of three prefabricated house units. One serie thermocouples is located in each house as marked.

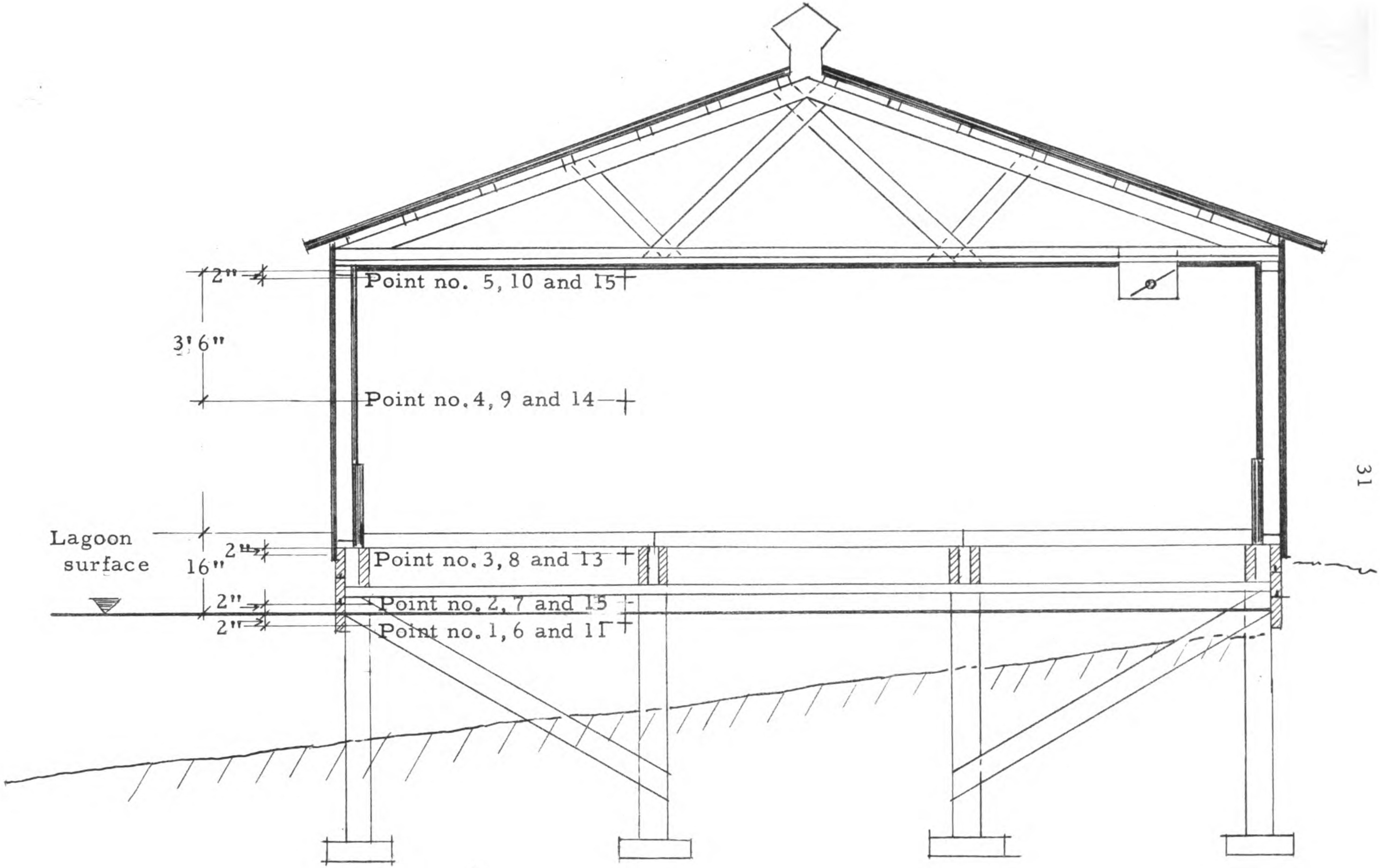


Figure 2. Cross-section of the hoghouse showing the location of the thermoelements.

All feeding is based on self feeding and both pens in each room are served by the same common feeder.

"Purina" Feed Company has delivered all the feed and the feed composition (protein content) is modified five times during the growing-finishing period. There is one automatic waterer in the middle of each pen.

The operator cleaned and disinfected the pens between each batch.

Light is only used for the operator at inspections.

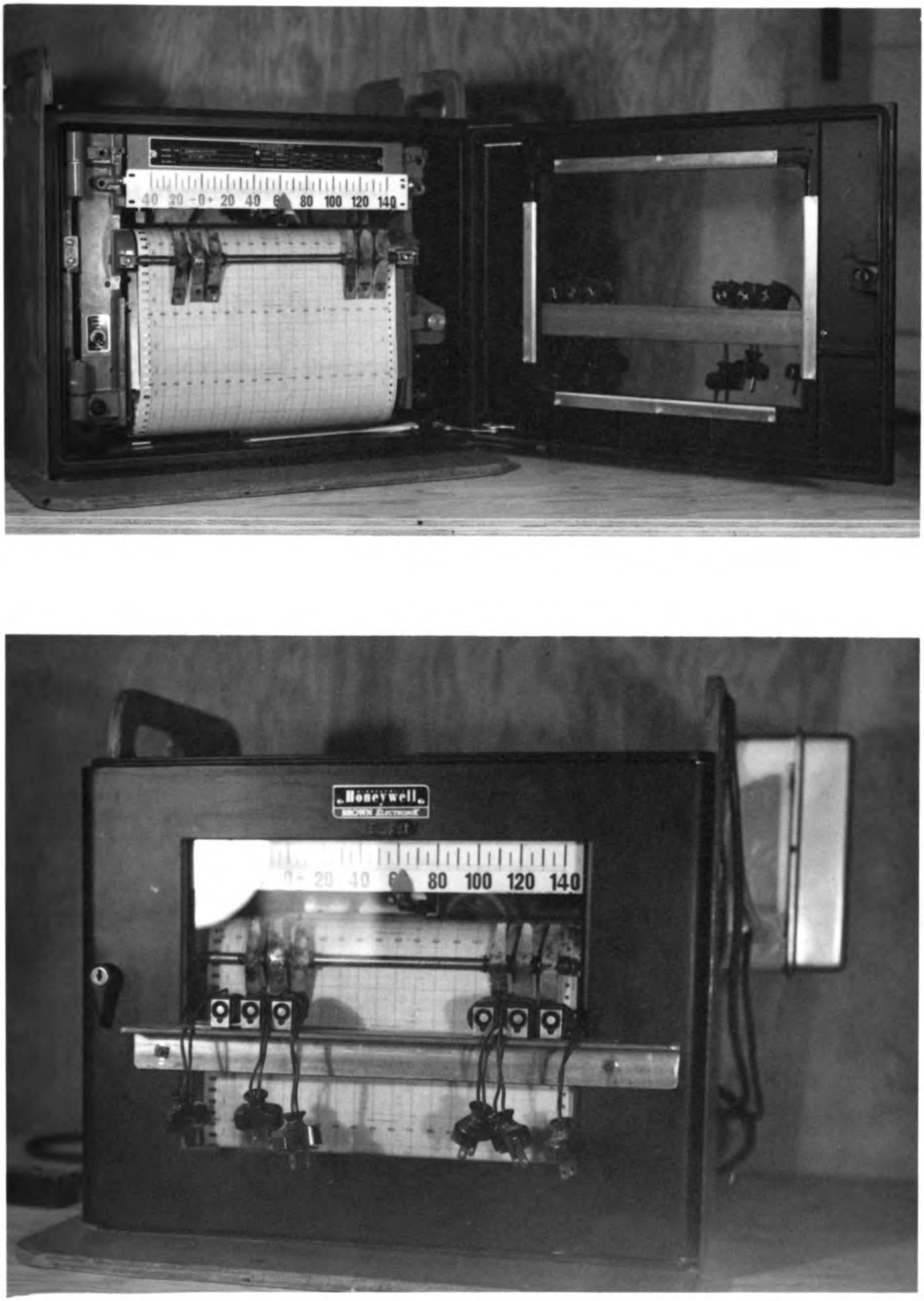
Each pen has a mist sprayer to relieve heat stress in hot weather.

E. PLAN OF THE INVESTIGATIONS AND PROCEDURE

Originally temperatures, temperature distribution, relative humidity and the operating time of the fans were to be recorded.

To obtain data for the operating time of the fans individual recording pens (one for each fan) were built into the potentiometer (Figure 3). These pens were brought into contact with the continuous running recording paper of the potentiometer by solenoids in parallel with the fan and actuated by the electric current and, therefore, only worked when the thermostat called for the fan. The pens were fastened to the one end of small arms which were balanced on a horizontal rod with small weights on the other end to react against the solenoids. When the elctric current ceased the weight dropped by gravity and removed the pen from the paper. Principally this worked perfect, but in operation the fast-running recording paper, 6 in/hr, drained the ink from the small pens (thermohygrograph pens) we used within a couple of days. Daily control would be necessary to ensure proper operation under these conditions. A slower running paper and pens with larger inkwells would have solved the problem. We found it too late in the winter to rebuild the instrument as the most interesting period for winter ventilation had passed.

The potentiometer had 16 points. To gain proper information on the temperature distribution hundreds would be necessary. As the floor and lagoon is the principal difference from traditional hog houses vertical temperature distribution should provide new and usable information. The temperature was measured at points shown in Figures 1 and 2.



A

B

Figure 3 A and B. Potentiometer with built-in recording device for operating time of fans. M.S.U. Photo No. 631562-8(A) and No. 631562-7(B).

The thermocouple for measuring outside temperature was located north of the building together with a mercury in glass thermometer for control of potentiometer reading and shielded with a white painted perforated can. The difference between mercury in glass thermometer and thermocouple did not exceed ± 2°F at the weekly control.

Table 16. Location of thermocouples.

	Point Number		
	Room 1	Room 2	Room 3
2" below lagoon surface	1	6	11
2" above lagoon surface	2	7	12
2" below wood slats	3	8	13
Midheight of room	4	9	14
2" below ceiling	5	10	15

Outside temperature point number 16.

The thermocouples were made of plastic insulated copper-constantan wires.

F. TEMPERATURE OBSERVATIONS

1. Winter

Temperature recording started January 16th after a period with fairly high outside temperature. In room number 1 only 24 hogs were left and these were marketed shortly after and replaced with 100 pigs. Room number 2 was filled to 85 percent and room number 3 to 90 percent capacity with market-ready hogs. Rooms number 2 and 3 should have about maximum heat production at this time and the temperature data for the last period of the first batch is composed and shown in Table 17 and Figures 5 and 6.

Table 17. Average temperatures in the last period of the first batch. January.

Location	Room No. 2 °F	Room No. 3 °F
2" below lagoon surface	41.5	39.0
2" above lagoon surface	41.5	38.9
2" below slatted floor	46.6	43.4
Midheight of room	59.9	59.1
2" below ceiling		59.1
Outside	16.7	

There appears to be a large temperature difference between ceiling and lagoon 18.4°F in room 2 and 20.2°F in room number 3.

After the second batch of hogs was moved into the house the temperature measurements show the performance of the house at low heat production with a low outside air temperature. During this period the hogs grew from an average of about 50 lb to 80 lb. The average temperatures are given in Table 18 and the variation in average daily temperatures are given in Figures 4, 5 and 6.

Table 18. Average temperatures in the three rooms of the hoghouse in February.

