WINTER PERFORMANCE AND THERMAL ENVIRONMENT OF SWINE IN A MODIFIED OPEN-FRONT HOUSE

by

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INTRODUCTION

In the past twenty years, pork production in the United States has evolved from a fairly low budget, simple operation to an expensive and complex operation. Probably the most significant aspect in this evolution has been in the area of growing and finishing. While many producers still grow and finish hogs in an unconfined area, many are moving to a confinement operation. This is taking place at a very rapid rate in areas where the value of land is increasing compared to the amount of pork it will produce. Many producers are also faced with a shortage of labor.

A confinement system is very attractive to a producer faced with high land values and few laborers. While confinement may solve these problems it is not without faults. The confinement system has a higher investment in buildings and equipment than an unconfined system. This higher investment must be offset by faster gains, lower feed consumption, and more pork produced per hourly labor input.

The basic philosophy behind confinement production is to restrict the activity of the pigs so that the major portion of feed input is converted to pork and the pigs are located in a central location. The producer can also make efficient use of more labor saving equipment so one man can produce more pork. There are two general confinement housing schemes used. One is a completely enclosed building with sufficient mechanical equipment to provide a high degree of environmental control. The other scheme is an open-front type which provides protection against environmental extremes. The first type has the disadvantage of being very costly. The second type is not as costly but will not provide the level of environmental control that the first type will.

Since swine are homothermic, there is a level of environmental conditions where productivity is maximum. The totally enclosed confinement building allows the producer to maintain an environment for optimum productivity. However, this is not economical during hot summer months. To provide this optimum environment, certain information must be known: the level of environmental conditions (temperature, relative humidity, air movement, etc.) where optimum production occurs, and types of structures which may be used to provide this environment.

Of interest to the agricultural engineer is the application of various research data reported, which provides information on the correct environment. The criteria most used to assess the level of pig performance is daily weight gain, feed efficiency, daily feed consumption, and cost per pound of gain. Using these criteria, the agricultural engineer is able to compare the effect of different environmental conditions on swine performance.

It would seem a reasonable possibility to construct an open-front building for summer operation and enclose it for the winter season. There is, however, little information provided for making such a modification. The need exists to provide:

1. Information on the type of environment which would result when certain modifications are made.

2. The level of swine performance in the modified environment as compared to the level of swine performance in the unmodified environment.

3. Guide lines as to type of modifications which can be made and their effect on the environment.

REVIEW OF LITERATURE

Heat Transfer Mechanisms

Conduction Heat Transfer

Heat flow by conduction involves the transfer of energy within a medium (solid, liquid, or gaseous) (Kreith, 1965). The energy is transmitted by direct molecular communication without displacement of the molecules. The direction of heat flow is from an area of high temperature to a region of lower temperature. Conduction is generally a minor element in heat transfer from swine (Bond, Kelly, and Heitman, 1959).

Convection Heat Transfer

The principal mechanism of heat transfer between a solid surface and a liquid or a gas is convection (Kreith, 1965). This process involves the combined action of heat conduction, energy storage, and mixing motion. Convection heat transfer can be of two types: free convection and forced convection. Free convection occurs when the mixing motion is caused by density differences due to temperature gradients. Forced convection occurs when the mixing motion is caused by a pump or blower. Convection is a major constituent of heat transfer from swine at temperatures less than 100° F (Bond, Kelly, and Heitman, 1959).

Radiation Heat Transfer

The transfer of energy by means of electromagnetic waves is known as radiation (Kreith, 1965). These waves are subdivided into classes according to wave length or frequency and also according to application. Radiation in the spectral region between 0.1 and 100 microns causes heating of the receiving body, and is therefore important in heat transfer. Thermal radiation is radiation emitted by an object by virtue of its temperature. The total amount of radiation that an object can emit per unit area and time is called the total emissive power. The total emissive power is dependent on the absolute temperature and surface characteristics of the object.

The amount of radiant energy exchanged between an animal and objects is dependent on the temperatures of the respective objects, and the geometric orientation of the objects with each other.

The characteristics of a material are very important when dealing with heat transfer by radiation. The absorptivity is the fraction of incident radiation absorbed by the object. The reflectivity is the fraction of incident radiation which is reflected from the surface of the object. The transmissivity is the fraction of the incident radiation transmitted through the object. The emissivity of an object is defined as the ratio of the emissive power of an object to the emissive power of an ideal (black body) radiator. At thermal equilibrium, the absorptivity and emissivity of an object are equal (Kreith, 1965).

The sun emits 90 percent of its total radiation between 0.1 and 3 microns, while an object at 100° F emits 95 percent of its total radiation between 2 and 40 microns (Hinkle and Stewart, 1958). Glass will transmit about 90 percent of all incident solar radiation while it is opaque to radiation in the 1 to 20 micron range.

Not all materials which are transparent to solar radiation are opaque to the longer wave radiation. Clear polyethylene will transmit over 80 per cent of the total incident radiation in the range of 2.5 to 15 microns (Hanson, 1963; Walker and Slack, 1970). It has been found, however, that the emissivity of polyethylene approaches one when condensation forms on it (Hanson, 1963).

Heat transfer by radiation is a significant portion of heat loss from swine at all temperatures below 100° F (Bond, Kelly and Heitman, 1959).

Evaporation Heat Transfer

Heat transfer by evaporation involves a specific case of the more general area of heat transfer by a change of phase (ASHRAE, 1967). Evaporation involves the change of a material from a liquid state to a gaseous state. The material of interest in animal cooling is water. In order to cause evaporation, energy must be supplied from somewhere. If cooling is to take place, energy (in the form of heat) must be supplied from the body rather than the surrounding air. For swine, evaporative heat loss is relatively minor until air temperatures over 60° F are reached (Bond, Kelly, and Heitman, 1959).

TABLE 1 is a summary of the effect of air temperature on the percent of total heat loss from swine.

Animal Heat Production and Temperature Regulation

Animals may be divided into two classes in relation to how their body temperature responds to the environmental temperature. If the animal's body temperature varies with the environmental temperature, it is a poikilotherm (Schmidt-Nielsen, 1964). Animals which are able to maintain a nearly constant body temperature in the face of a varying environmental temperature are homothermic. The activities of poikilothermal animals (such as frogs) are essentially controlled by the environmental temperature (Dukes, 1955). In cold weather the animal passes into a deep sleep, and in hot weather the animal may burrow into the mud to keep cool.

TABLE 1

THE EFFECT OF AIR TEMPERATURE ON PARTITIONAL HEAT LOSS FROM SWINE (FROM BOND, KELLY, AND HEITMAN, 1959).

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

The homotherm is able to maintain this constant body temperature, in spite of the fact that it is subject to the various modes of heat transfer, because it has an elaborately developed heat regulating device, which is centered in the hypothalamus (Dukes, 1955).

Figure 1 (Brody, 1945) illustrates the effects of the environmental temperature on the metabolism or heat production of the animal. Temperature segment B-B' is the zone of thermoneutrality and also that of physical temperature regulation. At thermoneutrality, A, the animal does not employ thermoregulatory devices since the environmental temperature is perfectly adjusted to keep the body temperature normal without regulation. Thermogenesis (heat production) begins to increase at environmental temperature B' in order to balance the increasing thermolysis (heat loss). At environmental

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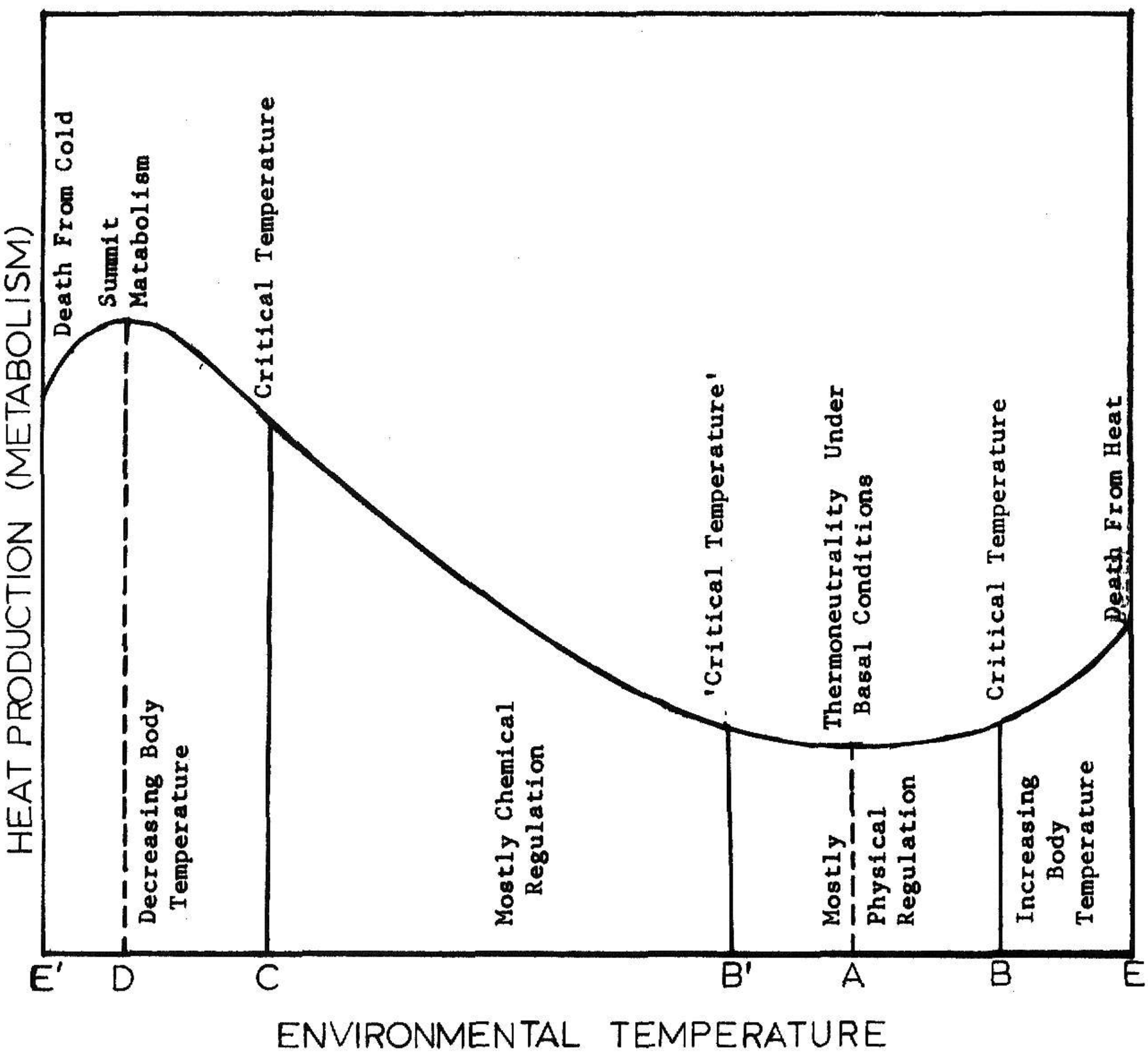

Figure 1. The influence of the environmental temperature on animal heat production and body temperature (From Brody, 1945).

temperature C the body temperature begins to decline despite the increasing thermogenesis. The temperature-regulating mechamism is no longer able to cope with the cold. Environmental temperature D represents the position at which heat production is maximum. Further decline in environmental temperature breaks down the homothermic mechamism, and heat production as well as body temperature declines.

For the homotherm, Hemingway and Stuart (1963) list five major physiological defenses against cold. These are: (a) behavioral responses which influence the animal to seek a comfortable thermal environment, (b) the thermal cutaneous vasoconstriction induced by cold, (c) piloerection, (d) shivering, and (e) non-shivering thermogenesis.

Behavioral responses include huddling or bundling in a group and finding shelter (Brody, 1945). Vasoconstriction and piloerection are methods by which the body controls heat lost through radiation, conduction and convection. Vasoconstriction, which is controlled by the vasomotor nerves, is the reduction of blood flow to the skin (Brody, 1945; Dukes, 1955). By doing this heat loss is reduced. Irving (1956) claims that the method apparently open for a naked mammal to regulate heat loss in cold weather is by changing the temperature of its surface through variation in the heat transported there by the circulating blood. Some animals are able to further control heat loss by piloerection (Brody, 1945; Dukes, 1955; Irving, 1956; Schmidt-Nielsen, 1964). This mechanism is controlled by the pilomotor nerves and muscles. Erection of hairs entraps a thicker layer of still air around the body which helps to conserve heat.

If the body continues to lose heat after the heat regulating devices have extended their maximum effort, the body must increase its heat production. This increase in heat production can be from two sources (Hemingway and Stuart, 1963): (a) an increase of cellular metabolism without muscular movement, the so-called non-shivering thermogenesis (called chemical heat regulation by older workers) and (b) increased muscular activity revealed mechanically or electrically, such as increased muscle tone or shivering. Of the two methods shivering is the most important mechanism. According to Hemingway and Stuart (1963), shivering can increase the oxygen consumption rate fivefold or 400 percent, while contributions of non-shivering thermogenesis are less than 100 percent and most values less than 25 percent. Non-shivering thermogenesis is caused by hormones of the thyroid and adrenal medulla (Dukes, 1955; Brody, 1945; Hemingway and Stuart, 1963).

Environmental Parameters Considered

To determine and assess the influence of the environment on the performance and well-being of swine, one must first determine what the environment is. Rohles (1971) suggests a great number of parameters, including psychological as well as physical, which must be considered to determine a level of human comfort. The environmental parameters considered in animal production systems have been more of a physical nature, since the agricultural engineer and animal scientist are more interested in establishing an environment for optimum production. Environmental parameters which have received attention are: climate, noise, light, ion concentration and crowding (ASHRAE, 1967). The primary interest of agricultural engineers has been the thermal environment.

The thermal environment is important because it directly influences heat dissipation in animals which will influence the animal's level of performance. The necessary requirements are to reduce heat dissipation during periods of cold and to increase heat dissipation during periods of high temperature. At low temperatures the animal will consume extra feed, which it converts to heat in order to maintain a constant body temperature. Since the object of animal production is to produce a marketable animal as fast and inexpensively as possible, the use of extra feed for fuel is very costly. On the other hand, if the animal is placed in a hot thermal environment it will reduce its feed intake.

Parameters Required to Establish the Thermal Environment

The parameters which must be measured in order to establish the thermal environment are: (a) air temperature, (b) humidity, (c) air movement, and (d) radiation. The extent to which each of these parameters affect animal production depends upon the species, age, weight, sex, quantity and type of feed, type of production system (reproductive or growing and finishing), etc. Present information is generally available in terms of temperature and relative humidity (ASHRAE, 1967). Some work has also been done concerning air movement (Bond, 1965).

Effects of Environmental Parameters on Swine Performance

Work done to the present has indicated that light and ion concentration have little effect on the growing and finishing of swine (Hazen and Mangold, 1960; ASHRAE, 1967).

Air Velocity

The work done on air velocity has indicated that weight gains are lower for pigs subjected to air velocities of 300 feet per minute than pigs subjected to air velocities of 35 feet per minute. Pigs exposed to the higher velocities also require more feed per pound of gain. The air temperature for both groups was maintained at the level for optimum production (Bond, 1965). Bond also reported that the animal surface temperatures were reduced as much as 13 degrees at 50° F air temperature with 300 feet per minute air velocity. Significant body temperature reductions were only of the order of 0.3 to 0.4° F. Air velocity did not have any effect on pulse or respiration rate. There appears to be only a limited temperature range between 90° and 104° F where benefits might be realized from additional air velocity. Figure 2 illustrates the effect of air velocity on weight gain and feed efficiency.

Air Temperature

Air temperature is probably the most important of the environmental parameters which must be considered and has been the subject of many investigations. Many investigators have tried to assess the effect of the environment on the performance and well-being of swine. As early as 1883, Shelton reported that it required about 25 percent more feed in winter for pigs kept in the open without protection than for similar pigs housed in the basement of a warm barn.

The critical temperature, which is the external temperature (Dukes, 1955) at which the heat retaining mechanisms are no longer able to maintain a constant body temperature and at which heat production has to be increased, has received some attention. In 1912 Tangle reported that the critical temperature of fasting pigs weighing around 100 pounds was 63° to 74° F. For hogs weighing over 200 pounds he showed that the critical temperature was less than 63° F. For a 300 pound fasting hog, Capstick and Wood (1922) reported a critical temperature of 70° F. Irving, Peyton, and Monson (1956) reported a critical temperature of 32° F for two young 110 pound boars raised in Alaska.

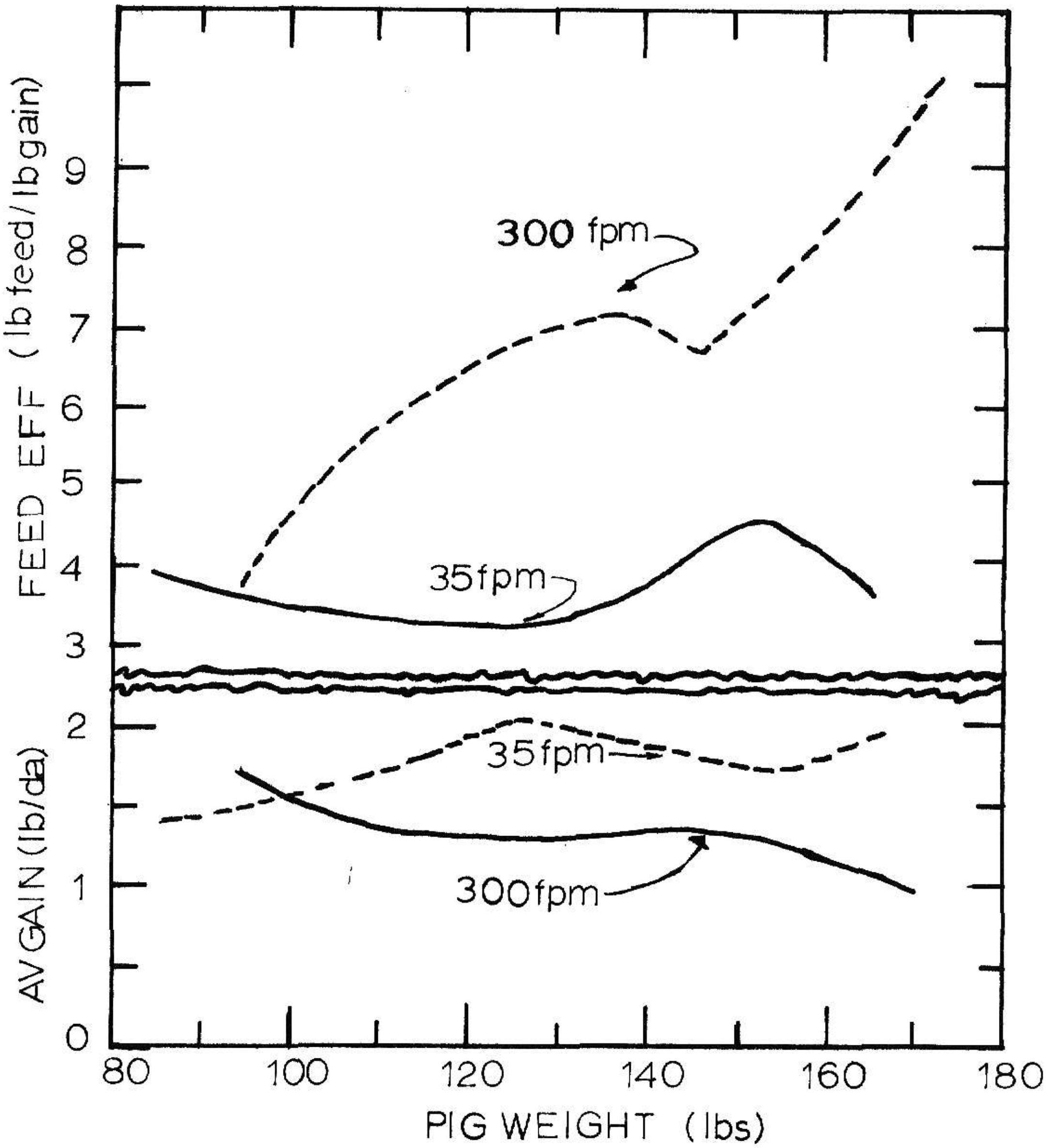

Figure 2. Feed utilization efficiency and rate of gain for pigs exposed at "optimum" air temperatures to different air velocities (From Bond, Heitman, and Kelly, 1965).

While the critical temperatures indicate when the pig is no longer in the zone of thermoneutrality (Brody, 1945), they are of little use to an individual interested in an optimum level of production. What is needed is some indication of an optimum production temperature.

Heitman, Kelly and Bond (1956) found that the constant air temperature at which daily gain was at a maximum varied from 61° F for 350 pound hogs to 73.5° F for 100 pound pigs. When the temperature falls below the optimum range, both average daily gain and feed efficiency (the amount of feed required per unit of gain or the amount of gain per unit of feed) decline (Hazen and Mangold, 1960). This is primarily because the animal is converting feed to fuel. The effects of air temperature are illustrated by Figures 3 and 4.

Clausen (1959) has reported that carcass value also declines with low temperatures because the pig can convert proteins into heat much more easily than carbohydrates. A too low temperature results in not only less efficient and slower growing pigs, but fattier pigs. Jensen, Kuhlman, Becker, and Harmon (1969) reported that pigs raised in a cold environment had a shorter carcass length than pigs housed in a warm environment. The pigs housed in the cold environment also had lower loin and ham weights. Sorensen (1962) reported that at temperatures below 59° F pigs retained less nitrogen and produced fatter carcasses than pigs with similar rate of gain in a warm environment.

Bond, Kelly and Heitman (1963) investigated the effects of diurnal temperature on the performance of swine, and found that as the temperature cycle varied from a constant temperature of 70° F, the average daily gain was reduced and the amount of feed required to produce a pound of gain increased. TABLE 2 shows the results of their experiment.

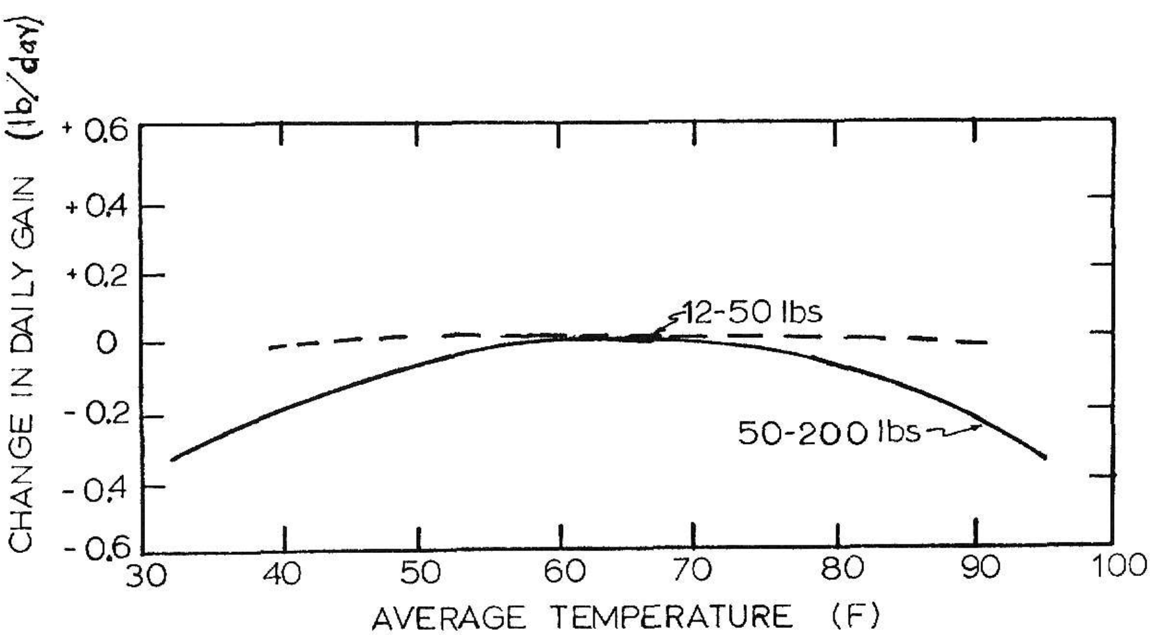

Figure 3. Deviation of average daily gain with temperature (From Hazen and Mangold, 1960).

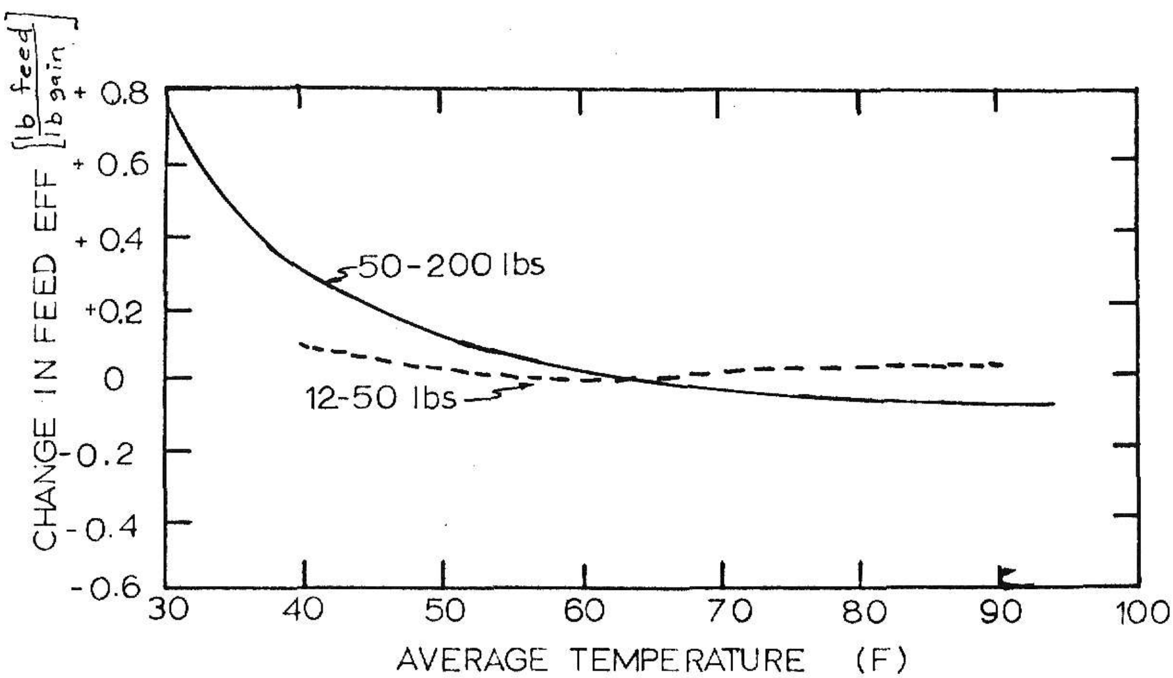

Figure 4. Deviation of feed efficiency with temperature (From Hazen and Mangold, 1960).

TABLE 2

EFFECTS OF VARIOUS TEMPERATURE CYCLES ON SWINE PERFORMANCE (FROM BOND, KELLY AND HEITMAN, 1963)

Temperature Cycle (F)	Gain (lb/day)	Feed Efficiency*
70°	1.66	3.50
50°-90°	1.07	6.15
40°-100°	1.34	4.56

* lbs. of feed/lb of gain

Relative Humidity

Relative humidity appears to have little effect on swine performance except when high humidity is accompanied with high temperature (Hazen and Mangold, 1960). This seems to be reasonable since at higher temperatures the principal heat transfer mechanism is the evaporation of moisture from the animal's surface (Bond, Kelly and Heitman, 1959).

Relative humidity is defined as the ratio of the partial pressure of water vapor in the air to the partial pressure of water vapor at saturation at the same temperature (Threlkeld, 1970). For evaporation to occur there must be a partial pressure gradient between the evaporative surface and the ambient air. If the partial pressure of water vapor at the evaporative surface is assumed to be at saturation, the potential for evaporation will decrease as the water vapor partial pressure of the ambient air approaches a condition of saturation. However, Morrison (1967) reports that skin moisture loss from swine is approximately independent of humidity. Morrison (1968) feels that this is because moisture is evaporated from the skin of slightly sweating animals as fast as it reaches the surface. This would probably not be true for skin surfaces wetted externally as by spraying.

High humidity has been thought to be helpful in the prevention and treatment of respiratory ailments in humans (Baker, 1960). Gordon (1963) reported fewer bacteria-carrying particles in hog houses with higher humidities and (1963b) the incidence and degree of pneumonia in pigs was lower in an environment of high temperature and humidity. Dunklin and Puck (1948) have demonstrated the existence of a narrow range of relative humidities lethal to bacteria (in the vicinity of 50 percent) with relative humidities of 20 and 80 percent much less lethal. In work done by the USDA and the California Agricultural Experiment Station, it was found that a six to eight percent decrease in average daily gain may result with an increase in relative humidity from 45 to 94 percent, while maintaining a temperature for optimum production (Morrison, 1966).

The general recommendations for design conditions have been to maintain relative humidities above 50 percent to prevent excessive dust and possible respiratory ailments and below 75 percent to prevent possible accelerated building and equipment deterioration (Hazen and Mangold, 1960; ASAE, 1970).

Radiation

At lower air temperatures, radiation and convection constitute the major channels of heat exchange for swine (Bond, Kelly and Heitman, 1959). Heat exchanged by radiation is not dependent on the air temperature, but on the temperature of objects which the surface of the pig 'sees'. If the objects are warmer than the pig's skin, the pig will gain heat; if the objects are cooler than the pig's skin, the pig will lose heat.

The mean radiant temperature (MRT) is used to describe an animal's radiant environment. The MRT is defined as the uniform black body temperature of an imaginary enclosure with which the animal will exchange the same heat by radiation as it would in the actual complex environment (ASHRAE, 1970). The MRT can be determined from data obtained with a black-globe thermometer (Bond and Kelly, 1955).

The black-globe thermometer used in agricultural engineering research is a black six-inch diameter hollow copper sphere with a thermocouple at the exact center (Bond and Kelly, 1955). The black-globe thermometer indicates the combined effects of radiation, air temperature, and air velocity. For this reason the black-globe thermometer temperature has been called the comfort temperature for slightly sweating animals (Brooks and Kelly, 1951; Bond and Kelly, 1955).

For swine housed in buildings which are either unheated or heated by forced air, it has been found that black-globe thermometer measurements have little additional value over ambient-air temperature measurements (Inglis and Robertson, 1951; Gordon, 1962; Gunnarson, Butchbaker, Witze and Dinusson, 1967). For pigs housed in buildings which are equipped with radiant heaters, the globe thermometer would probably indicate a much higher temperature than the ambient air temperature. [This does not necessarily mean that the pig would feel as warm as the globe thermometer indicates, but it also means that it will not feel as cool as the ambient air temperature.]

Housing of Swine

The domestic use of pigs began in the eighteenth and nineteenth centuries (Mount, 1968). The Food and Agriculture Organization Production Yearbook (1969) lists the world pig population as being over 600 million; of this number, 55.3 million are in the United States. In primitive peasant economies, pigs are kept in herds and are free to seek their own environment.

Pork production in the United States is centered around either a pasture system or a confinement system. Pasture systems require much land and labor to produce a pound of pork. For this reason many producers have moved toward a confinement system. Bowland and MacHardy (1962) have reported that pigs raised in central housing gained 19 percent faster and had gain to feed ratio 8 percent higher than pigs raised under a pasture system.

It is obvious that swine housing requirements vary with the climate. Providing shelter for hogs in the southern states is largely a matter of protecting them from sun and rain. In northern latitudes the house must be constructed tightly enough to give protection from severe winter weather (Krider and Caroll, 1971).

The type of housing used will determine the pig's environment. The general types of confinement housing are: (a) the completely enclosed and heated building, (b) the completely enclosed and unheated building, and (c) the open-front building.

If the completely enclosed heated building is used, the optimum temperature (Heitman, Kelly, and Bond, 1956) and humidity level (Hazen and Mangold, 1960) can be maintained. This, however, requires adequate ventilation and air conditioning. To do this the following information must be provided: (a) the optimum productive environment for hogs, and (b) the heat and moisture they release. From work done in the California Psychrometric Chamber (Heitman, Kelly, and Bond, 1956) it was determined that 100 pound pigs grew fastest at an air temperature of 73.5° F and 61° F was the best temperature for 350 pound hogs.

Heat Produced by Swine

To properly size air conditioning and ventilation equipment, the amount of heat and moisture produced by the animal must be known. Bond, Kelly, and

Heitman (1959) have used a regression analysis to predict the amount of heat produced by hogs which weighed 50 to 400 pounds, and air temperatures from 40° to 100° F.

The equation for heat loss is:

$$\mathrm{Log}(Q) = 2.477 + 0.034[\log(W)] - 0.577(t/100) + 0.148[\log(W)]^2 + 0.710(t/100)^2 - 0.313[\log(W)(t/100)] \quad (1)$$

Where:

Q = the total heat loss, Btu/hr-pig.

W = the animal's body weight, pounds.

t = the air temperature, degree F.

Moisture Produced by Swine

The amount of moisture which must be removed from a growing and finishing hog house is dependent on the amount of skin and respiration moisture produced by the hogs and the amount of moisture evaporated from spilled water, urine, and feces. Morrison (1967) has reported that skin moisture loss ranges from 35 to 67 percent of the total moisture produced.

Bond, Kelly, and Heitman (1959) have used a regression analysis to predict the amount of moisture produced by hogs housed on concrete floors which were scraped twice a day.

The equation for moisture loss is:

$$\mathrm{Log}(M) = -0.961 + 0.291(W/100) - 0.785(t/100) - 0.146(W/100)(t/100) - 0.026(W/100)^2 + 1.375(t/100)^2 \quad (2)$$

Where:

M = water loss, pounds/hr-hog.

W = the animal's body weight, pounds.

t = the air temperature, degrees F.

It has been observed that the ventilation rate required for moisture control for a slotted-floor house can be reduced below that required for a concrete-floored house (Harmon, Dale, and Jones, 1968). Harmon, Dale, and Jones, using groups of pigs that weighed 80 to 100 pounds, have developed least squares equations for moisture removed from: (a) concrete-floored house, (b) partially slotted-floor house, and (c) the fully slotted-floor house.

For the concrete floored house:

$$\text{Log}(M) = -0.434 - 1.71(t/100) + 1.89(t/100)^2 \quad (3)$$

For the partially slotted floor house:

$$\text{Log}(M) = 0.0421 - 3.59(t/100) + 3.48(t/100)^2 \quad (4)$$

For the fully slotted floor house:

$$\text{Log}(M) = 0.233 - 4.80(t/100) + 4.14(t/100)^2 \quad (5)$$

Where:

M = moisture removed, pounds/hr-hog.

t = the air temperature, degrees F.

Bond, Kelly, and Heitman (1963) have also reported that total daily animal heat and moisture losses will be similar to those estimated for constant temperatures equal to the mean of the cycling temperatures.

Performance of Swine Under Different Types of Confinement Housing

Since the different types of confinement housing provide different levels of environment, swine housed in each will perform differently.

Hazen, Curry, and Giese (1959) investigated swine growth and efficiency in a naturally varying environment. Their investigations covered three buildings covered with different materials. The buildings' temperatures were allowed to vary with the natural environment. The buildings were covered with: (a) aluminum, (b) steel, and (c) wood. The winter results, in TABLE 3, showed an advantage in both feed efficiency and growth rate for animals housed in the wood covered units.

TABLE 3

WINTER PERFORMANCE OF SWINE HOUSED IN BUILDINGS CONSTRUCTED OF DIFFERENT MATERIALS (FROM HAZEN, CURRY, AND GIESE, 1959)

House	Gain lb/day	Feed* Efficiency	Temperature (F)
Aluminum	1.69	3.46	35.3
Steel	1.71	3.46	35.8
Wood	1.75	3.38	40.7

* lb of feed/lb of gain

Bell, Marshall, Stanley, and Thomas (1967) studied slotted-floor swine housing in controlled, semi-controlled, and uncontrolled environments. Their investigations indicated that the type of floor did not affect the rate of gain for hogs. The type of housing used in a climate similar to that in southeastern Virginia seems to have little consistent effect on growth rate. The winter median of annual extremes for this area is 10° to 18° F with light wind. The median of annual extremes for Manhattan, Kansas, is -7° F with high winds.