Location	Room No. 1 ^{o}F	Room No. 2 ^{o}F	Room No. 3 ^{o}F
2" below lagoon surface	39.9	39.3	36.5
2" above lagoon surface	39.3	40.9	38.1
2" below slatted floor	43.0	45.0	41.9
Midheight of room	50.6	55.8	48.6
2" below ceiling	52.3	56.1	49.4
Outside air	16.3		

Temperatures in room 2 are above those in rooms 1 and 3, probably due to the fact that it has the least surface area exposed to the outside climate.

Tests at Davis, referred to previously, indicated that the optimal temperature for hogs of this weight is about 70-75^{o}F. The figures in Table 18 indicate that the temperature at hog level is about 50^{o}F at most. At 50^{o}F a feed conversion of 4.1 is found compared to optimal of about 2.5. On this basis for the whole batch (300 hogs) for a 30 day period with a daily gain of weight 1 lb/hog and a feed price of 3.5 cents/lb we get an extra expense of $500 for this period. As discussed

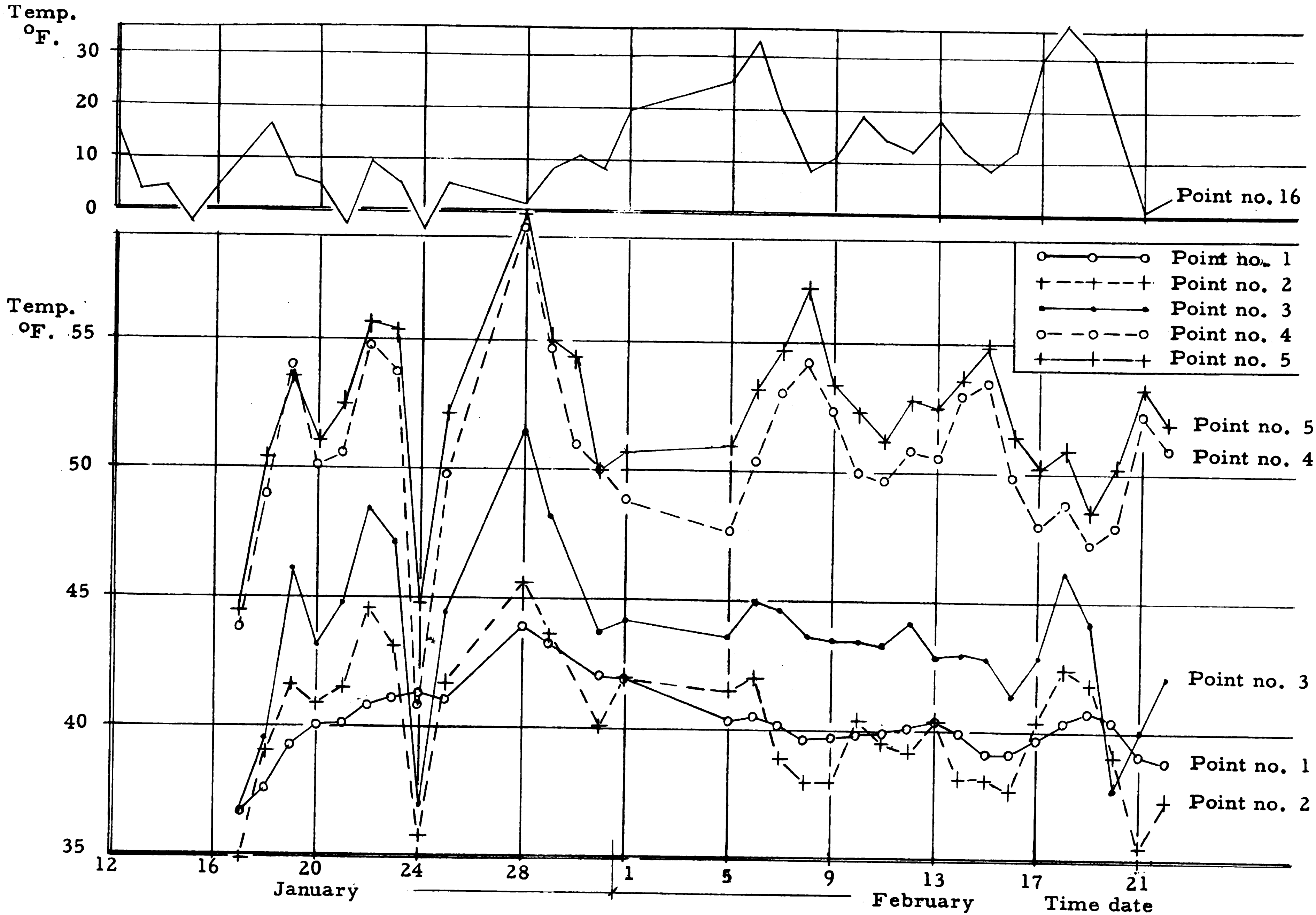


Figure 4. Curves showing the variation in daily mean temperature in January and February. Room no. 1.

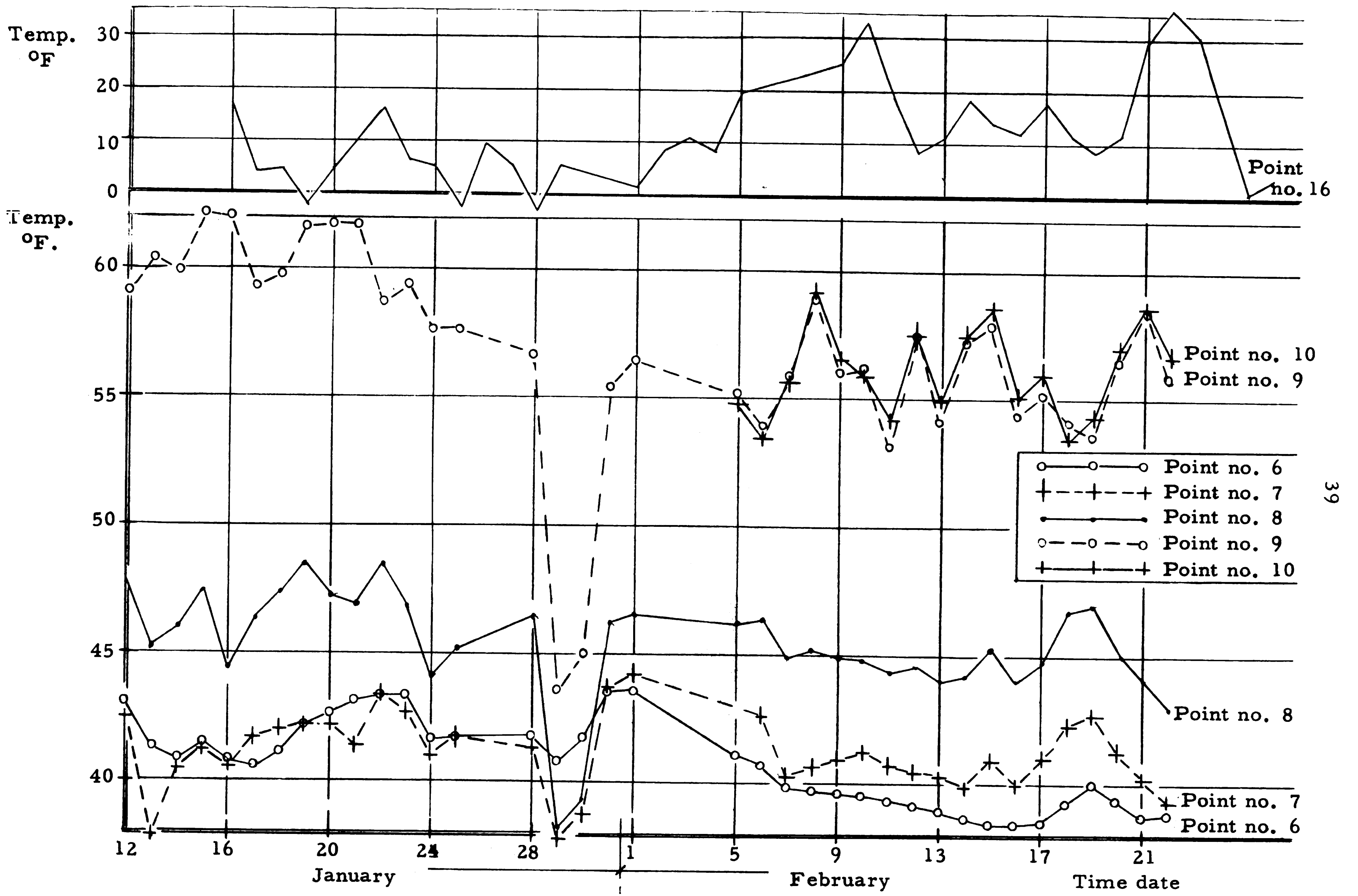


Figure 5. Curves showing the variation in daily mean temperature in January and February. Room no. 2.

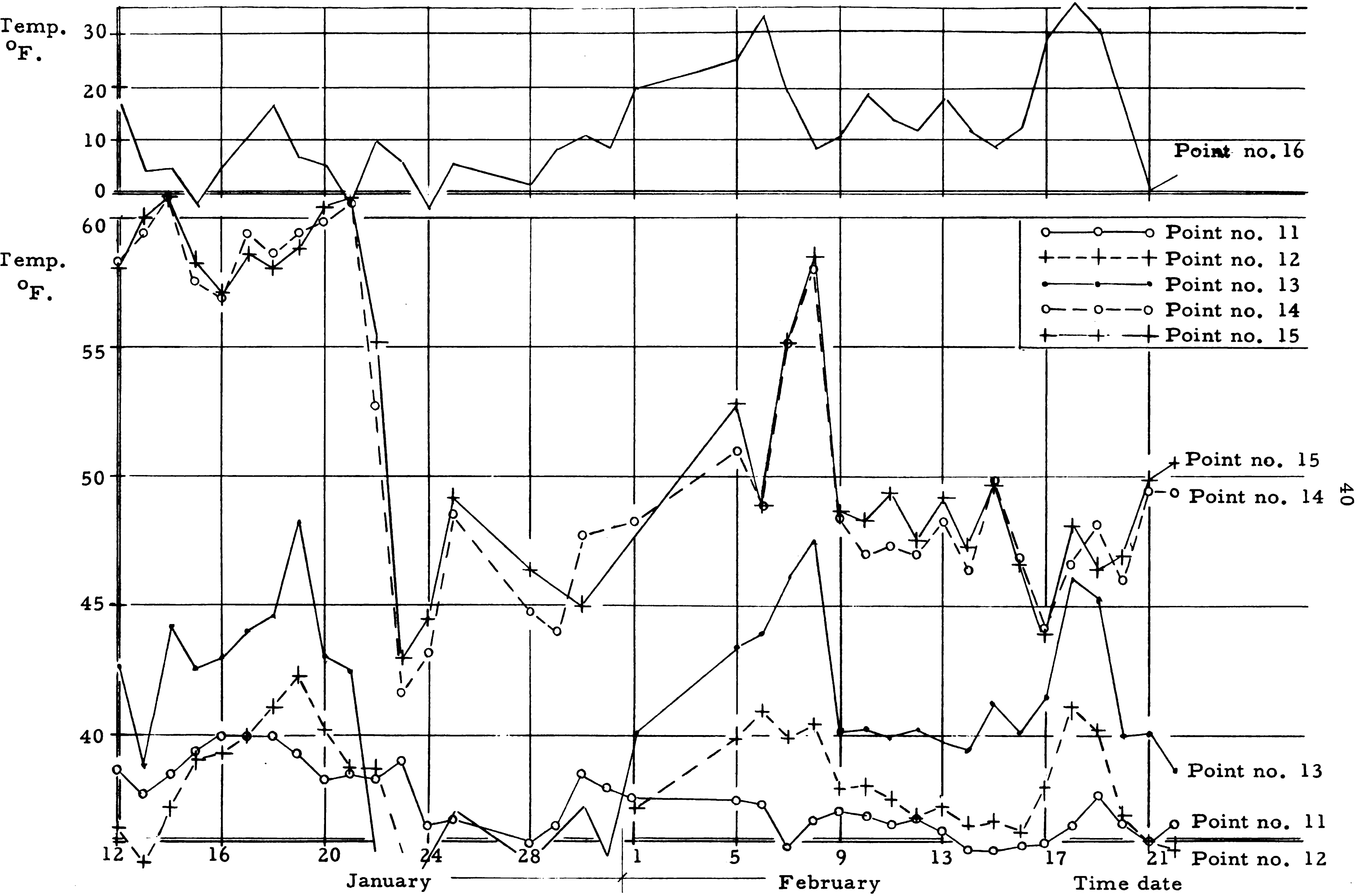


Figure 6. Curves showing the variation in daily mean temperature in January and February. Room no. 3.

previously (page 17) this difference in feed conversion is probably much too high, but the trend definitely indicates a cause for additional expense due to the poor feed conversion. Five hogs died of pneumonia in this batch, which also indicates an unfavorable climate in this period.