Animal scientists working with the project felt that small pigs housed in the open-front shelters on slotted floors in cold weather were exposed to undesirable conditions and exhibited extreme discomfort. The rate of gain after weaning for small pigs (45 to 100 pounds) housed in the open-front building tended to substantiate this observation. During the first six weeks after weaning, the pigs in the open-front house showed less gain than the pigs housed in the enclosed, ventilated building. Feed efficiency has shown a slight advantage for the enclosed building in winter trials.

Jensen, Kuhlman, Becker, and Harmon (1969) investigated the winter performance of swine in three different buildings (TABLE 4). The buildings were: (a) enclosed heated, (b) enclosed unheated, and (c) open front. The enclosed buildings had partial slotted floors, while the open-front building had concrete walls and a solid floor, and was also the only building provided with bedding.

For each winter, the results are reported for the growing period and the finishing period. For the growing period, the pigs housed in the unheated enclosed building showed the highest average daily gain, but also consumed more feed per day than the pigs housed in the heated building. The pigs housed in the open-front building had the lowest average daily gain and the highest daily feed consumption.

For the finishing period, the pigs housed in the heated building showed the lowest average daily gain, but also had the lowest daily feed consumption. The pigs in the open-front building showed the highest feed consumption and poorest feed efficiency.

It appears that the performance of hogs housed in open-front buildings

TABLE 4

COMPARISON OF THE EFFECTS OF DIFFERENT HOUSES ON SWINE PERFORMANCE
(FROM JENSEN, KUHLMAN, BECKER, AND HARMON, 1969)

Period	House											
	1*				2				3			
	Gain lb/day	Feed lb/day	Feed Eff	Temp (F)	Gain lb/day	Feed lb/day	Feed Eff	Temp (F)	Gain lb/day	Feed lb/day	Feed Eff	Temp (F)
Growing	1.65	3.91	2.37	69.8	1.74	4.21	2.42	51.8	1.55	4.30	2.77	20.3
Finishing	1.75	5.99	3.42	68.0	1.83	6.58	3.62	57.5	1.77	6.78	3.83	32.0

*
1 Enclosed heated
2 Enclosed unheated
3 Open-front

will compare favorably to hogs housed in totally enclosed buildings if the hogs in the open-front building are provided a suitable microclimate. This microclimate can be provided by bedding or zone radiant heating. The zone microclimate concept has been demonstrated for summer conditions. Animals which had access to a shaded refrigerated slab gained at the rate of 0.03 lb/day more than animals in a normal environment (Andrews, 1956). Inglis and Robertson (1951) have reported that pigs housed in a poorly insulated barn did not perform well until electric radiators were installed over their sleeping area. The environment in buildings, which had pig mortality from cold as high as 40 percent, was improved by: (a) relaying concrete floors to provide an air space underneath, (b) continuing pen partitions to the ceiling, (c) sheeting off the central alley from the pen, and (d) providing an air space between the ceiling and the outer roof (Lamont, Duke, and Gordon, 1950).

Bedding acts as an insulator and reduces body heat loss, which makes the animals more comfortable. Bedding also absorbs liquids which helps to maintain a dry resting area conducive to dry animals. Sorenson (1962) has shown that pigs in a group with straw bedding gained 60 percent more per day than individual pigs with no straw bedding, and 14 percent more than pigs in a group with no straw bedding. Bedding is used to provide an effective microclimate in an open-front building with a solid floor.

Cramer, Grummer, and Barr (1970), in winter research conducted in Wisconsin, found that swine housed in a solid floor open-front building gained more rapidly than similar hogs housed in an enclosed heated building. The hogs in the open-front building required about three times more bedding than the hogs housed in the enclosed building.

In 1962, research at Purdue University (Mentzer, Hinkle, Jones, and

Kadlec, 1969) was initiated to evaluate four types of confinement housing: (a) open-front building, (b) enclosed solid concrete floor, (c) enclosed partially slotted floor, and (d) enclosed fully slotted floor. Three winters of research clearly showed that animal performance in the open-front buildings was excellent when compared to the other units.

The performance of the animals used in the research was then compared to the performance of animals raised by commercial producers. A favorable comparison was made in all cases except the open-front buildings. Here the performance of the research animals was better than the commercial animals. The only apparent reason for this difference was the fact that the research animals were provided with bedding and commercial animals were not.

Beginning with the winter of 1964, research at Purdue (Mentzer, Hinkle, Jones, and Kadlec, 1969) was conducted to evaluate the influence of bedding on animal performance. During the winter of 1966-67 the research was expanded by replacement of bedding with radiant gas heat. Their research showed that pigs with radiant heat and pigs with bedding gained significantly faster than pigs with no bedding or heat (TABLE 5). Feed efficiency favored the pigs with heat over the bedded pigs (TABLE 6).

It appears that bedding can be replaced with a thermostatically controlled radiant gas heater, without adversely affecting the performance of the animals.

TABLE 5

COMPARISON OF RATE OF GAIN FOR PIGS PROVIDED WITH DIFFERENT MICROCLIMATES (FROM MENTZER, HINKLE, JONES, AND KADLEC, 1969)

Microclimate	Gain lb/day				
	1964-65[1]	1965-66[1]	1966-67[2]	1967-68[3]	Avg
Bedded	1.39	1.38	1.36	1.43	1.39
Not bedded (not heated)	1.18	1.25		1.18	1.21
Not bedded* (with heat)			1.14		1.14
Not bedded** (1 heater)				1.32	1.32
Not bedded** (2 heaters)				1.40	1.40

* Manually operated gas heaters.

** Thermostatically controlled radiant gas heater.

1 Pigs in the bedded area gained significantly faster than those in the non-bedded area.

2 Pigs in the bedded area gained significantly faster than those in the non-bedded, heated area.

3 Pigs in the bedded area and in non-bedded, heated areas gained significantly faster than those in the non-bedded, non-heated area.

TABLE 6

COMPARISON OF FEED EFFICIENCY FOR PIGS PROVIDED WITH DIFFERENT MICROCLIMATES (FROM MENTZER, HINKLE, JONES, AND KADLEC, 1969)

Microclimate	Feed Efficiency*				
	1964-65[1]	1965-66[1]	1966-67[2]	1967-68[3]	Avg
Bedded	3.96	3.69	4.33	4.17	4.01
Not bedded (not heated)+	4.18	3.79		4.78	4.14
Not bedded (with heat)			4.48		4.48
Not bedded (1 heater)				3.83	3.83
Not bedded 2 heaters)				3.55	3.55

* lb feed/lb gain

\+ See footnotes of TABLE 5.

INVESTIGATION

Formulation of the Experiment

The review of literature has shown that an optimum air temperature for growing and finishing swine exists. This air temperature varies from 73.5° F for 100 pound pigs to 61° F for 350 pound hogs. While relative humidity has not shown consistent effects on swine performance, the recommended design levels for confinement housing are from 50 to 75 percent. Winter daily weight gain, daily feed consumption, and feed efficiency have generally favored the heated, enclosed house which provides a temperature level near the optimum.

The growing and finishing unit at the Kansas State University Swine Research facility was constructed as an open-front building with total slotted floors. The winter of 1968-69 was the first time that this unit was used. During a trial which began on December 10, 1968, weight gains were about 0.25 lb/day for the first 30 days and thirteen pigs died from pneumonia (Koch and Hines, 1969; Koch, 1969). For the following winters (1969-70, 1970-71), the open-front was covered with plywood and clear polyethylene, as in Figures 5 and 6, and propane burning radiant heaters were installed over the pigs' sleeping area.

A research project was initiated during the winter of 1970-71 to determine the effectiveness of these modifications. This evaluation was done by: (1) comparing the performance of the pigs raised during the winters of 1970-71 and 1969-70 to the winter of 1968-69, and (2) installing equipment to monitor and record thermal data and compare this data to recommended design con-

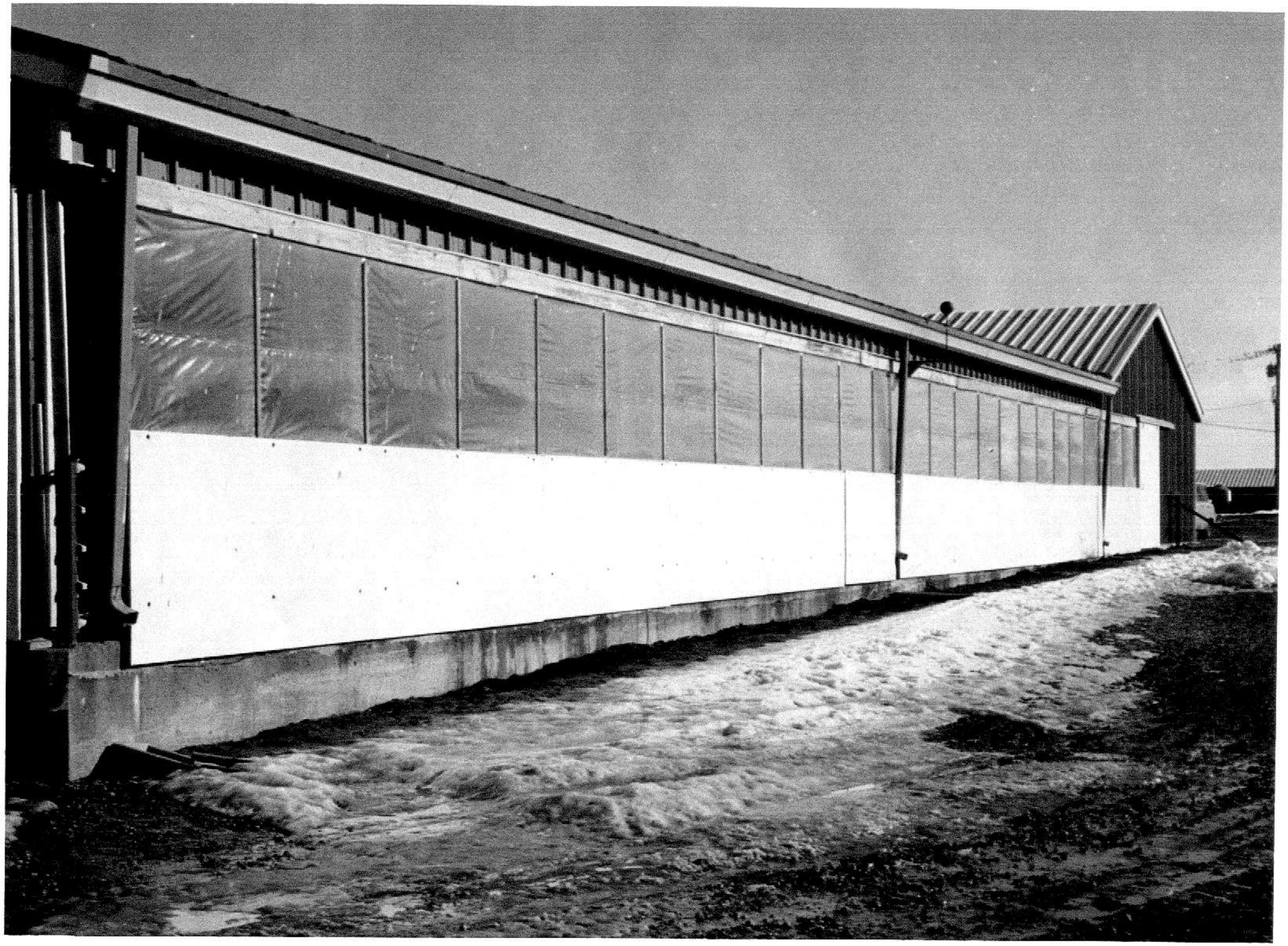

Figure 5. The exterior of the growing and finishing unit, covered with a polyethylene film and plywood.

Figure 6. The interior of the enclosed front.

ditions.

Objectives

The specific objectives of this research were: (1) to compare the performance of growing-finishing swine raised in the modified building during the winters of 1969-70 and 1970-71 with the performance of swine raised during the winter of 1968-69, and (2) investigate and report the thermal environment of the modified building during the winter of 1970-71.

Materials and Equipment

Description of the Building

The growing and finishing unit is illustrated by Figure 7. As the building was originally constructed, it was to be operated as an open-front building for the entire year. The original building did not have the wall-mounted exhaust fans or the radiant heaters in the pen, which were installed after the disastrous winter of 1968-69. During the winter of 1968-69 when animal performance was very poor, the operators of the building attempted to enclose the open front with clear polyethylene and steel roofing materials, but the results were not satisfactory.

The building consists of two wings which are connected by a storage and service area on the east end. Each wing is a metal-sided, clear-span structure which is open to the south (Figure 8). Each wing contains sixteen 6 ft by 15 ft pens or eight 12 ft by 15 ft pens. The floor of the pen area is totally slotted, and a liquid manure oxidation pit is located under the slotted floor. Nine square feet are allowed for each pig, giving a capacity of ten pigs in the smaller pens and twenty pigs in the larger pens. A self feeder and automatic watering cup are provided for each ten pigs.

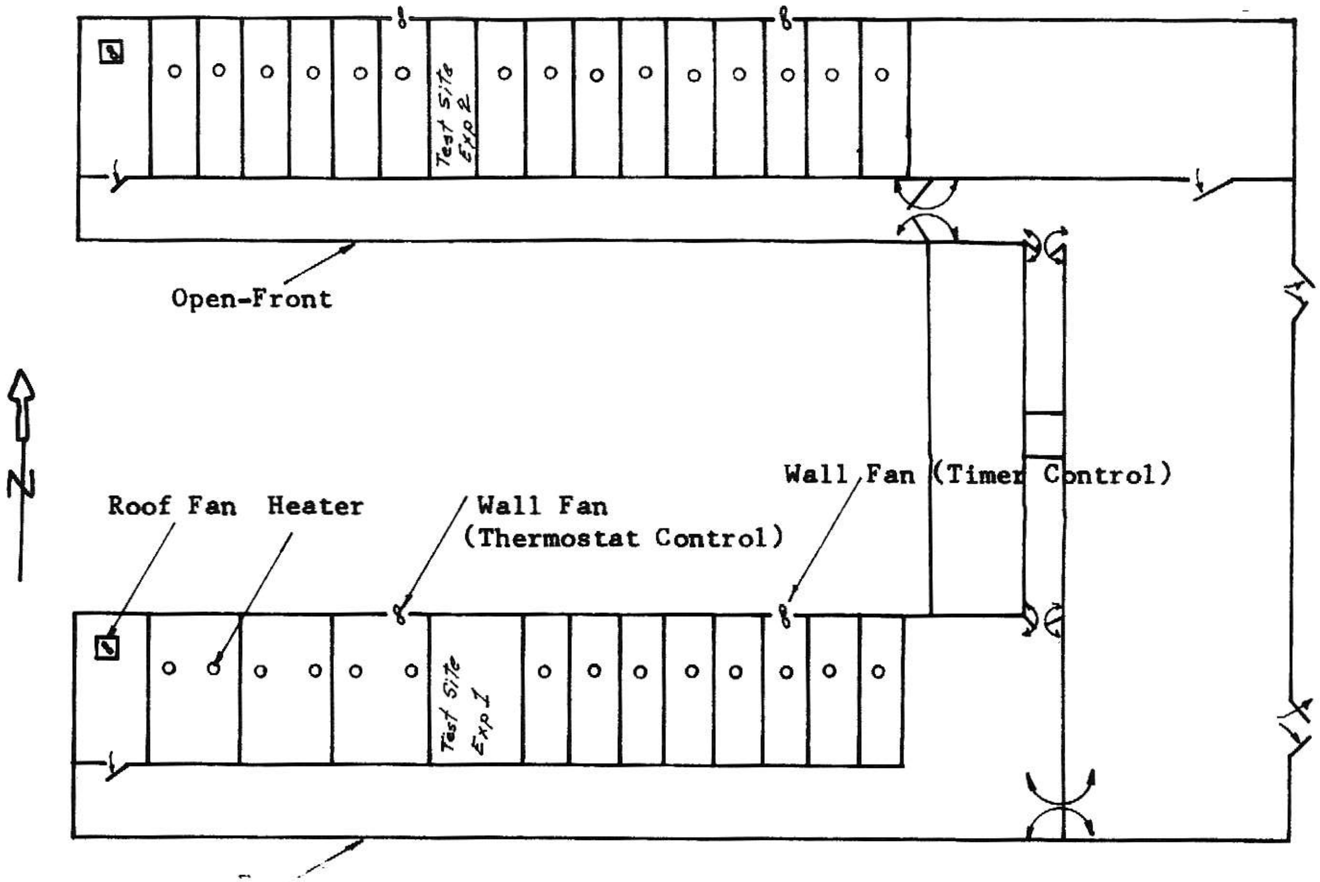

Figure 7. Schematic diagram of the Kansas State growing and finishing unit.

Figure 8. The interior of the south wing of the growing and finishing unit.

The radiant heaters are approximately 45 inches above the floor of the pen, 55 inches from the back wall, and are centered over the pigs' sleeping area. Each heater has a 7200 Btu/hr input and is thermostatically controlled so that operation begins when the temperature falls below a desired set point, 50° in this case. In this building the heaters are located so that six square feet of heated area is provided per market-weight pig, which provides a 120 Btu/hr sq ft input (approximately 100 Btu/hr sq ft output).

There are two exhaust fans in the back wall which have a total capacity of 3000 cfm. One is controlled by a thermostat so that it will operate when the temperature is above 55° F, and the other is controlled by a time clock. There is also an exhaust fan located in the roof; this fan operates continuously, primarily for odor control. The building is constructed so that this air is drawn down through the floor.

For winter operation, the open front is enclosed with 6 mil clear polyethylene film and 3/8 inch plywood. The opening is approximately eight feet high. The lower half is covered with the plywood and the upper half is covered with the polyethylene.

Description of Equipment Used in the Investigation

The following equipment was used in the investigation: copper constantan thermocouples, two six-inch diameter black-globe thermometers, a psychrometer, and a Honeywell multipoint recording potentiometer. The psychrometer was similar to one developed by Saul (1956; discussed in Appendix A). The recording potentiometer was connected to a time clock so that temperatures could be recorded at selected times.

Method of Procedure

During the fall of 1970, the psychrometer was constructed and its reliability verified (Appendix A), and the thermocouples installed in the building.

The three thermocouples in the pen were located at the walls of the pen near the center (Figure 9). The lower thermocouple was placed at the level of the floor between the slots. The middle thermocouple was about fourteen inches from the floor. The upper thermocouple was placed at the top of the pen partition. This was about 38 inches from the floor. The psychrometer was placed about five feet from the floor over the center of the pen. The inside black-globe thermometer was suspended over the pigs' sleeping area so that its center was about 36 inches from the floor. The equipment was placed in one of the large pens for the first experiment so that the black-globe thermometer was located between two heaters. For the second experiment, the equipment was put in a small pen, and the black-globe thermometer was about eighteen inches in front of the heater (Figure 10).

For the first experiment, the thermocouples at the three levels in the pen were constructed of two thermocouples connected in parallel. These were placed opposite each other in the pen. This idea was abandoned for the second experiment because the equipment was installed in a small pen.

The other thermocouples inside the building were: one at each of the three exhaust fans, one in the oxidation pit, one on the plywood front, and one on the polyethylene front.

A black-globe thermometer was placed outside (Figure 11) along with a thermocouple. This black-globe was about ten feet from the ground.

The equipment was installed in the south wing of the growing and finishing unit for experiment 1. It was conducted in a large pen near the center

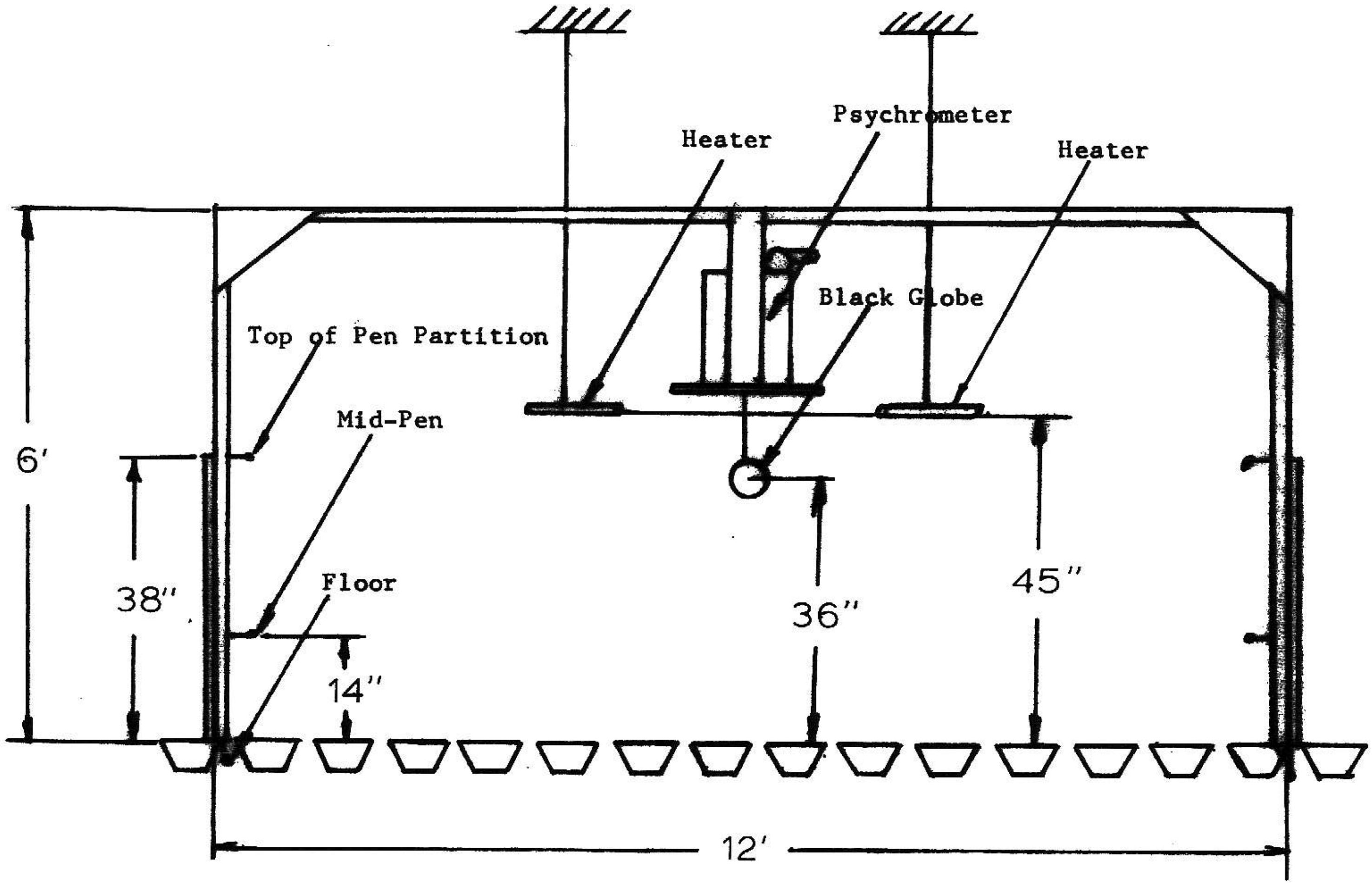

Figure 9. Schematic diagram of the equipment placed in the pen for experiment 1.

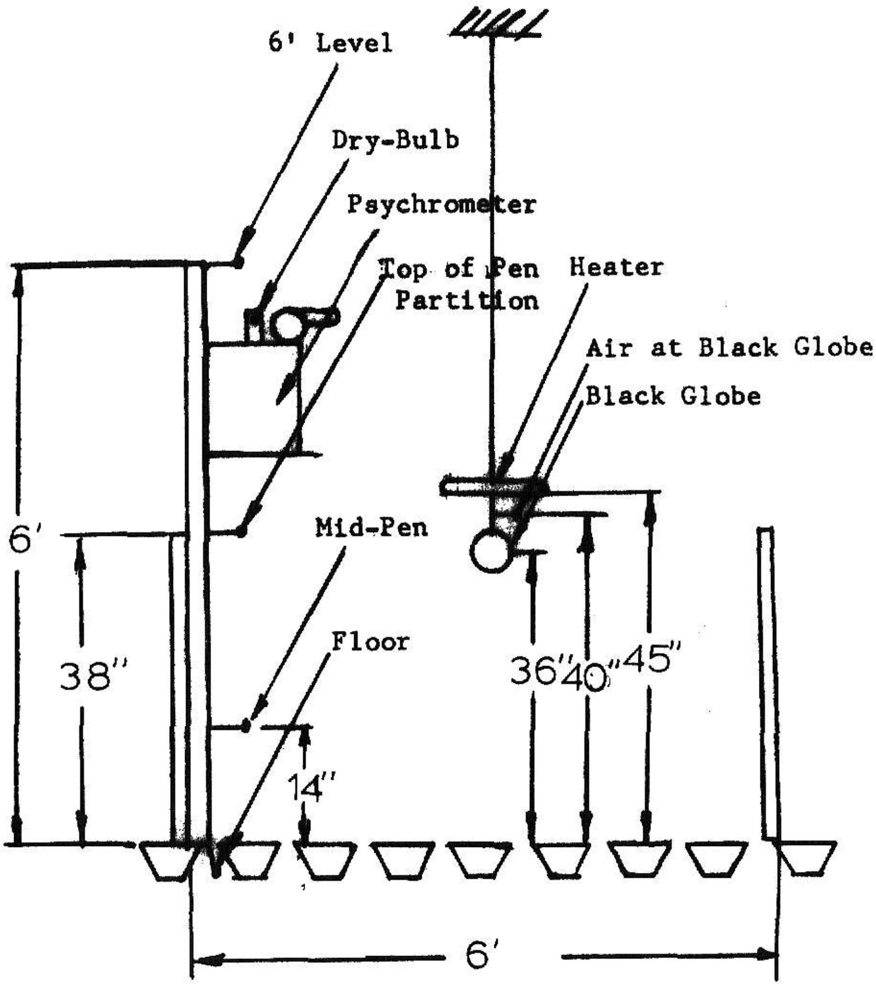

Figure 10. Schematic diagram of the equipment placed in the pen for experiment 2.

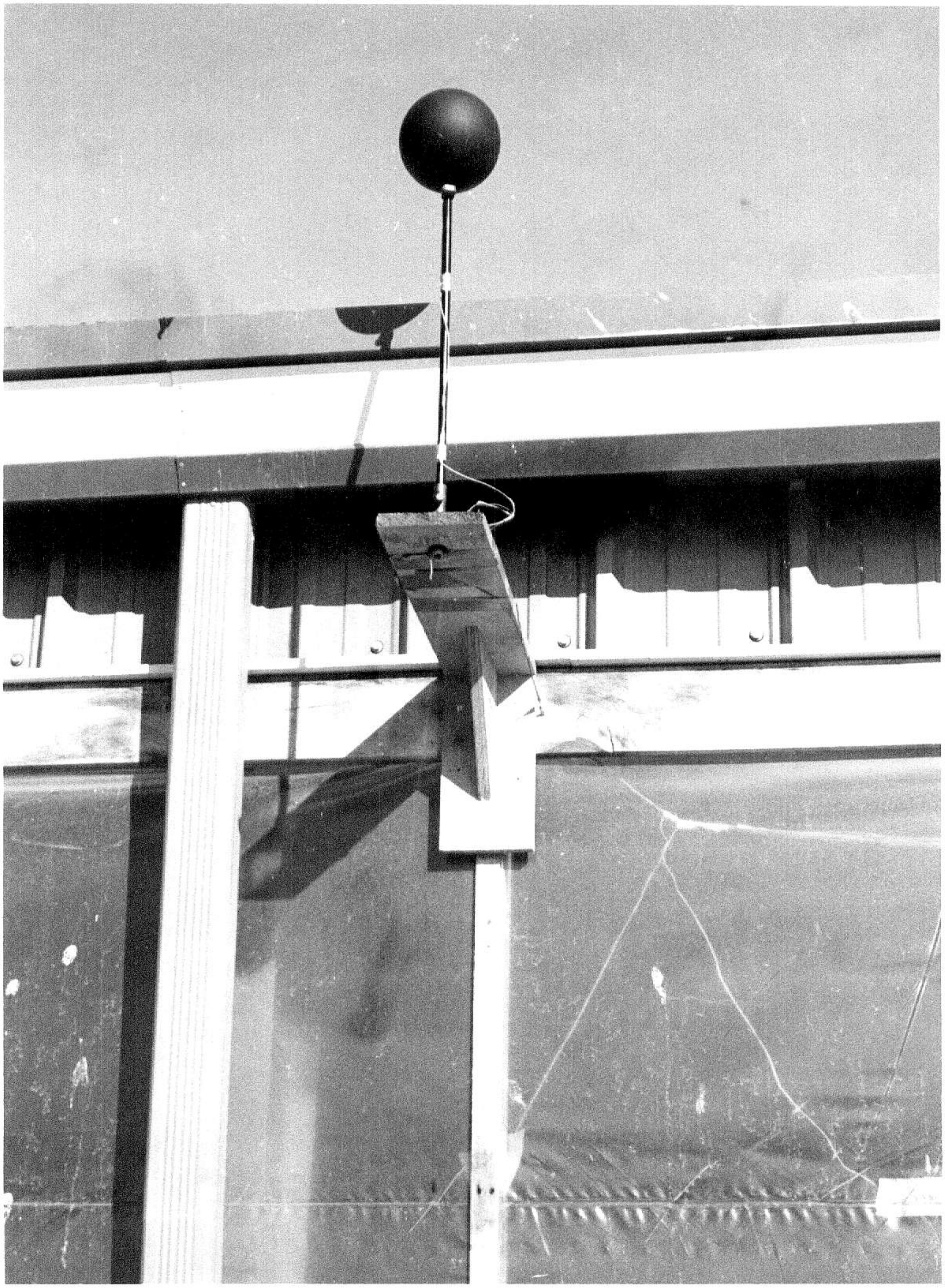

Figure 11. The outside thermocouple and black globe installation.

of the building to minimize any possible end effects (Figure 12).

The recorder was started on November 25, 1970. The time clock was set so that a reading could be taken every half hour. This was done to check the operation of the equipment and to obtain a shorter time interval for later analysis. The timer was set at one-half hour intervals until December 8, 1970, when it was changed to a three-hour interval. The timer operated in this manner until January 18, 1971, when experiment 1 was terminated.

The building contained 127 pigs, 50 of which weighed an average of 101 pounds, and 77 which weighed an average of 75 pounds. The building contained 127 pigs for an average of 72 days until January 13, 1971. The average ending weight for the group of 50 was 218 pounds. The final weight of the group of 77 was 177 pounds, but the final weighing for the group of 77 was on January 7, 1971.

For experiment 2, the equipment was installed in the north wing (Figure 13). This installation was similar to the previous one with a few exceptions. The notable exceptions were two additional thermocouples added to the pen, one six feet above the floor and one four inches above the black-globe thermometer. This experiment ran from February 18, 1971, to March 24, 1971. The timer was set at three-hour intervals until March 12, when it was set at one-hour intervals.

The animals were weighed at approximately two-week intervals by personnel of the Department of Animal Science.

Theory

Since the animals are housed in an environment which is warmer than the outside environment, their daily weight gain and feed efficiency will be significantly better than animals exposed to the outside environment. The

Figure 12. Pen and test site for experiment 1.

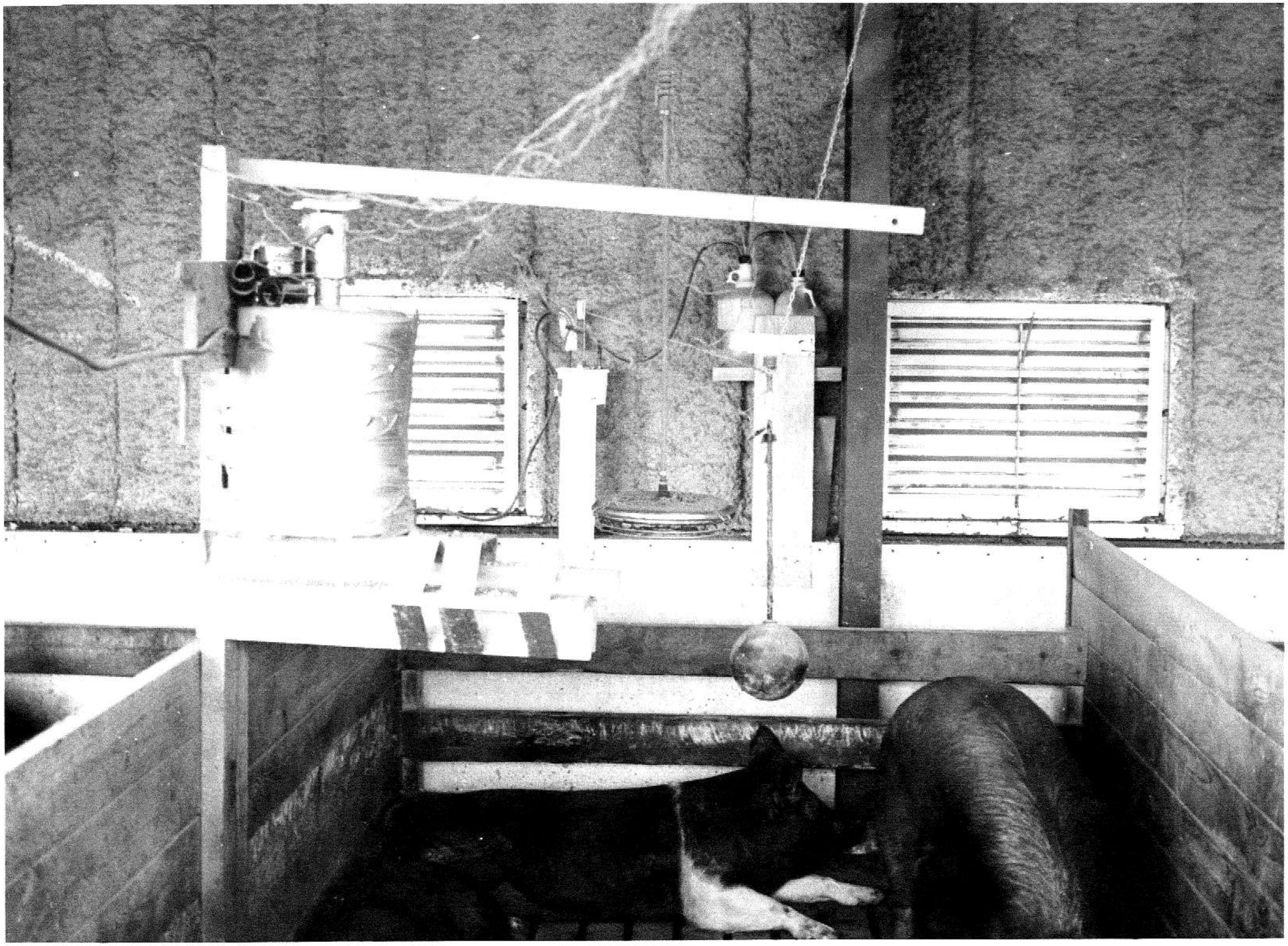

Figure 13. Pen and test site for experiment 2.

thermal environment of the building will be improved because the enclosure on the front will reduce heat loss caused by cold temperatures and higher winds. The relative humidity will not be excessive because of the ventilation equipment, and the front enclosure is constructed so that any condensed liquid which runs off the polyethylene film will run out of the building.

Collection of Data

The original record sheets for the winter of 1968-69 were apparently misplaced, so the data used in this comparison were obtained from the 1969 Swine Industry Day publication (Koch and Hines, 1969). The data for 1969-70 were taken from the 1970 Swine Industry Day publication (Koch and Hines, 1970). The original records were obtained for the 1970-71 winter. The 1970-71 data used were taken from the group of 77 pigs. This was done because this group had approximately the same beginning and ending weights as those reported in the Swine Industry Day publications. All three performance trials were conducted through the months of December, January, February, and March, with the exception of the 1970-71 trial which began on November 2, 1970, and ended on January 7, 1971.

The daily gain and feed efficiency for 1969-70 and 1970-71 were compared to 1968-69 and checked for significance by using Student's t test. Climatic data for the three winters in question were obtained from the Physics Department.