2. Spring

In the last period (April) with the second batch the following average temperatures were found (Table 19). Figures 7, 8 and 9 show the development of the average daily temperature in the period.

Table 19. Average temperatures in the house at the finishing time for the second batch, April.

Location	Room No. 1 °F	Room No. 2 °F	Room No. 3 °F
2" below lagoon surface	51.2	50.6	49.4
2" above lagoon surface	51.8	50.1	49.6
2" below slatted floor	58.9	55.0	52.1
Midheight of room	58.9		55.1
2" below ceiling	58.0	58.2	54.8
Outside air	45.1		

The temperature of the lagoon has increased considerably and the vertical temperature differences reduced to less than 8°F compared to 20°F in January. In this period the window shutters were opened to increase ventilation, which led to considerable variation in the

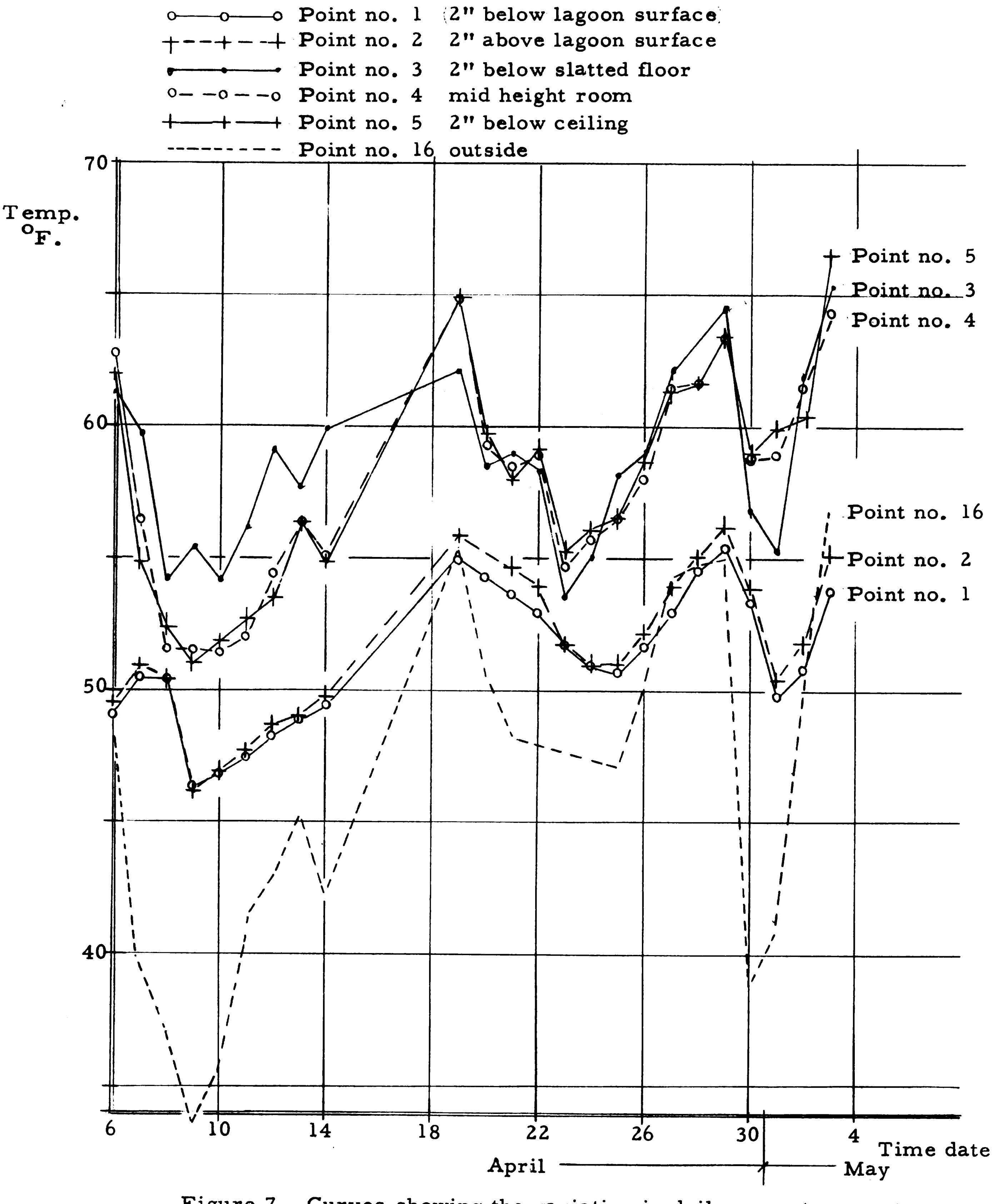


Figure 7. Curves showing the variation in daily mean temperature in April and May. Room no. 1.

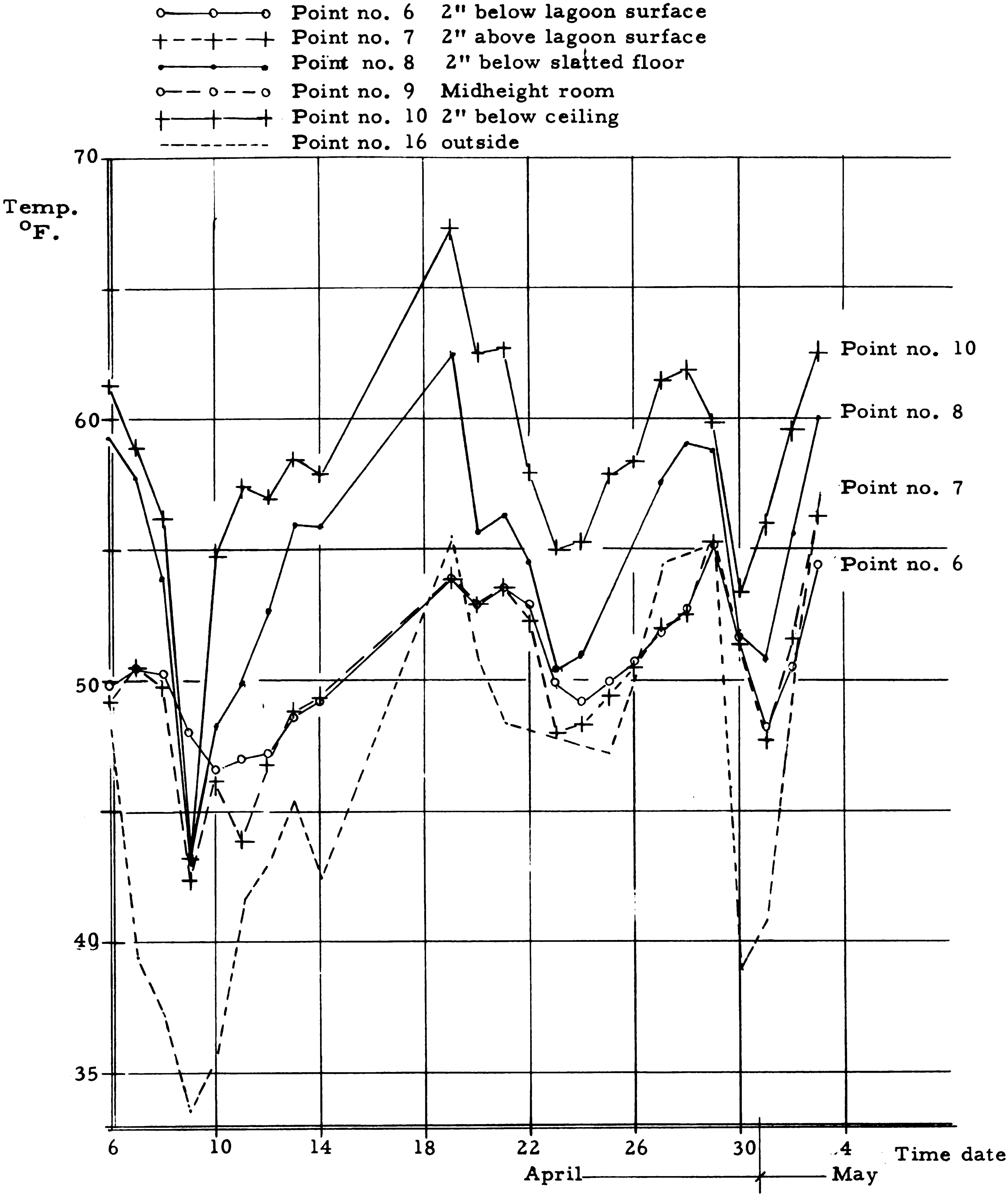


Figure 8. Curves showing the variation in daily mean temperature in April and May. Room no. 2.