Experiment 1

Thermal environmental data were collected during experiment 1 from November 25, 1970, to January 18, 1971. The data from experiment 1 were analyzed in five time periods. The data for each time period were averaged for each day and then averaged for the entire period. The data for each time interval of the time period were also averaged. TABLE 7 contains the time periods and days of experiment 1.

TABLE 7

TIME PERIOD OF DATA COLLECTION AND ANIMAL WEIGHTS FOR EXPERIMENT 1

Time Period	Dates	Mid-pt	Freq of Rec+	Weight*
1	Nov 26-Dec 2, 1970	Nov 29	48	156.6
2	Dec 3-Dec 8, 1970	Dec 4	48-24	167.3
3	Dec 9-Dec 14, 1970	Dec 12	48-24	175.3
4	Dec 15-Dec 28, 1970	Dec 22	15	191.3
5	Dec 29-Jan 18, 1971	Jan 8	15	217.2

+ Number of temperatures recorded per day.
48: One-half hour intervals.
48-24: Recorded at one-half hour intervals, but hourly intervals were used in the analysis.
15: Data recorded at 3:00 am, 7:00, 7:30, 8:00, 9:00, 10:00, 12:00 noon, 3:00 pm, 4:00, 4:30, 5:00, 5:30, 6:00, 9:00, 12:00 midnight

* These weights are the average weights of the group of 50 hogs. This group was used because there were more weight intervals. It also assumes a linear weight increase between weighings.

Animal weight records and feed consumed were obtained from the Department of Animal Science. The group of 77 pigs was used in the performance analysis because this group closely approximated the initial and ending weights of the trials reported in Swine Industry Day.

Experiment 2

Experiment 2 was conducted in the north wing from February 23, 1971, to

March 24, 1971. Data were recorded at three-hour intervals from February 23 to March 12, and at hourly intervals from March 12 to March 24. The performance data for experiment 2 were obtained from a group of 39 pigs which had an average initial weight of 112 pounds, and an average ending weight of 214 pounds.

RESULTS AND DISCUSSION

Animal Performance

The average daily weight gain, feed efficiency, and average temperatures for the three winters in question are presented in TABLE 8 and Figure 14. As reported previously, average daily gain for the winter of 1968-69 was around .25 lb/day with the building not enclosed. Following this, a haphazard attempt was made to enclose the building by covering the open front with steel roofing and a polyethylene film. For the following discussion, the results of the 1968-69 winter are from the building which was enclosed with the steel roofing and polyethylene film.

TABLE 8

COMPARISON OF DAILY GAIN, FEED EFFICIENCY, AND AVERAGE TEMPERATURES FOR THREE WINTERS

Winter	Duration of Trial[+]	Beg Wt[++]	End Wt[++]	Gain lb/da	Feed Eff[†]	Outside Temp	Inside Temp
68-69[1]	92	60	185	1.41	3.20	26.5	40.0[1]
69-70[*]	72	80	201	1.69	3.09	30.5	
70-71[*]	66	75	191	1.58	3.10	37.2	53.4
71[*]	63	112	214	1.70	3.42	37.7	59.3

+ days
++ pounds
† lb feed/lb gain
* Building was enclosed with plywood and polyethylene film, radiant heaters installed in pens.
1 Jan 10-Feb 8, 1969, front of building was covered with polyethylene film and steel roofing (Koch, 1969).

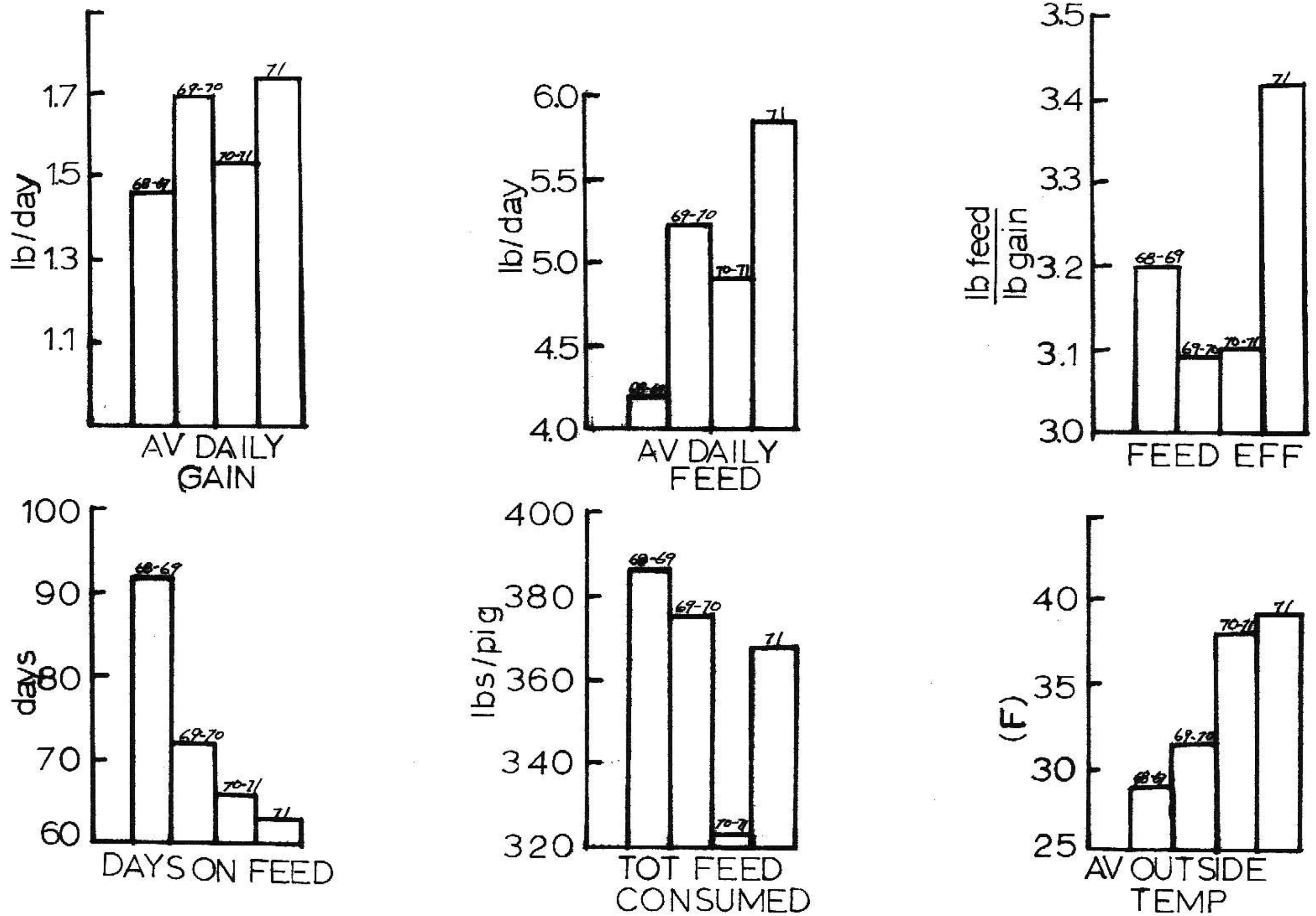

Figure 14. Comparison of animal performance and outside temperatures for three different winters.

Average daily weight gain for 1969-70, 1970-71, and 1971 were found to be significantly better than the average daily weight gain of 1968-69. Feed efficiency for 1969-70 and 1970-71 was improved over the winter of 1968-69, but this improvement was significant only between the winters of 1968-69 and 1969-70. Feed efficiency for 1971 was significantly poorer than feed efficiency for 1968-69, but this is not a valid comparison since the average beginning weight for this group was much higher than any of the other groups. Heavier weight pigs do not gain as efficiently as lighter weight pigs, which explains the poor feed efficiency of the 1971 group. Even with the poor feed efficiency, the 1971 group consumed about 20 lb feed/pig less than the 1968-69 group.

During the winter of 1968-69, 13 pigs died from cold-inflicted causes. A number of other pigs suffered carcass damage by cold-inflicted causes. It was impossible to determine whether any animals died from cold during 1969-70, but it may be assumed that the inside environment for the winter of 1969-70 was similar to the inside environment of 1970-71 when no deaths occurred.

Another factor which probably influenced the level of animal performance during the 1968-69 winter was the severity of the winter. The average temperature of this winter was about 27° F. This is about 10° F lower than the typical average winter temperature. The average winter temperature for 1969-70 was also lower than the typical average winter, but swine performance during this winter was better than the performance of 1968-69, and generally better than 1970-71 and 1971 when the average winter temperature was near the typical average winter. It appears that the improved building modifications had a greater influence on the improved swine performance than the improving winter conditions did. Even if no increase in daily gain resulted from the modifications to the building, the reduction of death loss and time required to feed the animals to market weight would justify the modifications to the building.

Thermal Environment

The thermal environment consisted of temperature and psychrometric conditions inside the building and was considered in two sections: the average inside conditions for a time period, and the average diurnal variation for a time period.

For experiment 1, five time periods were used for the daily average. The average diurnal variation was investigated for the first three time periods. For experiment 2, three time periods were used for the daily average. The average diurnal variation was investigated for period 3.

The inside dry-bulb temperature was assumed to be the inside temperature, since it was also used for the psychrometric calculations. The floor temperature was assumed to be the temperature of the air between the slots in the floor.

For the analysis of the thermal environment, the temperature data collected were transcribed onto computer cards. Psychrometric conditions were calculated by the equations reported by Brooker (1967; discussed in Appendix B).

Daily Average

From Figures 15, 16, 17, 18, and 19, it can be seen that the temperature trends during experiment 1 were decreasing. The average outside temperature was 37.2° F. The average inside dry-bulb temperature was 52.1° F. The average temperature difference between inside and outside was 18.4° F.

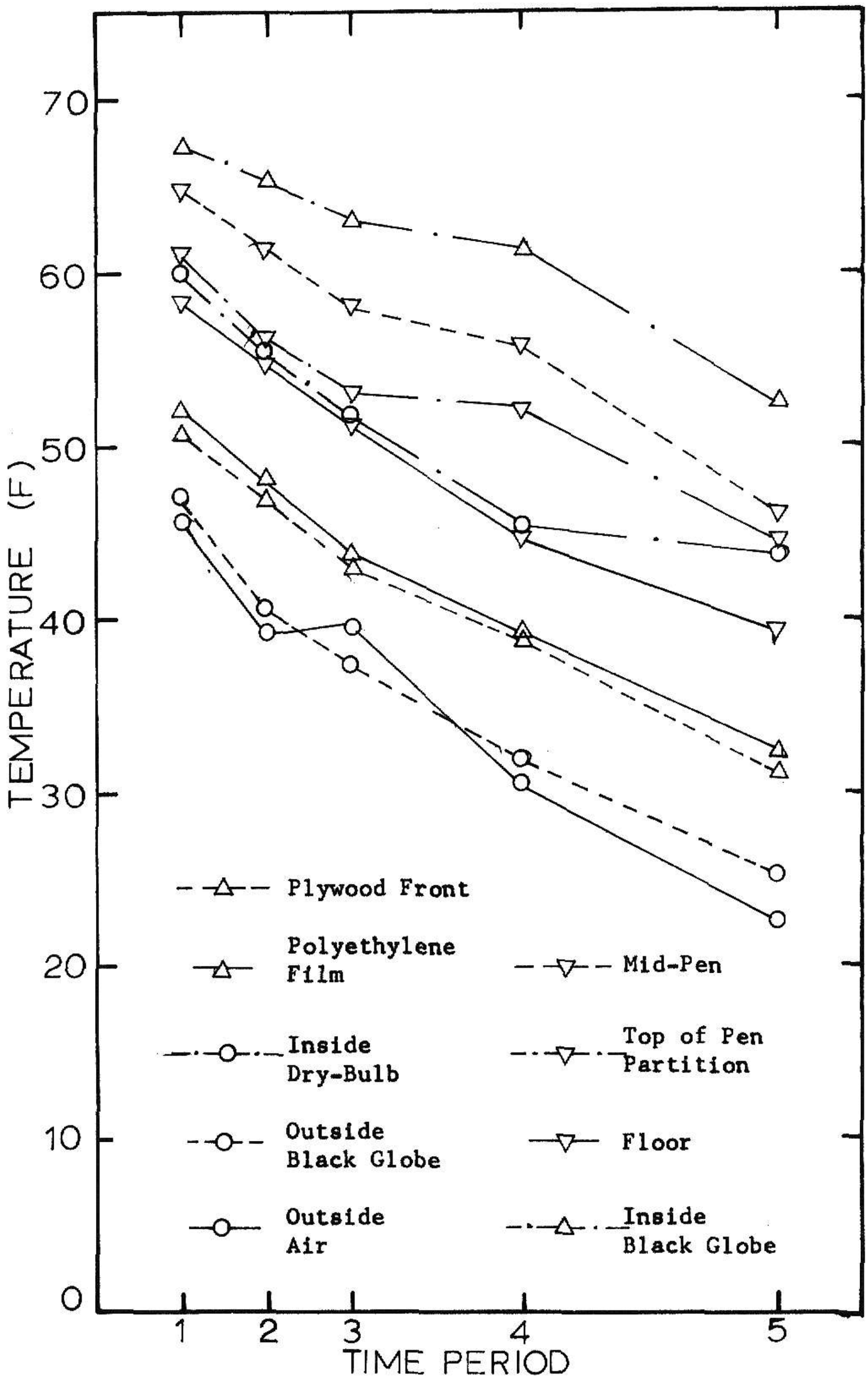

Figure 15. Temperature trends during experiment 1.

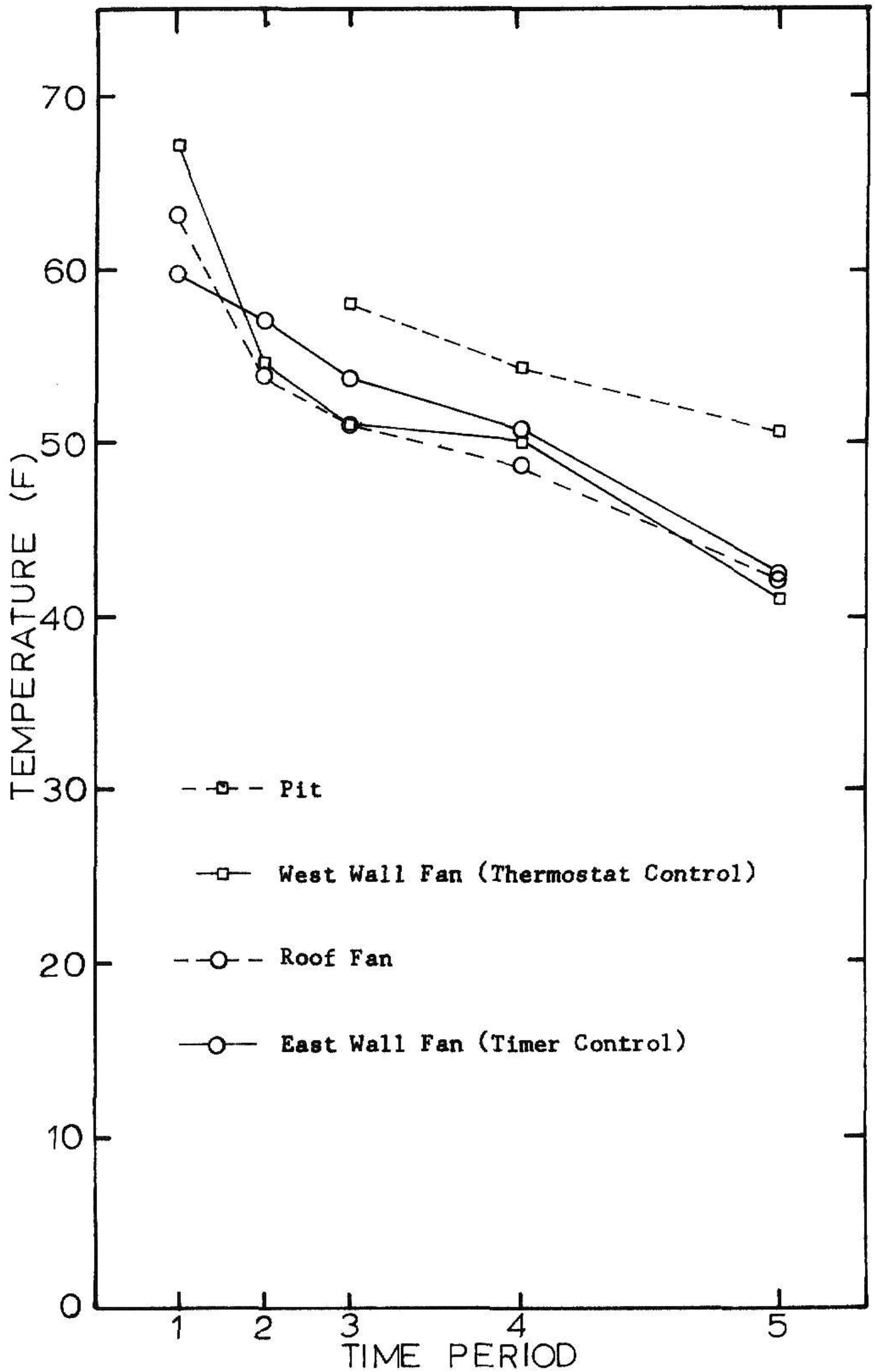

Figure 16. Temperature trends of fans and pit during experiment 1.