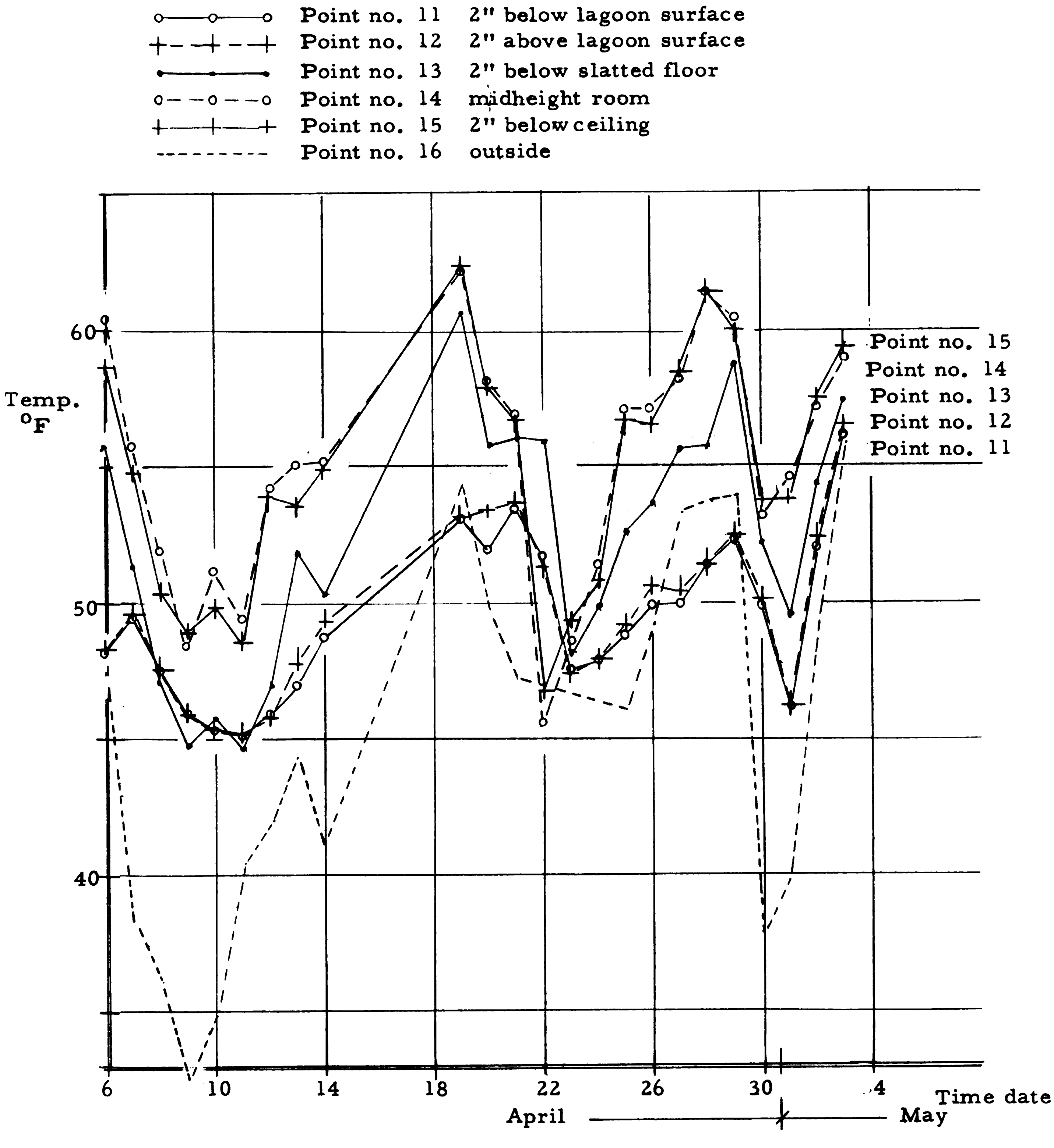


Figure 9. Curves showing the variation in daily mean temperature in April and May. Room no. 3.

average daily temperature. Figures 7, 8 and 9 show the inside temperature to vary according to the outside temperature.

During this period any proper temperature could be established; it is more a question of proper management than the capability of the house. There may be a desire for more automatic climatic control at this time of the year.

3. Summer

The temperature observations from June 14th to July 14th represent the summer conditions in the house. The third batch of hogs was put into the house May 21st and increased in average weight from about 100 lb to 150 lb during the time under consideration. The results are shown in Table 20 and Figures 10, 11 and 12.

Table 20. Average temperatures in the hoghouse in June-July.

Location	Room No. 1 °F	Room No. 2 °F	Room No. 3 °F
2" below lagoon surface	63.3	64.4	64.3
2" above lagoon surface	63.7	64.5	64.4
2" below slatted floor	65.9	68.3	68.6
Midheight of room	70.2	71.7	72.5
2" below ceiling	70.8	72.1	73.0
Outside air	67.5		

In this period the fans were reversed and the mist sprayers operated during hot weather.

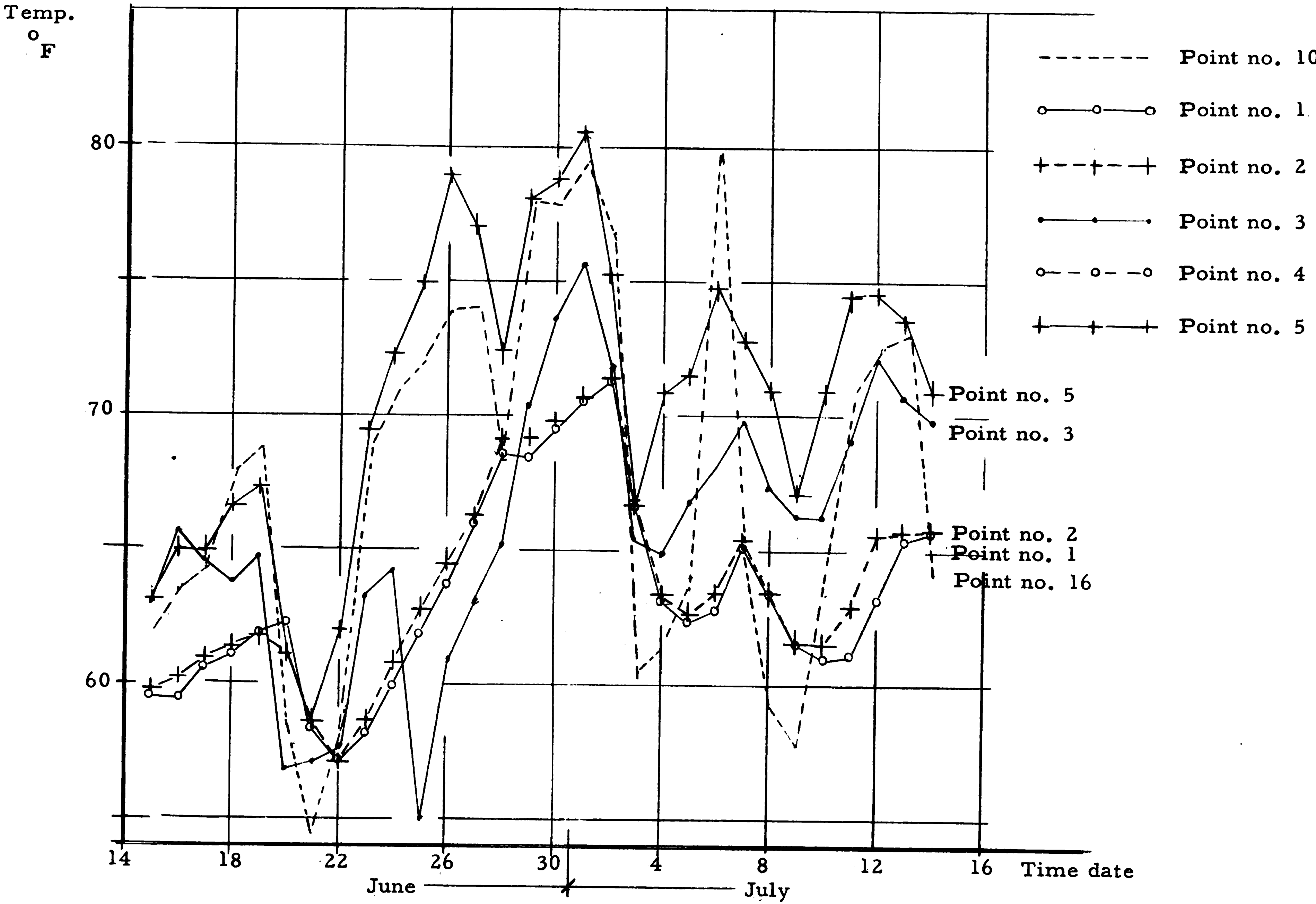


Figure 10. Curves showing the variation in daily mean temperature in June and July. Room no. 1.

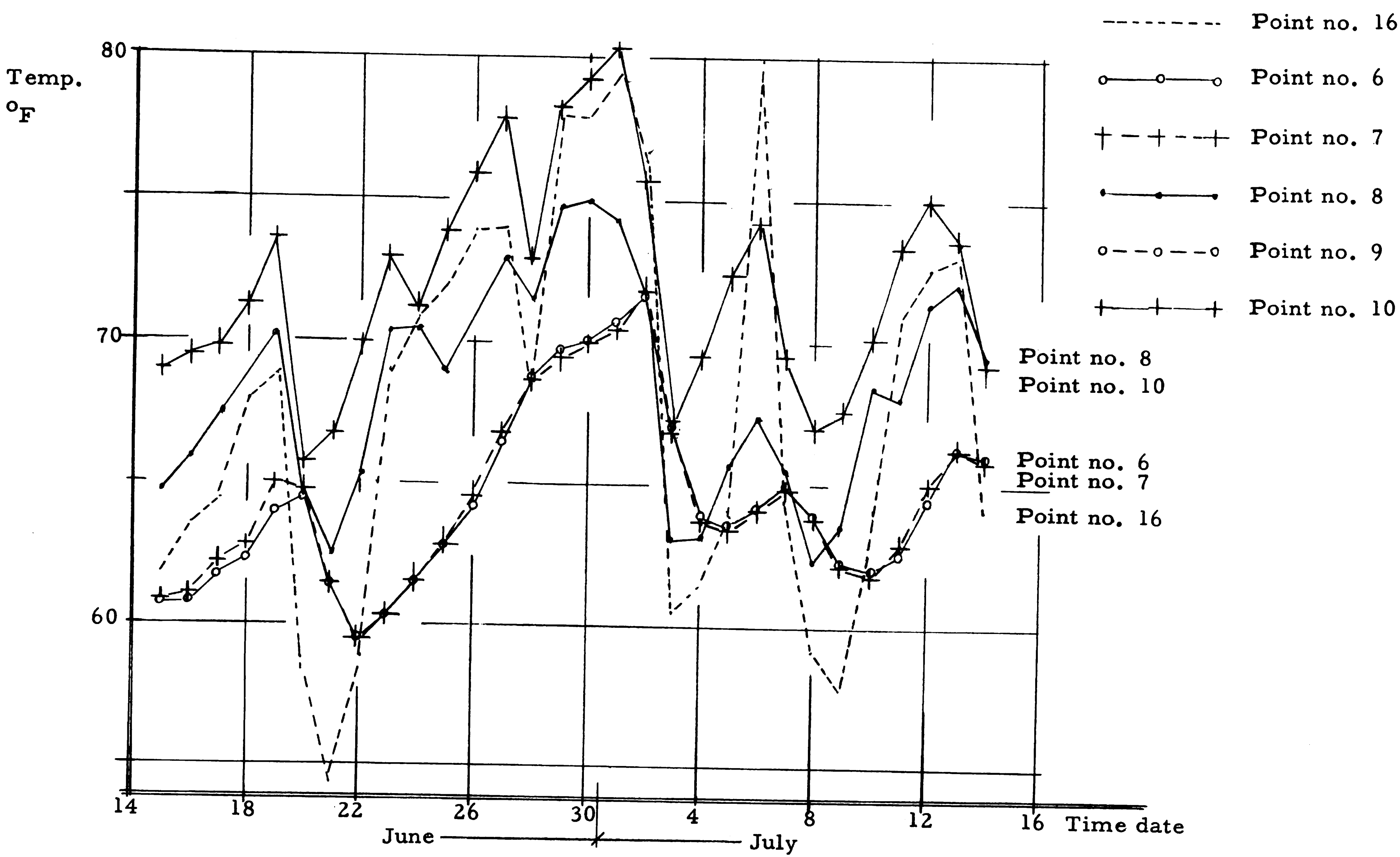


Figure 11. Curves showing the variation in daily mean temperature in June and July. Room no. 2.