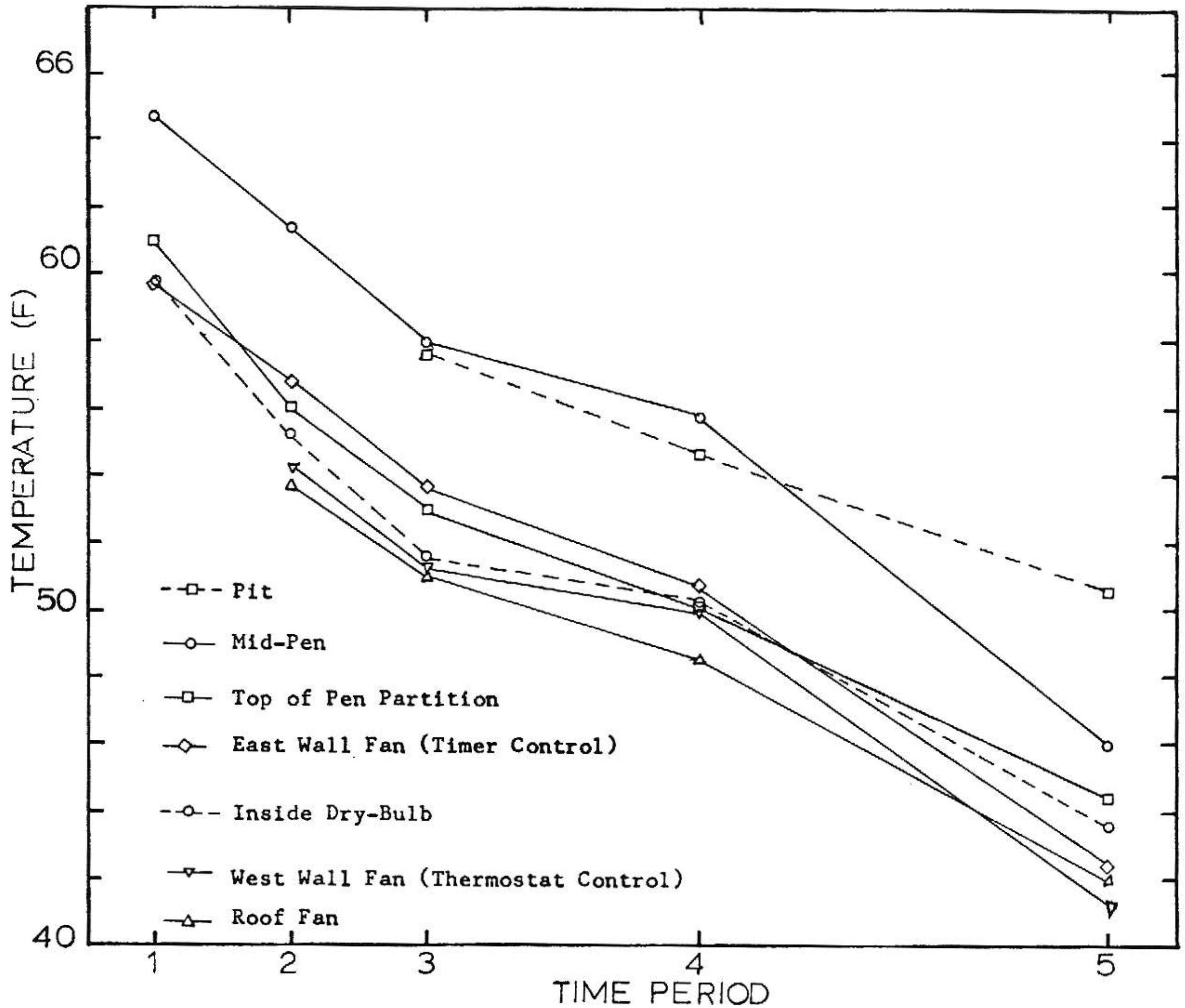

Figure 17. Trends of the inside temperatures during experiment 1.

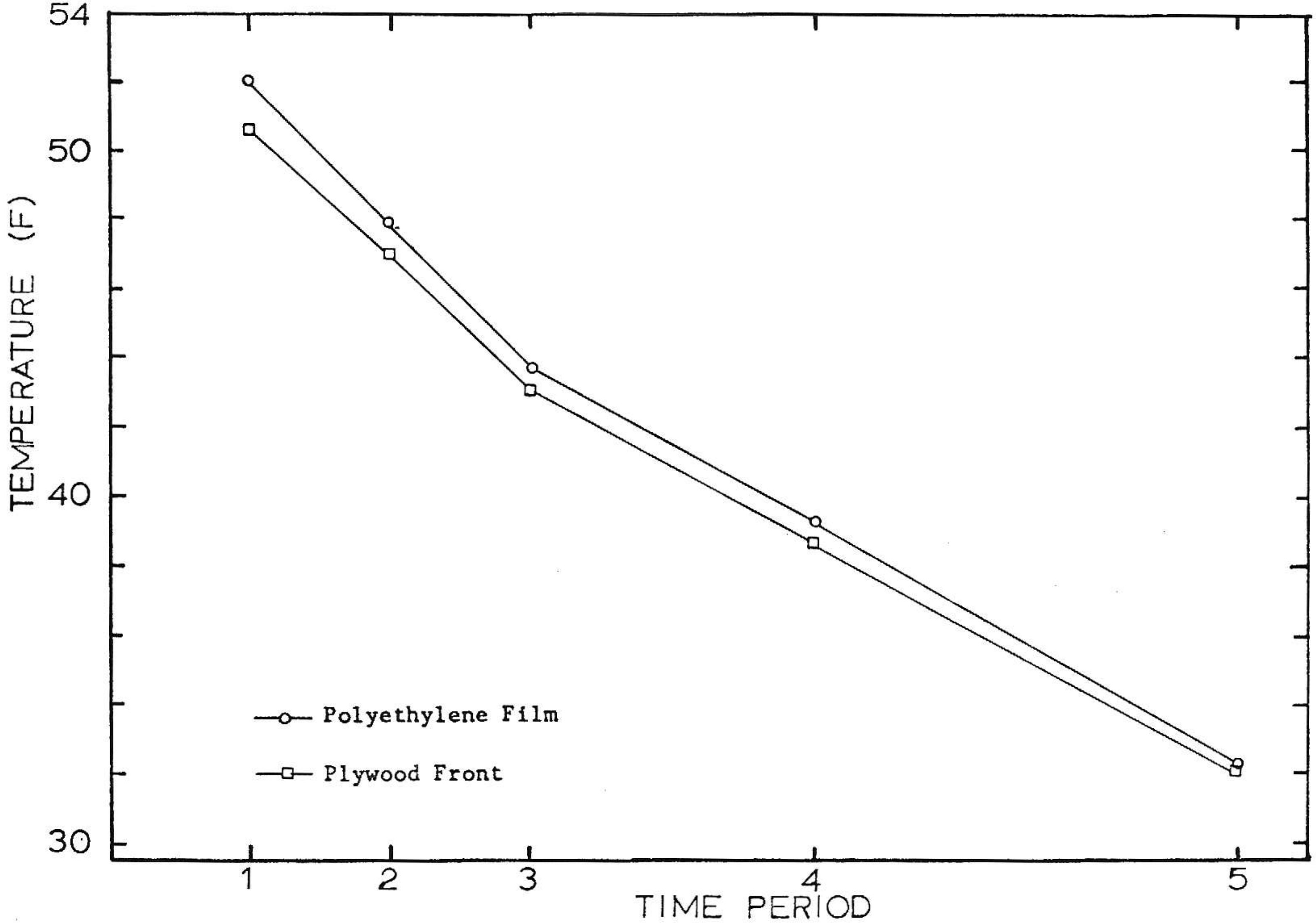

Figure 18. Temperature trends of the plywood front and polyethylene film during experiment 1.

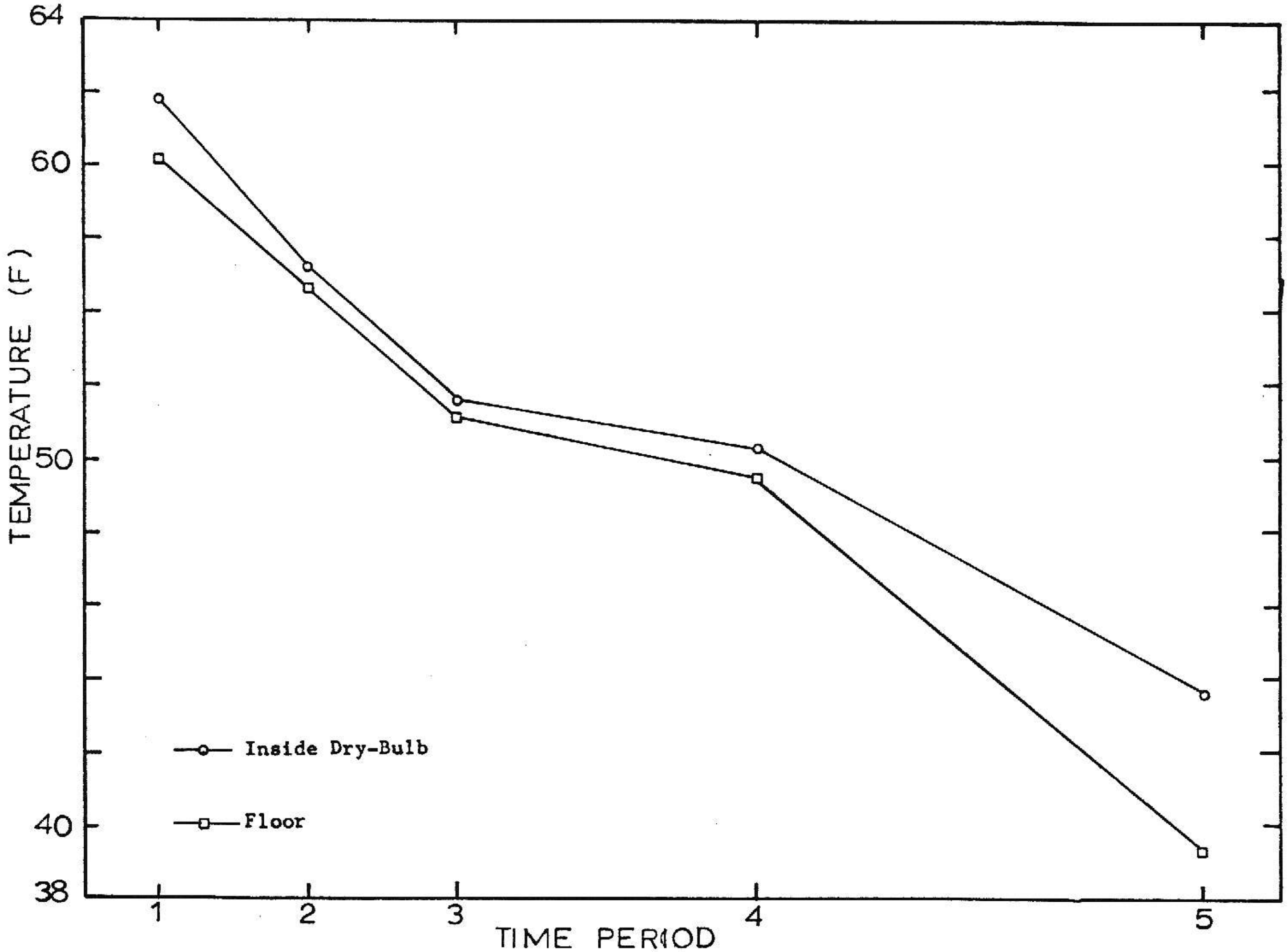

Figure 19. Comparison of the inside dry-bulb and floor temperature trends during experiment 1.

The average dry-bulb temperature of 52.1° F is below the range considered to be optimum for swine growing and finishing, but does not take into account the effect of the radiant heaters. On the average, the average inside black-globe temperature was 9.8° F higher than the dry-bulb temperature. While the pigs were under the heaters, they probably sensed a temperature between the black-globe and dry-bulb temperatures.

Since pigs spend about 81 percent of their time sleeping (Hultgren and Hazen, 1971), it is important that the floor temperature not be too cool. During experiment 1, it was found that the average floor temperature was only about 1.6° F cooler than the dry-bulb temperature (Figure 19).

The mid-pen temperature was higher than the dry-bulb temperature, but it is probable that it was influenced by the heaters and the pigs. Pigs were observed chewing on the protective guards of the mid-pen thermocouples quite often. The temperature at the top of the pen partition was also higher than the dry-bulb temperature, but it is also probable that this temperature was influenced by the heaters.

The dry-bulb, floor, mid-pen, and inside black-globe temperatures declined at approximately the same rate until period three. After period three the inside black-globe, mid-pen, and top of the pen partition temperatures declined at a slower rate than previously. The floor temperature declined at approximately the same rate throughout experiment 1. The floor temperature declined at nearly the same rate as the outside temperature. The dry-bulb temperature declined at a slower rate after period four. The change in the rate of decline for the inside black-globe, mid-pen, and top of the pen-partition temperatures is probably because the heaters were activated when the dry-bulb temperature fell below 50° F.

The air temperatures at the exhaust fans were nearly the same as the inside dry-bulb and the other temperatures in the pen (Figure 17). The inside surface temperature of the plywood front was slightly lower than the inside polyethylene film temperature (Figure 18). However, the polyethylene film temperature may have been influenced by its attachment, causing it to read high during the daytime hours.

It was reported that the oxidation pit froze several times during the winter of 1968-69. During experiment 1, the daily average temperature of the pit declined from 57.7° to 50.6° F. During the same period of time the inside dew-point temperature declined from 43.1° to 35.1° F. The rate of decline for the pit and dew-point temperatures were nearly the same.

The average inside relative humidity was 70.4 during experiment 1. This does not exceed the recommended design limit, but a more important measure of moisture in the air is the specific humidity. The specific humidity declined from a high of .0067 to .0042 lb water/lb dry air (Figure 20). Since the thermostatically controlled exhaust fan would not operate below 55° F, it might be expected that the moisture in the air would increase. Apparently the declining animal moisture production caused by the lower air temperature and increasing condensation on the polyethylene film was more than enough to offset the effect of the inoperative exhaust fan. The specific humidity remained fairly constant until the average film temperature fell below the dew-point temperature.

The daily average temperature trends of experiment 2 (Figures 21, 22, and 23) were similar to those in experiment 1, except that those in experiment 2 were increasing. The additional points of temperature measurement (air temperature at the black-globe and the air temperature at the 6 ft level) of

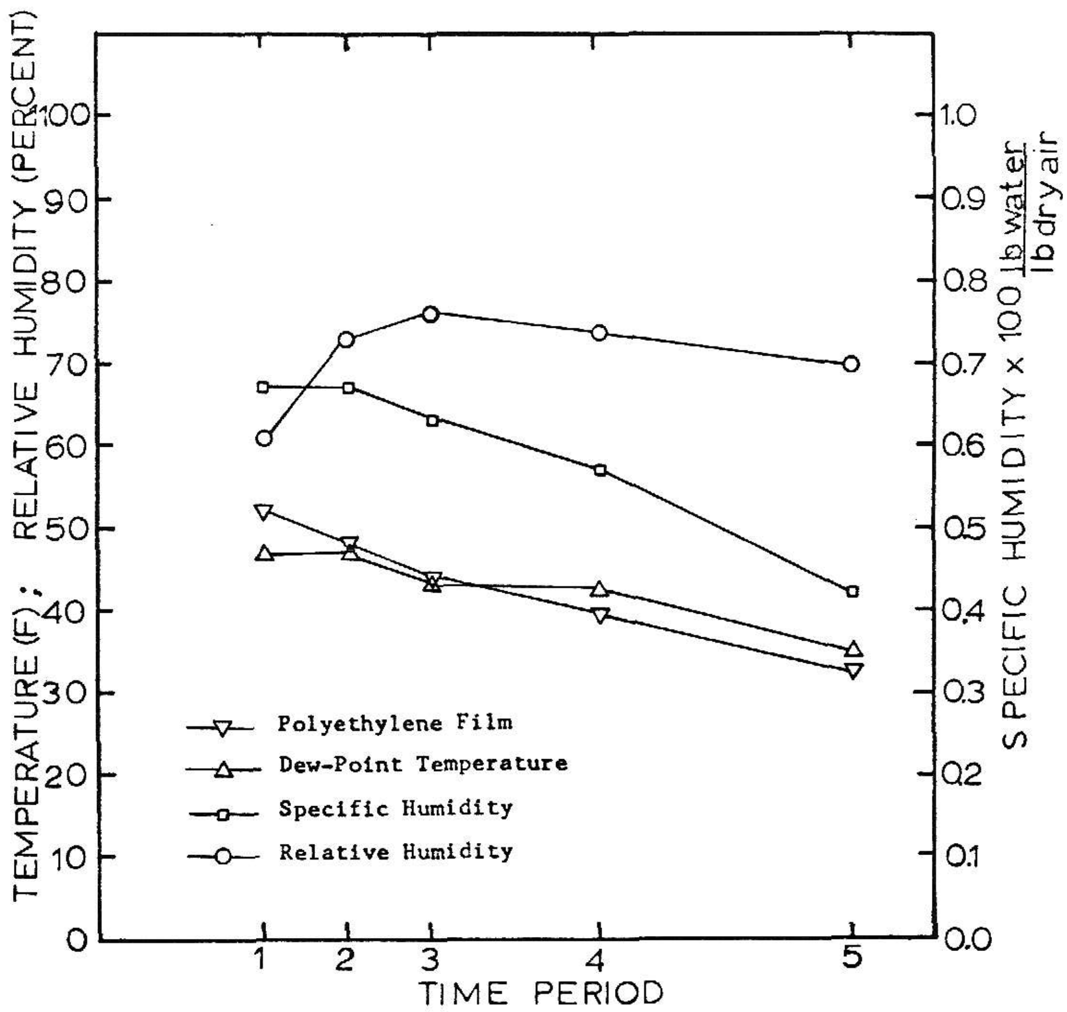

Figure 20. Trends of the psychrometric conditions and polyethylene film temperature during experiment 1.