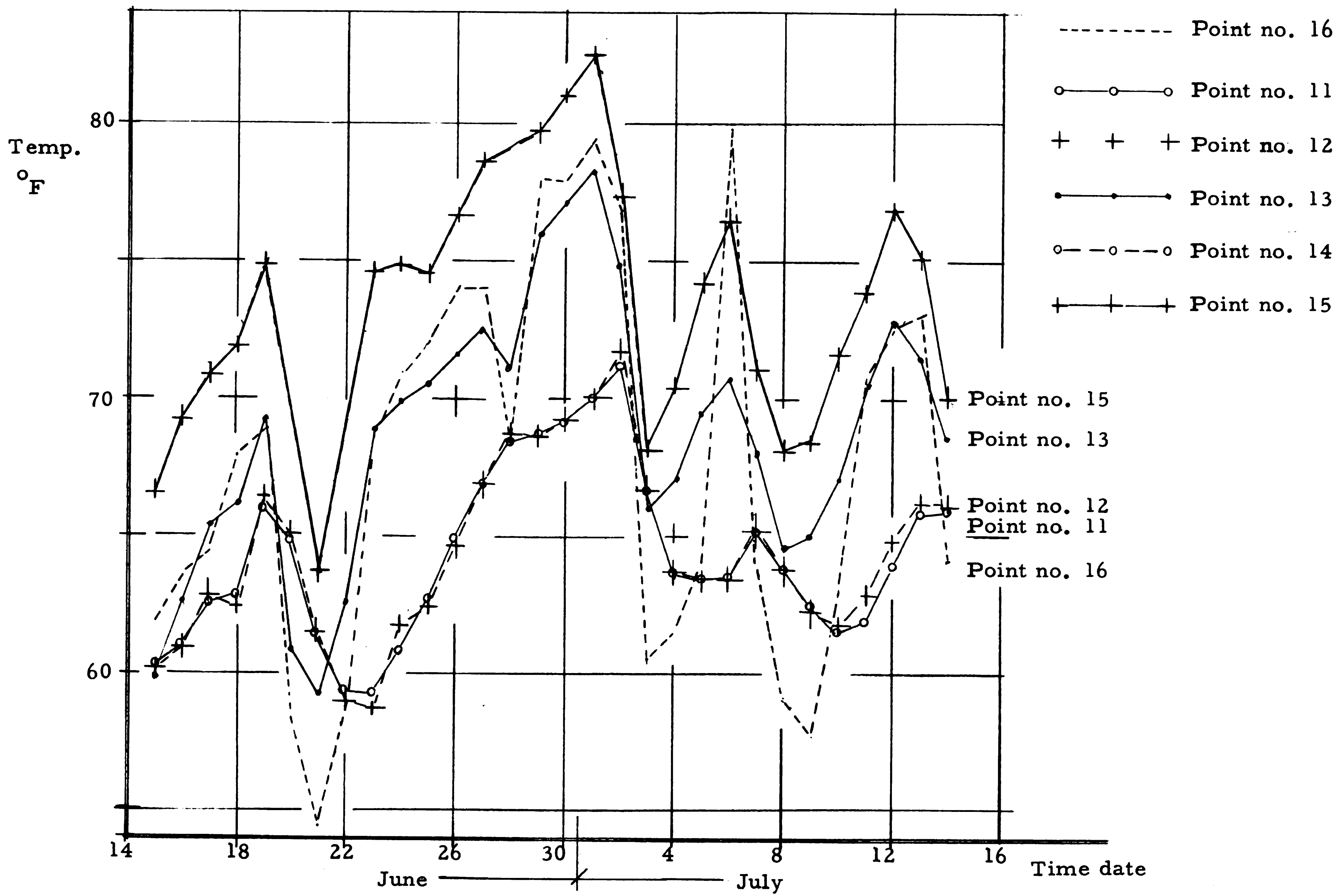


Figure 12. Curves showing the variation in daily mean temperature in June and July. Room no. 3.

The lagoon temperature increased considerably from the spring. The room temperature should be good for small hogs, but a bit high for market-ready ones. The average daily temperatures in the house varied considerably with the outside temperature as shown on Figures 10, 11 and 12, a span of daily mean temperature difference of about $10^{\circ}F$ in the lagoon and about $20^{\circ}F$ in the room air in the period.

G. HEAT BALANCE OF THE HOUSE

The present hog house cost $12,000. An annual cost of 10 percent of original value makes $1,200 a year or $100 a month which calls for a continuous operation of the house. The management also favors this. The house, therefore, should be designed to provide a profitable climate inside the house at any time of the year and at any practical operating condition.

Traditional hoghouses consist usually of a number of pens in a room. In some pens there may be small pigs, in other pens there may be hogs ready for market. This will even out the heat production in the room as the larger hogs produce more heat than the small ones. In cold climate the central located and warmer pens may be reserved for the smaller hogs.

In the present hoghouse the designs do not permit small and large hogs in the same room. Both pen groups get their feed from a common feeder and as the feed composition has to be changed throughout the growing-finishing period this is not possible without providing individual feeders for each pen. If the size of the hogs on the two sides varies considerably heavy condensation is likely to occur in the pen of the smaller animals during cold weather as a consequence of the temperature gradient created in the house.

As the new batch of hogs must be put into the house at any cold period of the year and knowing the economic effect of cold especially on small hogs the heat balance should be designed for a hog size of 50-60 lb.

1. Heat and Moisture Production in the House

The heat and moisture production of hogs has been discussed previously. Reference is made to Table 4 and ventilation data given by Bond *et al*. (1959).

The effect of the lagoon on moisture production and heat balance is unknown but deductions can be made for the temperature measured and available knowledge. Morrison (1956) shows that about 25 percent of gross energy of ground corn is lost in feces. This energy could be utilized for heating the house providing complete decomposition of manure by microorganisms would occur within the house.

In the present house it appears that no appreciable heat is supplied to the house by microbic decomposition in wintertime when heat is needed. The growth rate of common microorganisms is at maximum at about 35°C (95°F) (McKinney, 1962). At 0°C the growth is negligible. The growth rate about doubles for every 10°C temperature increase to the optimal temperature. In January and February the temperature in the lagoon was below 40°F (4.4°C) which provide for a very slow microbiologic activity.

The manure is suspended in water. The organic matter therefore is metabolized anaerobic rather than aerobic. The end products of an anaerobic process have higher energy content than those of an aerobic process and therefore release less heat.

According to the temperature observations the lagoon gains rather than gives off moisture to the room air during the critical winter period. The relative humidity was 80 percent and the temperature 60°F at the ceiling in the first period of January. The lagoon temperature at the same time was about 40°F. The saturation pressure at the lagoon is 0.122 lb/in^2 and the vapor pressure at the ceiling 0.205 lb/in^2. A vapor pressure gradient of 0.083 lb/in^2 therefore exists and a diffusion of moisture should occur toward the lagoon. The lagoon therefore works positive to remove the moisture in the critical period, but works negative on the heat balance.

Based upon data from Bond et al. (1958) the total heat production of a 50 lb hog is about 340 Btu/hr and of a 100 lb hog 440 Btu/hr at 70°F air temperature. At this temperature 28.4 percent of the heat is released as latent heat. Bond et al. (1958) account for vaporized water from other sources as urine, feces, waterer, etc., and came up with data showing that more than half the total heat production is removed as latent heat at this temperature. These results were observed in a laboratory with solid floor and with floor temperature equal to the air temperature in the chamber. The relative humidity was 50 percent which is lower than experienced in practice. The slatted floor does not allow much moisture to accumulate on floor subjected to evaporation in contact with the hog bodies. As the air is less favorable for evaporation and the lagoon likely drains moisture from the air, we have chosen 30 percent of total heat production bound in water-vapor as a reasonable figure for winter-ventilation in the present house. Calculations will be based upon these assumptions.

2. Heat Loss From the House

Heat is lost from the house according to the common principles of heat transfer through the enclosure, by ventilation and by air leakage. The air leakage may be regarded as a form of ventilation and therefore no extra burden upon the heat balance of the house. The air leakage may, however, have an unfavorable influence upon the temperature distribution which will be discussed later.

The heat loss through the walls and ceiling are theoretically determined when we know the thermal properties of the materials. The heat loss through the floor, on the other hand, has to be an estimate as no simple method is available for calculation. Heat loss by ventilation is well-founded upon reliable physical data for air and water vapor.

The calculated U-value for walls and ceiling is 0.1 Btu/ft^2/hr/$^\circ$F. The exposed area of walls and ceiling is 1270 ft^2 for room number 1 and 3 and 1150 ft^2 for room number 2.

The outside design temperature is based upon the extreme temperature plus a "judged" addition as advocated in reference Barre and Sammet (1959). It is noticeable here that the heat capacitance of the house is very low disregarding the lagoon, but the lagoon has a low temperature in winter. The extreme temperature for Mason is -21°F U.S.D.A. (1941) and should apply for this area. In the examples either 0°F or 10°F is used as outside design temperature. The desired inside temperature is 70°F for 50-100 lb hogs in the winter period for the present house with an allowable relative humidity of 80 percent.

a. Assuming 50 lb hogs, inside design temperature 70°F and outside temperature 0°F.

Total heat production	= 340 Btu/hog/hr	
Latent heat 35 percent of total	= 120 Btu/hog/hr	= 0.115 lb water/hog/hr
Sensible heat available	= 220 Btu/hog/hr	

1. Sensible heat available per room + 20,000 Btu/hr
2. Heat requirement for heating ventilation air:

$$\frac{0.115 \times 0.24 \times 100 \times 70}{(0.01582 - 0.00079)\ 0.8} = 19,300 \text{ Btu/hr}$$

3. Heat loss by transmission through walls, ceiling, shutters and door:

   Room no 1 or 3: 0.1 x 70 x 1270 = 8,900 Btu/hr
4. Heat loss through floor

   Assume U = 1 and t = 10°F

   1 x 18 x 36 x 10 = 6,500 Btu/hr = 34,700 Btu/hr

   Deficit 12,700 Btu/hr

This shows a large heat deficit to obtain the desired room temperature at the assumed conditions. Disregarding the most questionable item, the heat loss through floor, a large deficit still remains.

b. Assuming a more frequent outside temperature of 10°F, which may exist for long periods of time, 50 lb hogs, inside temperature of 70°F and outside temperature of 10°F:

1. Sensible heat available		= 22,000 Btu/hr
2. Heating ventilation air	= 14,300 Btu/hr	
3. Heat transmission over floor	= 7,600 Btu/hr	
4. Heat loss through floor	= 5,000 Btu/hr	= 26,900 Btu/hr
	Deficit	4,900 Btu/hr

According to the calculation it is still difficult to provide proper environment at the assumed conditions.

c. Assuming 100 lb hogs, inside temperature 70°F and outside temperature 0°F.

Total heat production	= 440 Btu/hog/hr	
Latent heat 35 percent of total	= 154 Btu/hog/hr	= 0.148 lb water/hog/hr
Sensible heat available	= 286 Btu/hog/hr	

1. Sensible heat available		= 28,600 Btu/hr
2. Heating ventilation air	= 20,700 Btu/hr	
3. Heat transmission over floor	= 8,900 Btu/hr	
4. Heat loss through floor	= 6,500 Btu/hr	= 36,100 Btu/hr
	Deficit	7,500 Btu/hr

d. Assuming 100 lb hogs, inside design temperature 70°F and outside temperature 10°F.

1. Sensible heat available		= 28,600 Btu/hr
2. Heating ventilation air	= 18,400 Btu/hr	
3. Heat transmission over floor	= 7,600 Btu/hr	
4. Heat transmission through floor	= 5,000 Btu/hr	= 31,000 Btu/hr
	Deficit	2,400 Btu/hr

Also with 100 lb hogs it is impossible to provide the desired environmental conditions. With the assumption made this house therefore cannot provide optimal climate for hogs up to 100 lb under winter conditions in this area without additional heat.

e. As small hogs were put into the house in January calculations should be based on 50 lb hogs. The inside temperature was 50°F and outside design temperature chosen 0°F.