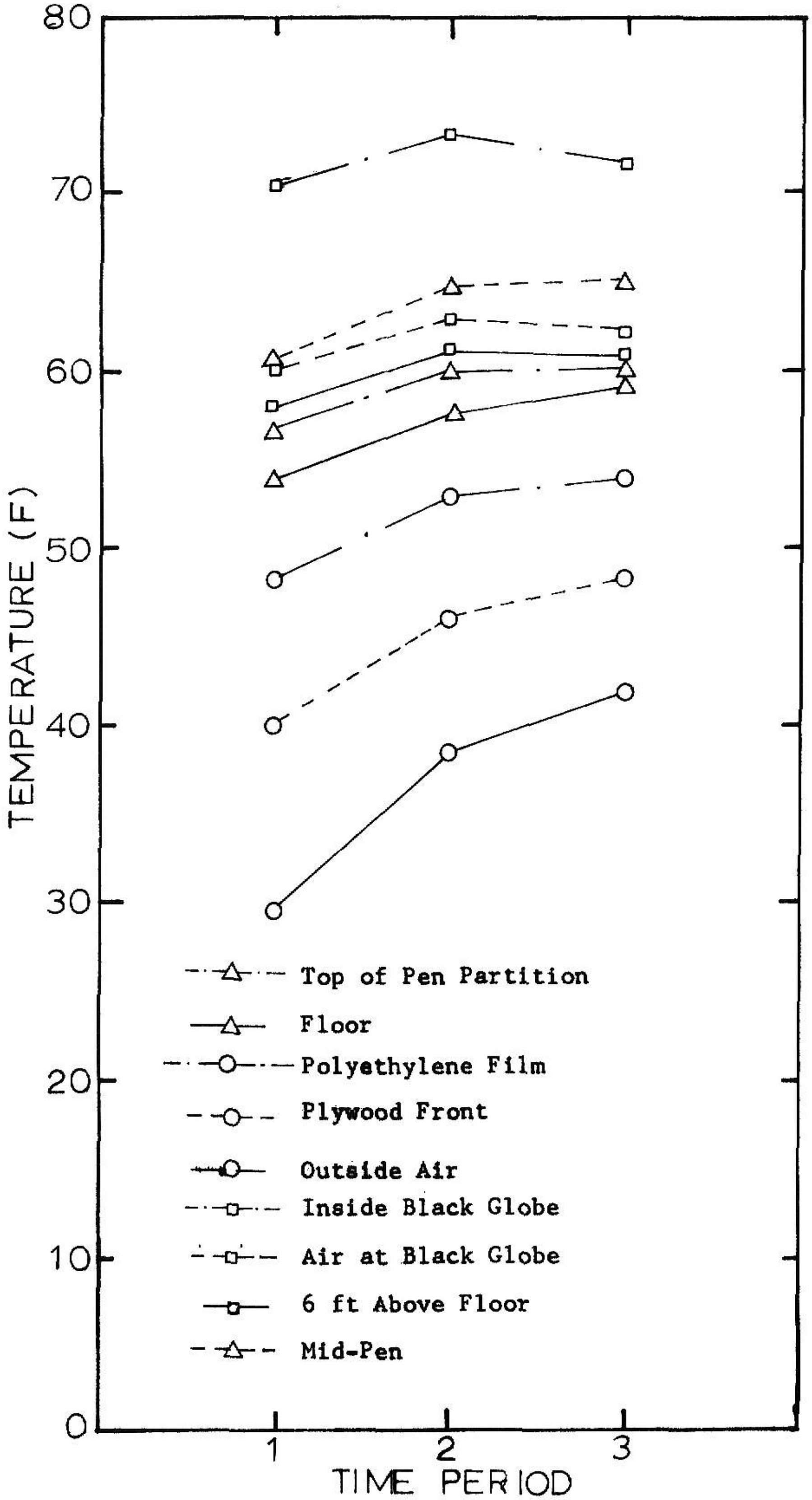

Figure 21. Temperature trends during experiment 2.

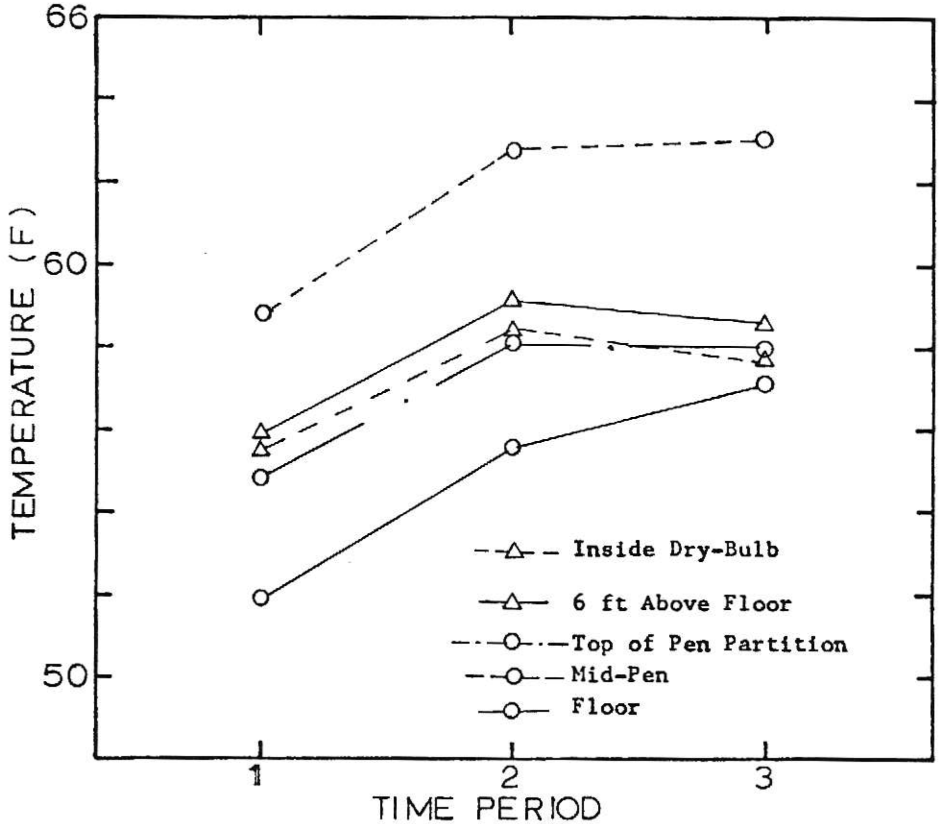

Figure 22. Trend of pen temperatures during experiment 2.

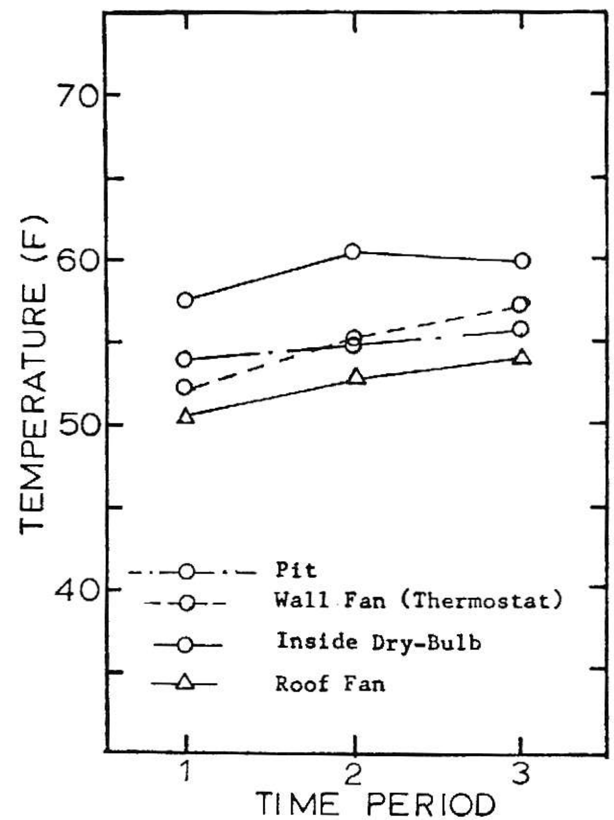

Figure 23. Temperature trends of fans and pit during experiment 2.

experiment 2 revealed little additional information.

The average psychrometric conditions for experiment 2 remained fairly constant (Figure 24). The average relative humidity for experiment 2 was 51.9 percent; the average specific humidity was .0055 lb water/lb dry air.

A summary of the thermal environmental conditions for experiments 1 and 2 are presented in TABLES 9 and 10.

TABLE 9

AVERAGE TEMPERATURES FOR EXPERIMENTS 1 AND 2

Exp	(1)*	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)
1	43.0	42.3	50.5	57.2	53.3	52.7	61.9	52.1	51.7	52.8	54.3
2	51.2	44.8	56.9	63.5	59.0	--	71.8	59.2	52.9	54.9	54.9

* 1 Polyethylene film
2 Plywood front
3 Floor
4 Mid-pen
5 Top of pen partition
6 Timer controlled fan
7 Inside black-globe
8 Inside dry-bulb
9 Roof fan
10 Thermostatically controlled fan
11 Pit

TABLE 10

AVERAGE PSYCHROMETRIC CONDITIONS FOR EXPERIMENTS 1 AND 2

Exp	Dry-bulb (F)	Dew-point (F)	Relative Humidity (percent)	Specific Humidity $\frac{\text{lb water}}{\text{lb dry air}}$
1	52.1	42.9	70.4	.0059
2	59.2	42.8	51.9	.0055

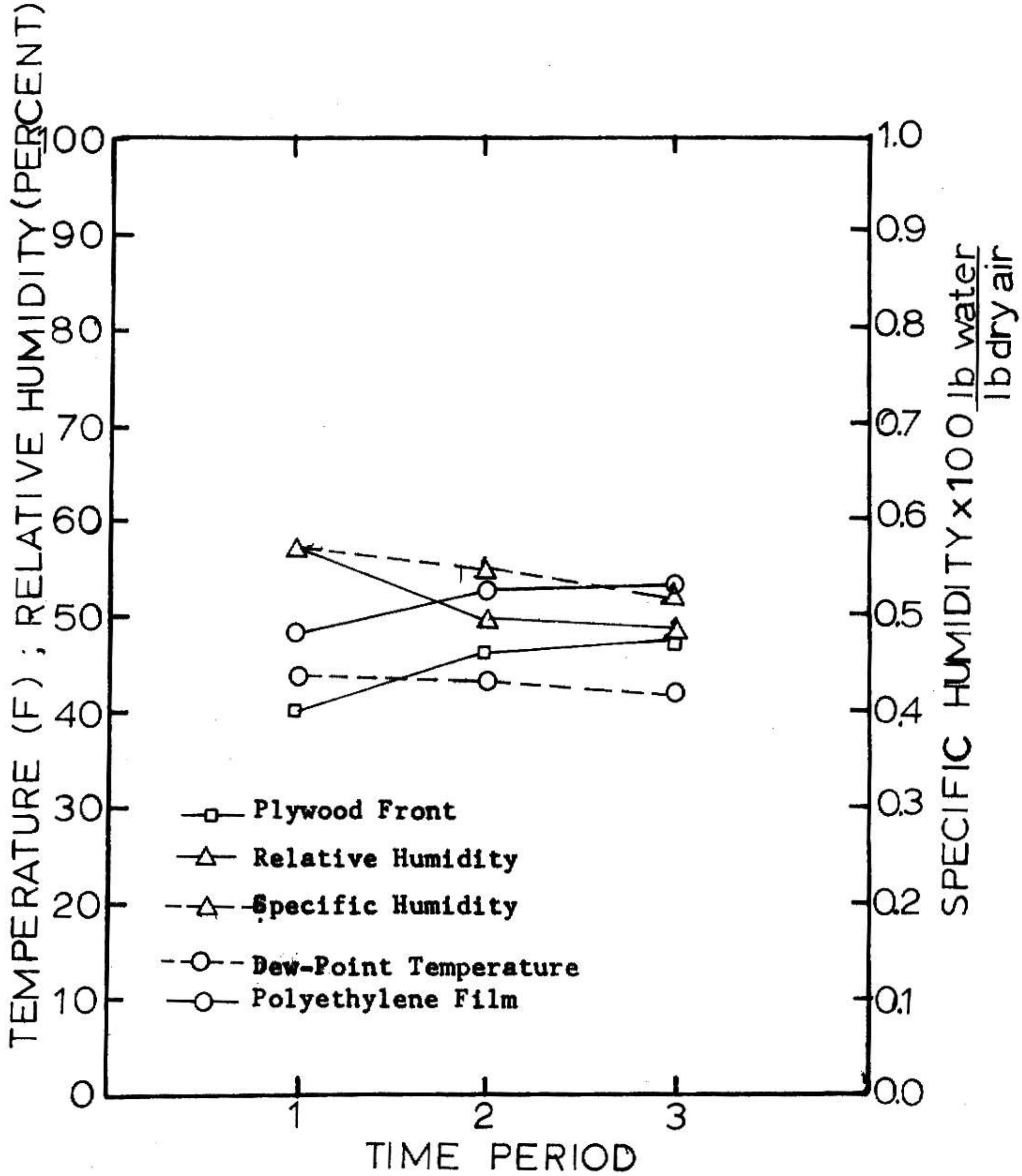

Figure 24. Trend of the psychrometric conditions and inside enclosure temperatures during experiment 2.

Diurnal Variation

The inside diurnal variations were markedly influenced by the outside temperature variation (Figures 25, 26, 27, and 28). The floor and dry-bulb temperatures were nearly equal during the nighttime hours with the dry-bulb temperatures being higher during the daytime hours.

The dew-point temperature remained relatively constant throughout the day (Figures 27 and 28). It is important to note that the polyethylene film temperature was lower than the dew-point temperature during experiment 1 during the nighttime hours. This indicates that moisture was condensing on the polyethylene film, which reduces infrared radiation to the cold sky.

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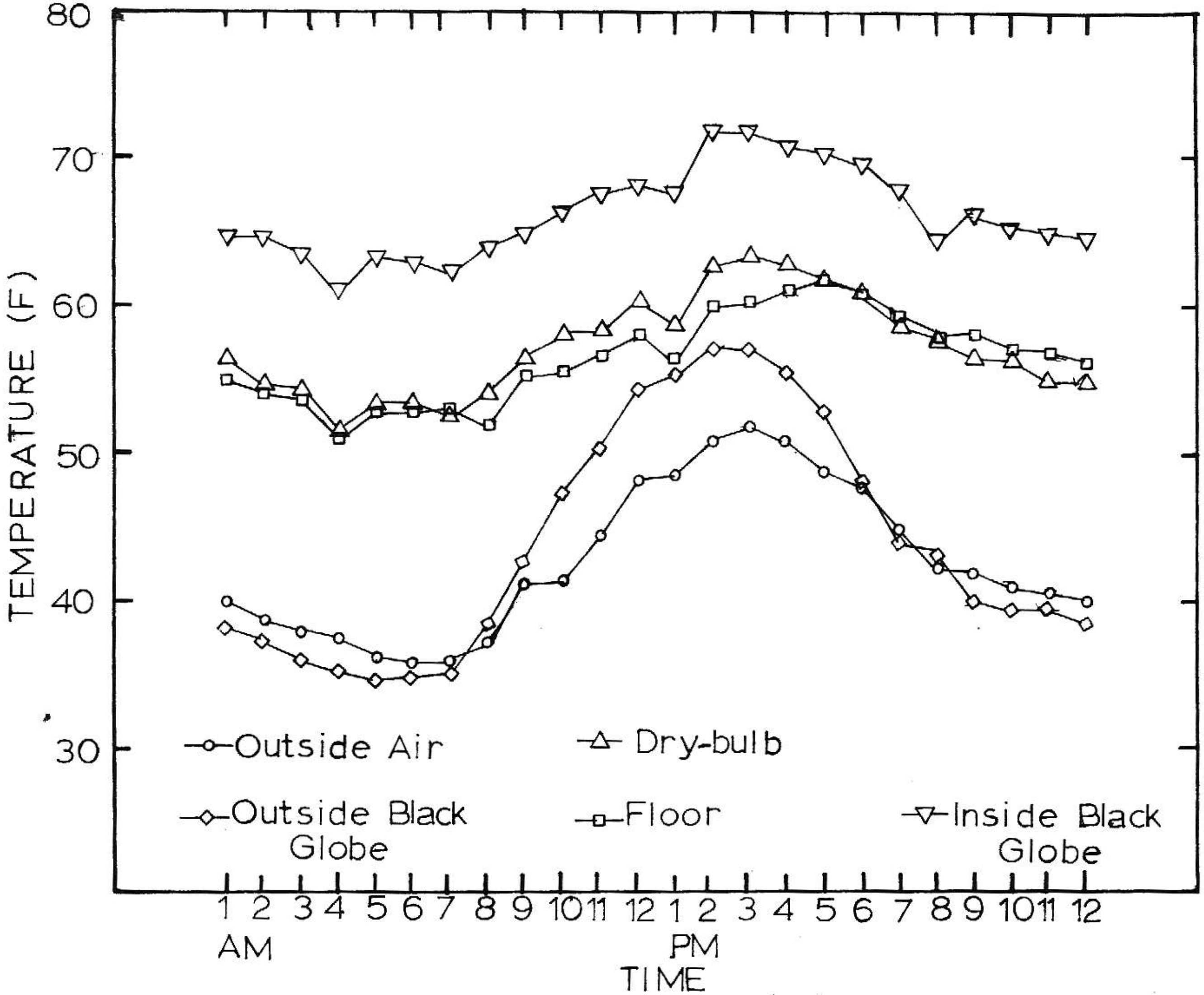

Figure 25. Diurnal variation during periods 1, 2, and 3 of experiment 1.