Total heat production	= 380 Btu/hog/hr	
Latent heat 25 percent of total	= 95 Btu/hog/hr	= 0.091 lb water/hog/hr
Sensible heat available	285 Btu/hog/hr	

1. Sensible heat available		= 28,500 Btu/hr
2. Heating ventilation air	= 19,900 Btu/hr	
3. Heat transmission over floor	= 6,300 Btu/hr	
4. Heat transmission through floor	= 5,000 Btu/hr	= 31,250 Btu/hr
	Deficit	2,750 Btu/hr

f. Assuming 50 lb hogs, inside temperature 50°F and outside temperature 10°F.

1. Sensible heat available		= 28,500 Btu/hr
2. Heating ventilation air	= 17,200 Btu/hr	
3. Heat transmission over floor	= 5,100 Btu/hr	
4. Heat transmission through floor	= 4,000 Btu/hr	= 26,300 Btu/hr
	Surplus	2,200 Btu/hr

In the period after the second batch of hogs was put into the house considerable condensation occurred in all rooms. The stabilized temperature in this period seemed to be what the rooms could afford with reasonable conditions. The higher temperature in room 2 during this period may also support this as the two other rooms have more wall exposed for heat loss. These observations are in good agreement with the calculated capability of the hog house as shown in examples e and f.

Undoubtedly it would be right and profitable, by having the economic effect of proper climate in mind, to improve the insulation of the house. The 4 in. framing in walls allow space for 2 in. more insulation without any extra costs than the material itself and the labor involved. The ceiling allows practically unlimited space for extra insulation on the same basis. It is also important to prevent uncomfortable dripping of condensation on hogs from ceiling in cold weather. Two in. fiberglass would only cost $185 for the whole house, including walls and ceiling, and based on 0.05 cents/ft^2 (Sears, Roebuck and Co., 1963). If we also include labor we anticipate the extra cost $250-$300 for the house ($25-30 a year) which is negligible in relation to the savings obtainable by more favorable temperature.

H. VERTICAL TEMPERATURE DISTRIBUTION IN THE HOUSE

The temperature observations show a large vertical temperature-gradient in cold weather. This difference decreases with higher outside temperature and is undesirable because the supposedly more cold sensitive surface of the hogs is exposed to the cold bottom and may give them an uncomfortable resting place. Ultimately this makes it difficult for the operator to ensure the desired temperature for the hogs.

The build-up of a temperature gradient is due to the fact that air of different temperature has different density. The cold air settles and the warm air rises. In an investigation on 60 dairy barns with cellars in Norway (Graee, 1962) an average temperature difference of $3^{o}C$ ($5.5^{o}F$) was found between ceiling and floor level and the same difference between the level over and the level under the floor.

The best way to reduce the temperature gradient seems to be to conserve the heat at the lower part of the room by reducing the heat transfer to the outside at this location and preventing cold air from entering at this level. The cold entering air should preferably enter and be distributed at the ceiling to gain heat before reaching the hog level.

In Norway attempts have been made to improve the cellar temperature in slatted floor houses by locating the exhaust fan in the cellar wall without appreciable effects.

In the present house the heat transfer from the pit section is considerable as there is no insulation in the pit walls beyond the 1 1/2 in. pressure treated wood boards. This could likely be improved profitably by lining the pit walls with slabs of styrofoam. There is no information available how styrofoam performs in contact with manure, but polystyrene is very resistant to alkalies and many other chemical compounds (Handbook of Chemistry and Physics, 1961), and the capillary action is very low.

Because of the difference in density of warm and cold air a pressure-difference will occur between outside and inside air. In an airtight room communicating with the outside air through an opening different pressure-differences will occur between the inside and outside air according to the location of the opening, Figure 13. The pressure difference is proportional to the temperature difference and the distance from the neutral zone. The arrows on the figures (Figure 13) show the direction of the pressure drop and the length of the arrows the relative magnitude.

The pressure difference can be calculated from equation

$$\Delta p = h(\gamma_0 - \gamma_i) = h.c. (t_0 - t_i)$$

where

Δp = pressure difference, mm water

h = height from neutral level, m

γ_0 = density of outside air, kg/m^3

γ_i = density of inside air, kg/m^3

c = density difference of air/$^\circ C$

t_0 = temperature outside, $^\circ C$

t_i = temperature inside, $^\circ C$

For the present house the major openings are at the upper level of the room, the fan openings and the air inlets. A permanent low pressure therefore will exist at the lower level of the room when the outside temperature is lower than the inside, in addition to the suction caused by the fan when operating and the action of the wind. Relatively small openings or cracks in the lower part of the wall therefore will permit considerable quantities of cold air to enter at this level and even cause draft.

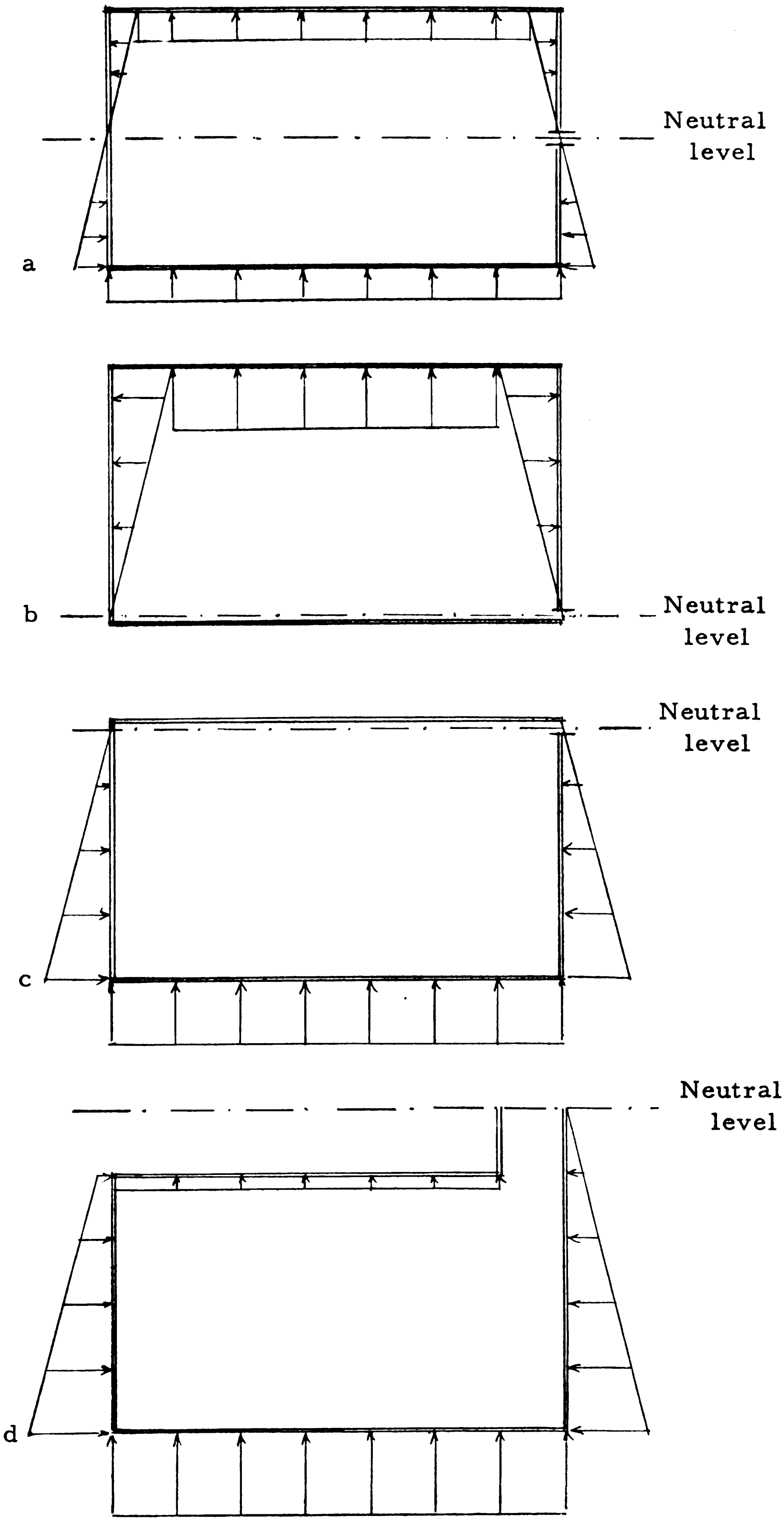


Figure 13. Air pressure performance caused by a temperature difference to outside in airtight rooms with one communicating opening at different location.

The vertical temperature gradient will create a higher relative humidity at the floor level. About 5 percent higher relative humidity was found at the floor level compared to the ceiling level in surveys of dairy barns in Norway (Graee, 1957, 1962).

I. DISCUSSION

The literature review showed that the effect of low temperature can be offset by the hogs if they have access to deep litter. Deep litter is not easily defined. In practical experience this may vary from a mudhole to a dry, soft and comfortable bed. We can assume the tests were carried out under the last mentioned conditions.

The Danish experiments show a clear difference between bedding and no bedding on concrete floor. This could probably be taken advantage of in cold and hot environment. The temperature requirement for optimal growth of hogs on solid floor can best be covered by laboratory experiments if proper adjustment can be made for differences in group size and effective temperature.

For slatted floors a still greater effect of low temperature is experienced. This system is the most easily defined and suitable for complete temperature control of the micro-environment to which the hogs are exposed. Laboratory experiments are the most adequate to give the right temperature condition, but corrections have to be made for group size and effective temperature.

Effective temperature is made up of room air temperature with adjustment for room surface temperature, air velocity and relative humidity (Barre and Sammet, 1959). For each $^{\circ}F$ the surface temperature deviates from the room air temperature $0.5^{\circ}F$ adjustment should be made in room air temperature for equal comfort. Laboratory tests have been carried out in rooms where surface temperature and air temperature were close. To transfer the data a correction must be made for the lower surface temperature in actual houses. In the present house an adjustment of 1.5°F has been calculated based on average outside temperature of 24°F in January. This does not include the lagoon which can be expected to have a 15-20° lower temperature than the optimal room air temperature in the present house. At least a correction of 5-7°F in room air temperature should be necessary in January. During other seasons other and smaller adjustments will be necessary.

The air velocities in the laboratory tests presumably lay in the same range as in the present house.

The air relative humidity in January was higher in the present house than in the laboratory experiments which accounts for a bit lower temperature for the same comfort.

Laboratory experiments were carried out with smaller groups of hogs than commonly used in practice. Larger groups are liable to be more comfortable at a lower temperature (compare the Danish research with single hogs).

Hogs being self fed may obtain a better feed conversion at elevated temperatures which affects their appetite and therefore experience a more profitable feeding rate.

As a conclusion we could assume that the hogs offset the effect of low lagoon temperature and surface temperature by community heating (huddling together), which make the laboratory findings directly applicable for winter condition. For summer conditions when the lagoon temperature is 20°F higher a somewhat lower temperature than obtained in laboratory experiment could be profitable.

In the present house a temperature schedule beginning with 65-75°F at hog level for 50 lb hogs and gradually dropping 1°F per week or 10 days throughout the growing-finishing period appears reasonable.

J. OBSERVATION FROM THE HOUSE

1. Condensation of Water-vapor in the House

a) Condensation in the attic. The ventilation system was designed to move the entering air to the rooms via the attic through air inlets in the ceiling. When the fan was idle the air current reversed and the air entered the fan opening, through cracks around doors and windowshutters (Figure 18), and other openings. It passed through the house leaving through the attic and ridgevents. This is due to the buoyancy effect in the house, Figure 13. The air inlets were supposed to close by use of solenoids when the fan stopped, but the shutters were poorly fit.

Serious condensation therefore occurred in the attic during the winter due to the high moisture air escaping from the rooms. In some periods more than one-half inch of ice or frost build-up was observed over the underside of the metal roofing. The roofing support and the upper part of the trusses also were covered with frost in the most severe periods. When the outside weather changed or during sunshine with no snowcover on the roof the frost and ice melted and dripped down on the ceiling occationally dripped further into the pens, soaked the supports and trusses with water or leaked along the underside of the corrugated aluminum roofing to the eaves. Heavy dripping often occurred from this condensation and sometimes icycles, 4-5 inches long, formed on the edge of the roof.

There is no access to the attic for inspection. Observations were made by looking up through the air inlets. After the first winter no signs of decay were visible on the trusses. An unfavorable temperature

Figure 14. The hog house seen from the lagoon side. The ice covered the lagoon close to the building till the general icemelting in the area. In mild weather a clearing of up to 1 in. appeared between the building and the icecover on the lagoon. M.S.U. Photo No. 63188-5.

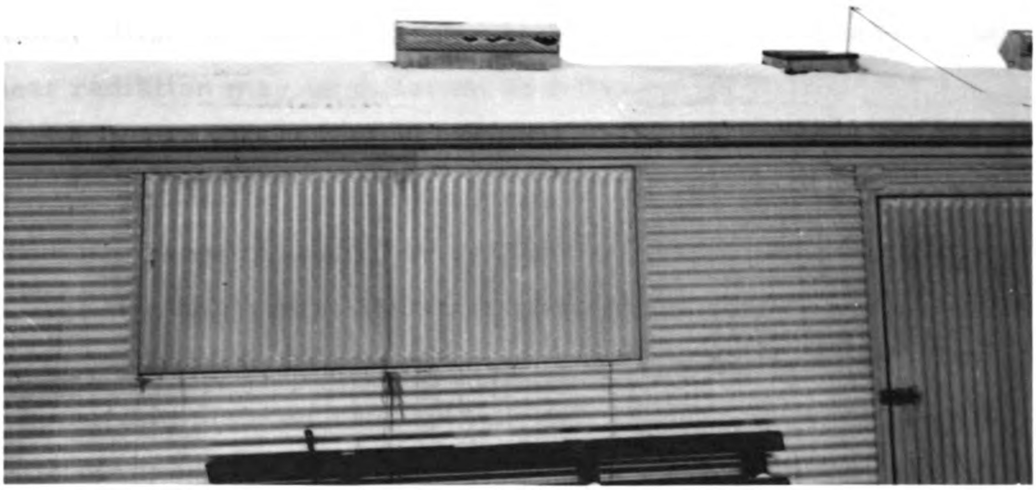


Figure 15. Snow melted on the roof where the warm room air escapes to the attic. Moisture trapped in the ridge vent. The feed is supplied to the feeder through the shutter to the right. M.S.U. Photo No. 63188-9.

at time of soaking can explain this. In the unaccessible area where water could accumulate the possibility for deterioration would be highest. In Norway many examples of damage were found due to moist air escaping through constructions (Graee, 1957, 1962; Torp and Graee, 1961).

Warm air escaping through the air inlets in the ceiling, caused the snow on roof to melt (Figure 15), and the screen in the ridge trapped moisture in the leaving air.

b) Condensation inside the rooms. The metal sheathing inside the walls and ceiling possess no moisture absorbing capacity. The condensation therefore becomes visible instantly. The most severe condensation occurred in the last part of January and in February after a new batch of hogs was started during the period with low outside temperature and therefore a critical heat balance of the house.

Surface condensation can theoretically be predicted when we know the inside air temperature and relative humidity, the outside temperature and the thermal properties of the construction. In practice surface condensation usually occurs in the rom before predicted. There are several reasons for this: The temperature is not even throughout the room. Discontinuity in the thermal insulation. Air movement and heat radiation may be different at different locations.

Figure 16 shows the heavy condensation caused by uneven heat distribution within the room. Only one of the two pens was used at the time of photographing. The ceiling over the occupied pen was dry while over the empty pen, shown on photograph, heavy condensation with dripping occurred.

Semirigid slabs of expanded polystyrene was used as thermal insulation in the house. We observed signs to suspect the insulation not to give calculated insulating effect as condensation frequently occurred along the wood framing members and presumably along the

Figure 16. Severe condensation on ceiling due to the horizontal temperature gradient in the room. The ceiling over the other pen with the heat source (hogs) was dry. No hogs in this pen. M.S.U. Photo No. 63188-3.

Figure 17. Condenspattern detect deficiency in thermal insulation. M.S.U. Photo No. 63188-2.

junctions between the insulating slabs. Convection currents are likely to occur when the insulating material don't fill the cavity and when there are cracks for the air to travel around the material (Handegord and Hutcheon, 1952). Figure 17 shows the condenspattern on the ceiling.

As cold air enters the room and mixes with the warm inside air the mixture always will have a higher relative humidity provided no exchange of sensible heat other than that in the air involved. This also led to severe condensation in the house and was found around doors, windowshutters, fan openings, etc. Figure 18 demonstrates this well. Twice during the winter the fanblades were blocked by ice and frost and blew the fuse when the thermostat called for the fan to start.

This surface condensation has likely done no harm to the construction other than possibly corrosion on the aluminum which is subjected to contamination in contact with alkalic compounds. No adverse effect of this kind is found after the first year in operation.

Eventually other damage has to be subscribed to the sanitary influence, uncomfortable dripping on the hogs from the ceiling and estetic considerations.

2. Wear of Floor

Slatted floors have been used for more than 30 years for sheep and goats in Norway without excessive wear, although most of the slats have been made of softwood. When this same floor system was used for cattle and hogs the durability of spruce and pine slats was poor. For cattle an average life for pine slats was only three to four years. In Norway the supply of suitable hardwood for this purpose is limited so few records are available for comparison. Concrete slats were found to be most economical and these are commonly used for cattle and hogs.

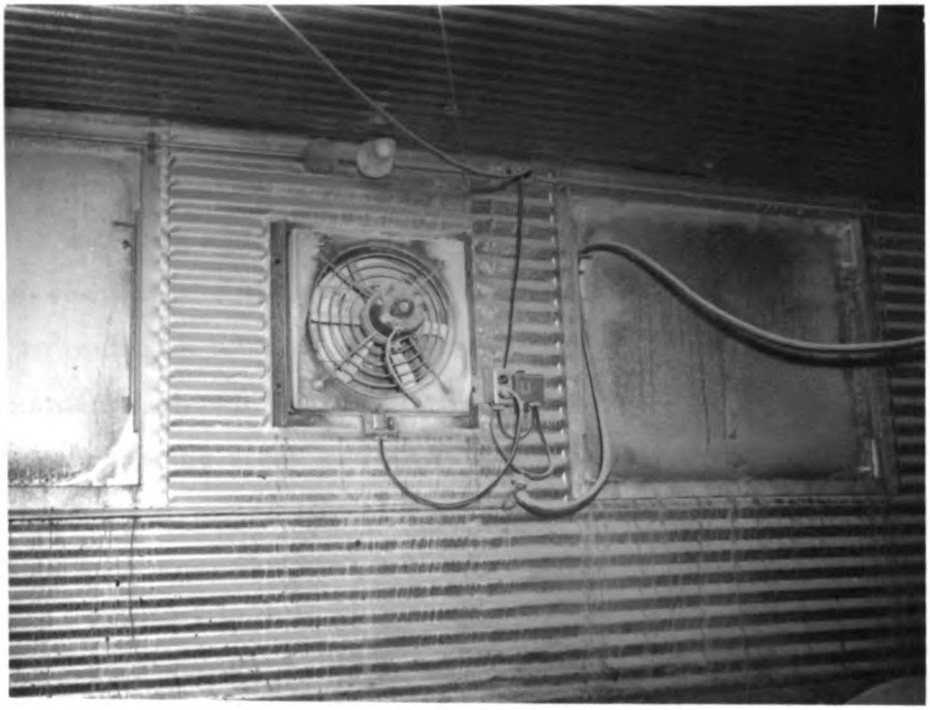


Figure 18. Where cold and warm air approach and mixes condensation is likely to occur. Heavy condensation around the fan. Thermostat to the right of fan. M.S.U. Photo No. 63188-6.

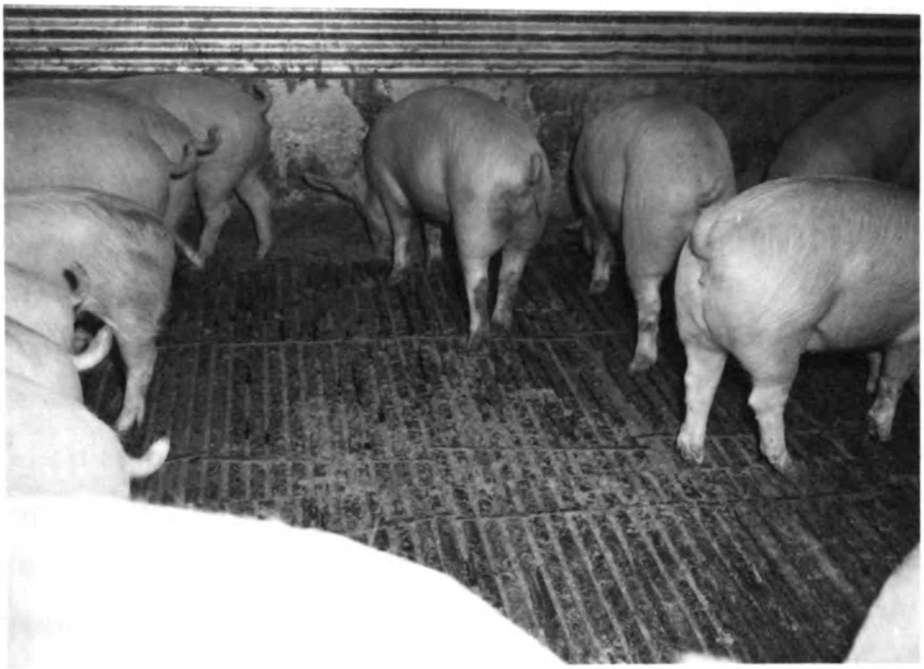


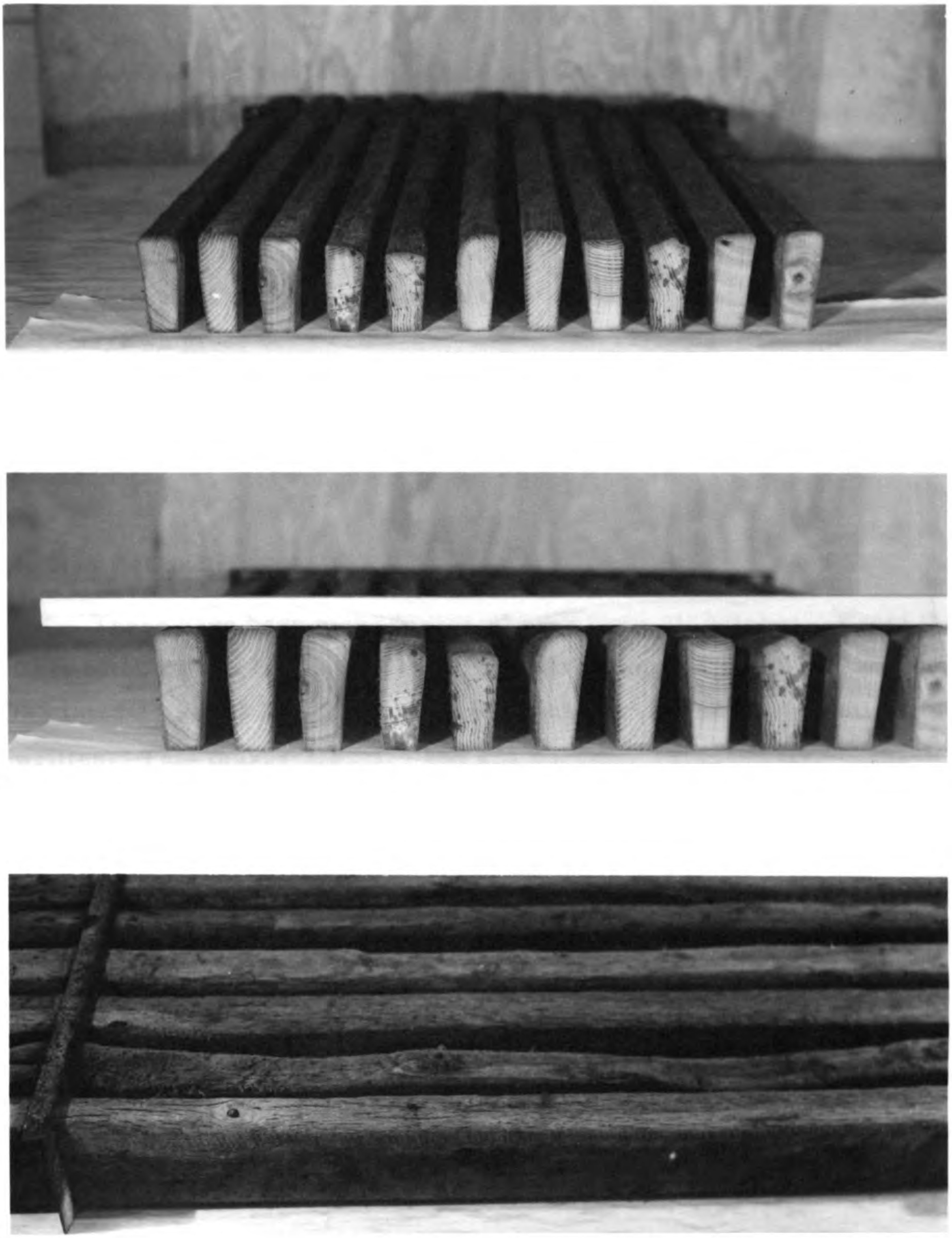
Figure 19. The hogs kept clean and also good houseorder. As dunging area the most trafficed space between the feeder and waterer was used. The resting area had a horseshoe form behind and to the sides of the waterer in the middle of the pen. The area between the feeder and waterer showed heavy wear. The tails of the hogs look miserable from the tailbiting. M.S.U. Photo No. 63188-7.

In the present house oak slats were used. Two floor sections were removed and examined to determine wear on the slats. The wear was most excessive around the waterer and in the heavy trafficed area between the waterer and feeder and was much a result of chewing. In a cross-section of a floor section (Figure 20), the wear is measured to be 3.6 in^2 out of a total cross-section of 40 in^2. The other floor section examined showed a wear of 3 in^2 after 11 months. If we assume replacement when the slats are worn down to half the original cross-section we get an average life of 7 years. Perhaps a more frequent replacement is necessary for particular slats as shown. The wear differed for different slats and as expected width of growth rings (density) sapwood and heartwood were important factors. Undoubtedly selection of the oak material according to location in pen would be profitable.

3. Odor in the House and from the Lagoon

An intense odor is experienced in the house both in the winter and the summer. No objective measure is available to compare the odor with other hoghouses. Subjectively, the odor in this house is worse than in the average hog house.

An unpleasant odor is also experienced from the outside lagoon when wind was blowing. There have been complaints of odor from neighbors. It is possible to reduce the odor by introducing oxygen into the lagoon and thus favor aerobic decomposition. Spillman (1962) suggests a requirement of 0.65 lb O_2/day/120-150 lb hog for complete aerobic decomposition of the waste. Oxygen may be provided by chemicals. $NaNO_3$ is suggested and will give 0.18 lb O_2/lb $NaNO_3$. If we assume half of the supply of oxygen would be sufficient 2 lb $NaNO_3$/day at 3.5 cents/lb would be 7 cents/day or a total of $7/hog. This is about the profit remaining after the feed cost.



A

B

C

Figure 20. Cross-section (A and B) of a slatted floor section illustrating the wear after eleven months use. Sideview (C) of a part of a floor section badly worn. M.S.U. Photo No. 631562-4(A), 631562-3(B) and 6 31562-5(C).

Another method is to introduce air into the lagoon. From an economic point of view this looks more promising. Isaac (1960) gives from Pasveer the energy requirement of oxygenation of liquid waste by the rotor principle to 1 Kwh/2000-3200 g O_2. Calculated on an average figure 2500 g O_2/Kwh or 5.5 lb O_2/Kwh and by providing the same amount of oxygen as in the previous example electricity at 2 cents/Kwh gives 0.13 cents/day/hog or \$0.13/hog for the whole finishing period the overhead costs not included. If operated continuously over the year, it would make \$130/year plus overhead costs for the whole house.

4. Health Condition of Hogs

There have been many losses of hogs from all batches. From the first batch 23 are lost out of 296, from the second 11 out of 313 and in the third 24 out of 297. The third batch was not finished when this is written. This makes 7.8, 3.5 and 8.1 percent, respectively.

Most of the losses in the first batch (fall) occurred from stomach ulcers, but none from the second or third batch. Two of the first batch died from chewed out rectum and the rest from tailbiting.

Of the second batch (winter) five died from tailbiting, one from chewed out rectum and five from pneumonia.

All the hogs lost in the third batch (spring, summer) died from cannibalism. Seven suffered from chewed out rectum and the others from tailbiting. Death resulted from bleeding or infection.

5. Operating Results

The results build upon feed bill from the Ralston Purina Feed Company, the total final weight of hogs, the judged initial weight of pigs and the guessed average weight of lost hogs. The judged initial weight may have an error of ± 5 lb/hog. As the losses occurred arbitrarily throughout the finishing period the average weight of the lost hogs is assumed to be 125 lb.

a. First batch.

Gain of weight:

Final weight (selling weight)	= 55,250 lb
Initial weight 54 lb x 296	= 16,000 lb
Net gain	39,250 lb
Loss of hogs 125 lb x 23	2,875 lb
Total gain	42,125 lb

Feed consumed:

Supplement	24,690 lb
Oats	2,600 lb
Corn	130,100 lb
Total feed	157,390 lb

$$\text{Feed conversion ratio} = \frac{157,390}{42,125} = \underline{3.74 \text{ lb feed/lb gain.}}$$

$$\text{Average daily gain/hog} = \frac{42,125}{273 \times 113 + 23 \times 57} = \underline{1.31 \text{ lb gain/day}}.$$

(Finishing period 113 days average)

Selling price (average price $16.49/Cwt)

	$0.1649 x 55,250	= $9,109.02
Total feed cost (3.25 cents/lb av.)	$5,117.30	
(include minerals and antibiotics)		
Purchase price	$5,152.60	= $10,269.90
	Deficit	$ 1,160.88

On the first batch the operator had a deficit of $1,160.88, the labor and the overhead costs nor vaccination and medication not included.

b. Second batch.

Gain of weight:

Final weight (selling weight)	= 60, 105 lb
Initial weight 60 lb x 313	= 18, 780 lb
Net gain	= 41, 325 lb
Loss of hogs 125 lb x 11	= 1, 375 lb
Total gain	= 42, 700 lb

Feed consumed:

Supplement	24, 480 lb
Oats	2, 505 lb
Corn	123, 245 lb
Total feed	150, 230 lb

$$\text{Feed conversion ratio} = \frac{150,230}{42,700} = \underline{3.52 \text{ lb feed/lb gain}}$$

$$\text{Average daily gain/hog} = \frac{42,700}{302 \times 104 + 11 \times 52} = \underline{1.34 \text{ lb gain/day/hog}}.$$

(Finishing period 104 days average.)

Selling price (average price $15.13/Cwt)		
$0.1513 x 60, 105		= $9, 096.66
Total feed cost (3.18 cents/lb av.)	$ 4, 761.80	
(include minerals and antibiotics)		
Purchase price	$ 4, 558.76	= $ 9, 320.56
	Deficit	$ 223.90

The deficit on the second batch was less than on the first batch, partly because of better feed conversion, lower purchase price, and less losses of hogs. On the other hand the selling price was lower.

A feed conversion of 3.74 is calculated for the first batch compared to 3.52 on the second batch. The hogs in the second batch were considerably more thirfty and the operator would attribute most of the difference to this effect.

Because of the health factor involved it is difficult to draw any conclusion concerning the effect of temperature on the different batches. The hogs in the first batch had a more favorable temperature and temperature change trend in accordance with the growth. The calculated feed conversion ratio did not, however, confirm this.

A proper estimate of economic results of the project should also include medication (assume $100/batch), labor and management ($400/batch), electricity, etc. ($100), and overhead costs (house $400), which together result in an additional loss of $1000 per batch.

To produce profits at the current selling prices both a better feed conversion (use second batch as example, assume 10% improvement = $450), less losses (about 3% = $300), and a lower purchase price of pigs seems inevitable.

K. CONCLUSIONS

The larger feed requirement of hogs raised at lower temperature is not only spent in a greater heat loss, but also in a higher specific energy-content of the pork.

Hogs on slatted floors are more influenced by low temperature than in the traditional hog housing systems. A more closely controlled temperature seems necessary on slatted floors to obtain optimal efficiency of hogs.

A great vertical temperature gradient was experienced in the house in wintertime. A particularly low temperature was encountered in the pit beneath the floor and in the lagoon. This requires a compensation in a higher room air temperature. As the temperature of the lagoon is different season to season by as much as 20-25^{o}F, it should be considered by the programmed room air temperature in winter and summer.

The lagoon does not add any moisture to the room air in the winter, and the bacterial activity in the lagoon is small in wintertime.

The house is not capable of providing an optimal climate for average hogs in wintertime because of lack in heat balance. To fill the wall cavities completely with insulating material and also add insulation to the ceiling is good economy at current prices.

The ventilation system caused damaging condensation in the attic of the house. The ventilation system must be redesigned.

The lagoon system may be prohibitive in inhabited areas if no feasible and economic way is found to remove the odor.

An average durability of the oak slats is estimated to be 7 years. This makes other slat materials more competitive, especially concrete.

To obtain a reasonable economic result of the project requires an optimal coincidence of contributing factors at the existing market prices.

L. SUGGESTIONS FOR FURTHER INVESTIGATION

1. Full-scale experiments to determine the optimal temperature for growing-finishing hogs on slatted floors.

   a. Compare different actual slat materials as wood, steel, concrete, etc. on hogs subjected to temperature stresses.

   b. Compare gradually decreasing temperature (10-15°F) with initial temperature of 75, 70 and 65°F to constant temperature throughout the growing-finishing period.

   c. Cycling temperature.

2. Reduce vertical temperature gradient.

   a. Internal mixing of air at ceiling and floor level with air fan.

   b. Improve insulation in the pit or cellar walls.

   c. Relocate air inlets to give better destribution.

These three alternatives could be tried in the present house.

3. Determine the heat transfer through slatted floors.

4. Investigate the effect of feeding frequency on hogs subjected to temperature stresses either hot or cold.

5. Further investigate pork quality and energy content in hogs raised at different temperatures.

6. Further investigate topographic distribution of skin temperature on hogs subjected to cold.

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