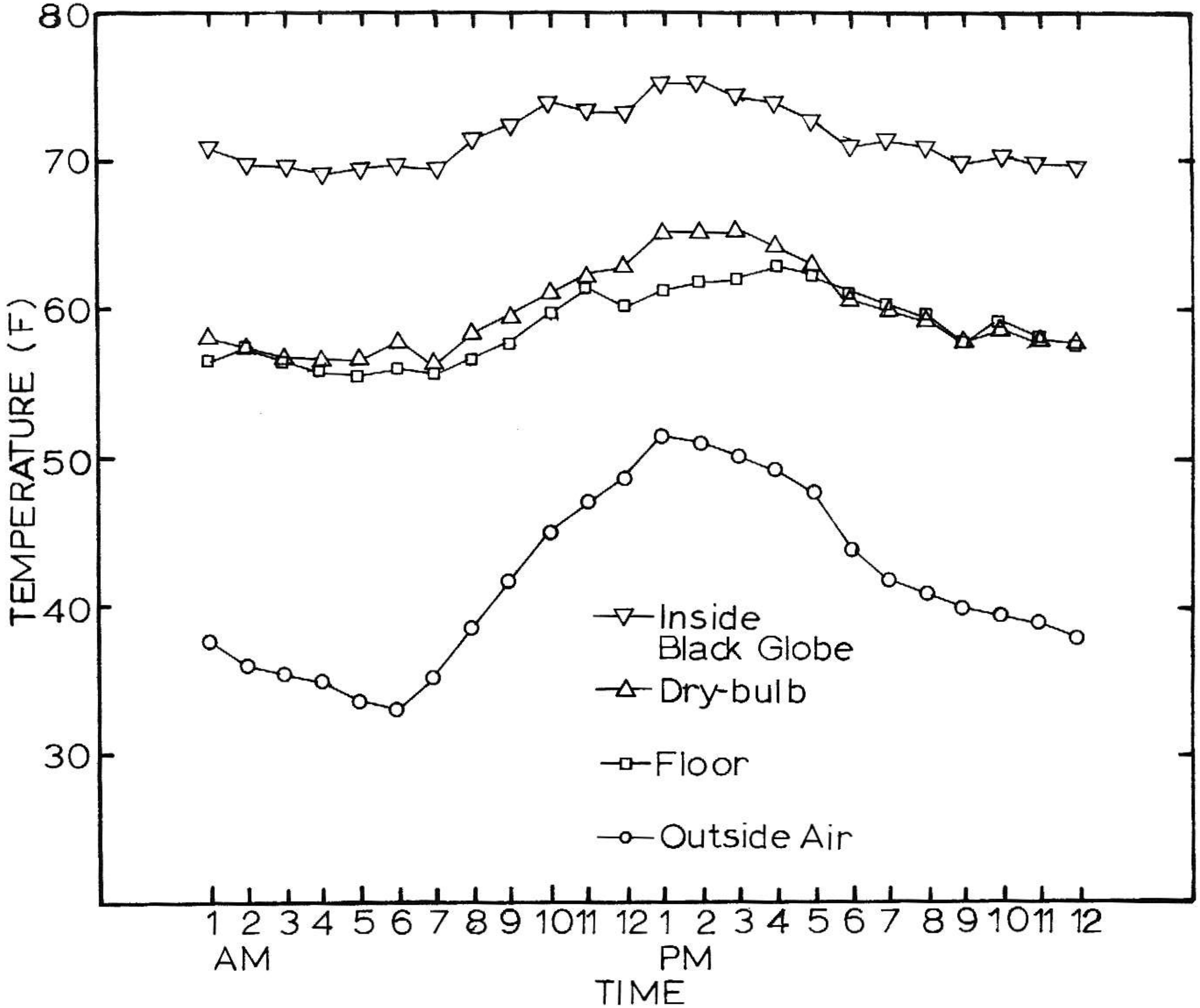

Figure 26. Diurnal variation during period 3 of experiment 2.

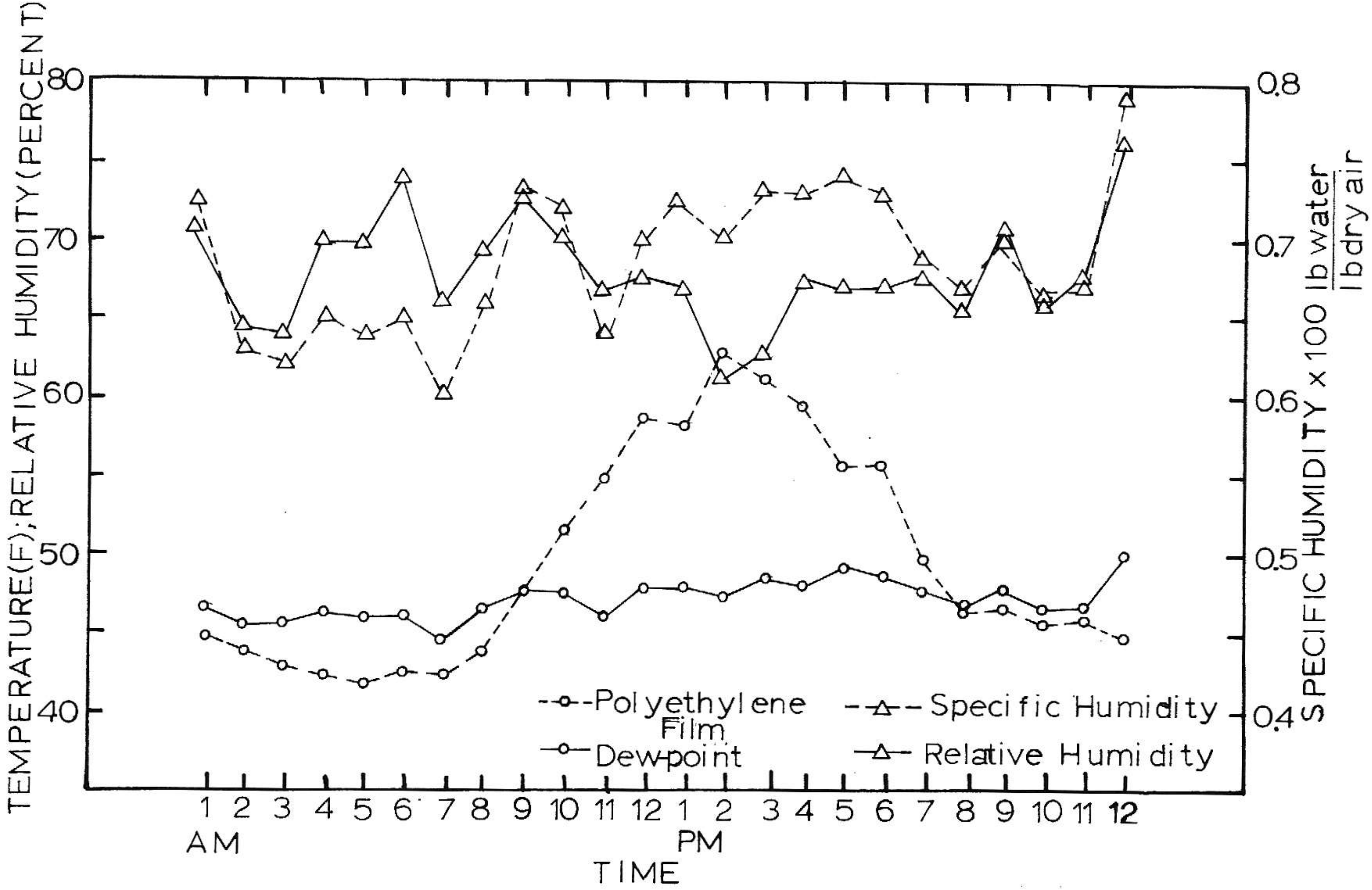

Figure 27. Diurnal variation of the psychrometric conditions during periods 1, 2, and 3 of experiment 1.

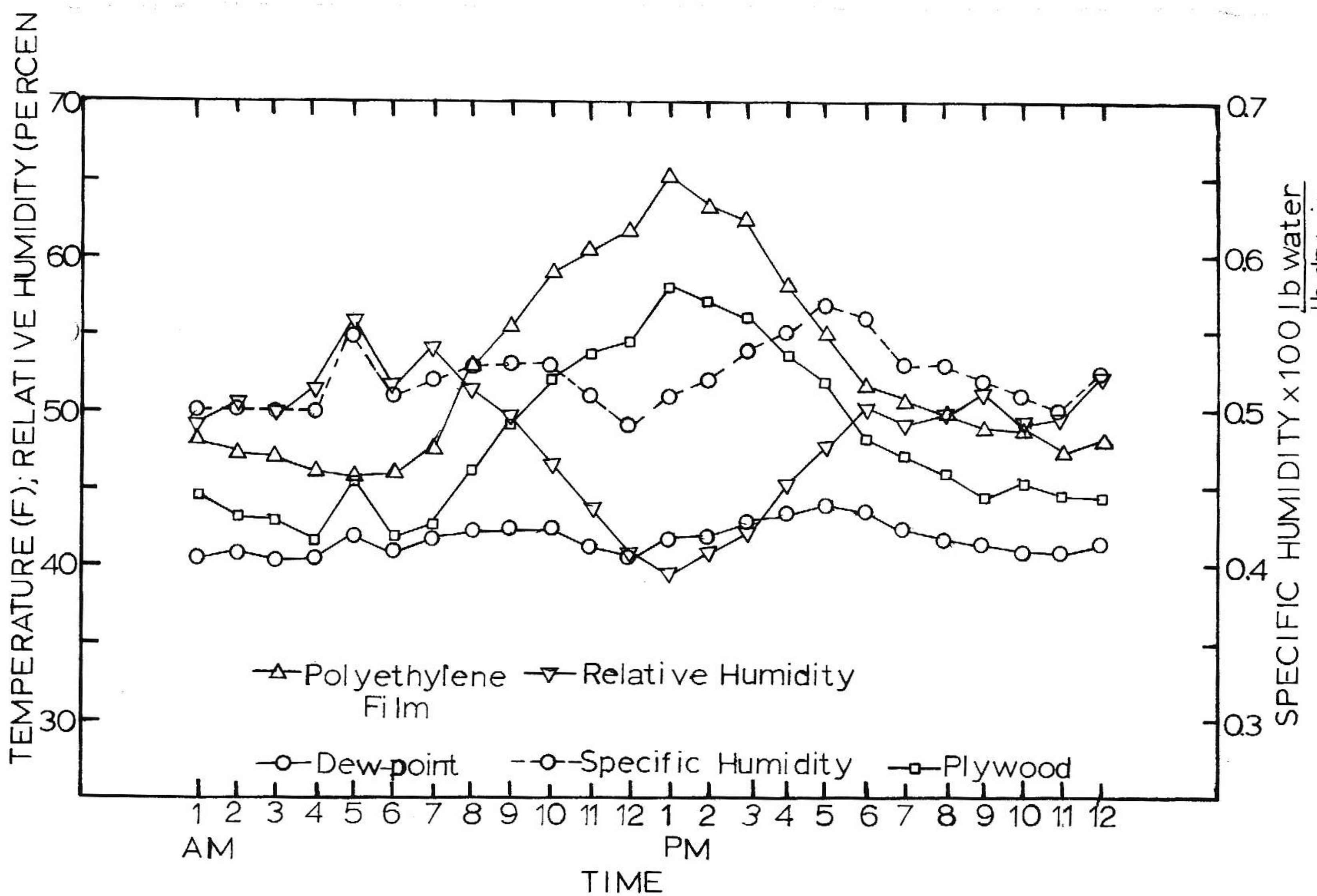

Figure 28. Diurnal variation of the psychrometric conditions during period 3 of experiment 2.

CONCLUSIONS

By using animal performance data from three years of operation, it is possible to make some conclusions which may have value to future designers.

1. Growing and finishing swine may be successfully raised in open-front buildings with total slotted floors in winter climates similar to that of northern Kansas if the building is modified by enclosing the open-front with low cost materials (such as clear polyethylene and plywood), and providing supplementary radiant heat to the pens.

2. Daily weight gain will be significantly improved over swine housed in an unmodified building.

3. The floor and dry-bulb temperatures will be nearly equal in a building modified similar to the one used in this study.

4. The amount of ventilation required for moisture control in the modified building may be reduced below that required for moisture control in a completely enclosed building. In the modified building, moisture will condense on the polyethylene film and run out of the building.

5. These modifications will allow a liquid manure oxidation pit to operate throughout the winter.

SUMMARY

Researchers have shown that an optimum air temperature exists for the growing and finishing of swine. It has also been shown that pigs tend to gain faster and consume less feed when housed in a building which provides a temperature near the optimum level.

Experience in northern Kansas has shown that the winter performance of swine housed in an open-front building with total slotted floors is unsatisfactory, and the operation of a liquid manure oxidation ditch is impaired by freezing.

Research conducted during the winter of 1970-71, using the open-front growing and finishing building at the Kansas State University swine research facility enclosed with clear polyethylene and plywood, with radiant heaters over the pens has shown that: daily weight gain is significantly better for swine housed in the modified building, excessive ventilation is not required because moisture condenses on the polyethylene film and runs out of the building, the floor and dry-bulb temperatures are nearly equal, and satisfactory operation of the liquid manure oxidation pit is achieved.

SUGGESTIONS FOR FUTURE RESEARCH

This study has shown that swine performance can be improved by modifying an open-front building with fairly low cost materials. The swine used in this study were of a fairly heavy weight when the coldest weather was experienced. For this reason it would be desirable to conduct an investigation with smaller pigs during the coldest weather. It would also be desirable to conduct a study over the entire year so that daily animal performance could be evaluated at different times of the year. This would provide an opportunity for a building optimization study so that an optimum cost per pound of gain could be reached. This could also be used to provide a schedule of optimum building use so that light weight pigs are not exposed to adverse growing conditions.

Another possibility to study the environmental conditions created by a modification would be the use of infrared photography. This technique would give an environmental map of the entire area in question very easily.

To determine the effectiveness of the radiant heaters, an experiment should be conducted using groups of pigs exposed to radiant heat and groups of pigs not exposed to radiant heat. In this experiment all conditions could be constant except for the radiant heat.

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APPENDIX A

DETAILS AND CONSTRUCTION OF THE PSYCHROMETER

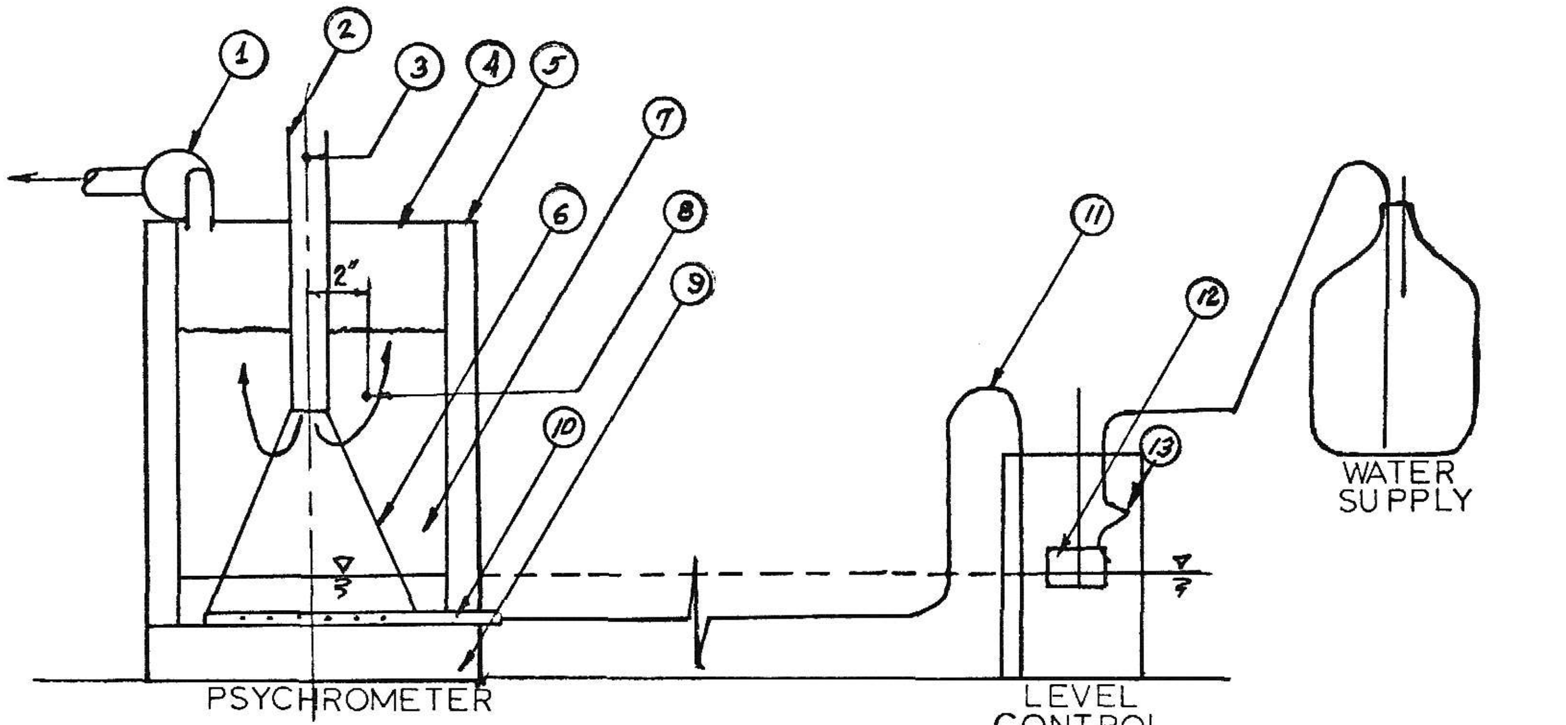
DETAILS AND CONSTRUCTION OF THE PSYCHROMETER

Obtaining a continuous wet-bulb temperature reading in a livestock environment is somewhat of a problem. A typical unit used in grain drying research is a thermocouple covered by a cloth wick, which is connected to a supply of water (Haynes and Smith, 1955). A small blower is used to blow air over the wick, but dust, generally present in livestock environments, will cause an erroneous wet-bulb reading if it collects on the wick of the thermocouple.

The psychrometer used in this study is similar to one constructed by Saul (1956: Figures 29, 30, and 31). The eight inch bed of vermiculite functions as a wick. The blower draws air into the can through the pipe in the center. This pipe is connected to a cone-shaped, plenum chamber constructed of screen. Approximately two inches of water are maintained in the bottom of the can to keep the vermiculite wet. As the air passes through the vermiculite, it is saturated adiabatically and the entire vermiculite mass tends to assume the wet-bulb temperature. A thermocouple placed in the vermiculite bed is used to sense the wet-bulb temperature.

To verify the reliability of this unit, an aspirated psychrometer with mercury-in-glass thermometers was used. This test took place during the morning in one of the Agricultural Engineering labs.

TABLE 11 contains the results of this test. It is suspected that the vermiculite unit would not respond to changes in the air temperature as fast as the aspirated unit, so this test was subject to this error. It was impossible to determine the magnitude of the error since there were no faci-



1 Blower
2 $1\frac{1}{2}$ in Tubing
3 Dry-bulb Thermocouple
4 5 gal Can
5 1 in Foam Rubber
6 Screen Plenum Chamber
7 Vermiculite Bed
8 Wet bulb Thermocouple
9 2 in Styrofoam
10 $\frac{1}{2}$ in Copper Tube
11 Copper Tubing
12 Styrofoam Float
13 Rubber Tubing

Figure 29. Schematic diagram of the psychrometer used in the investigation.

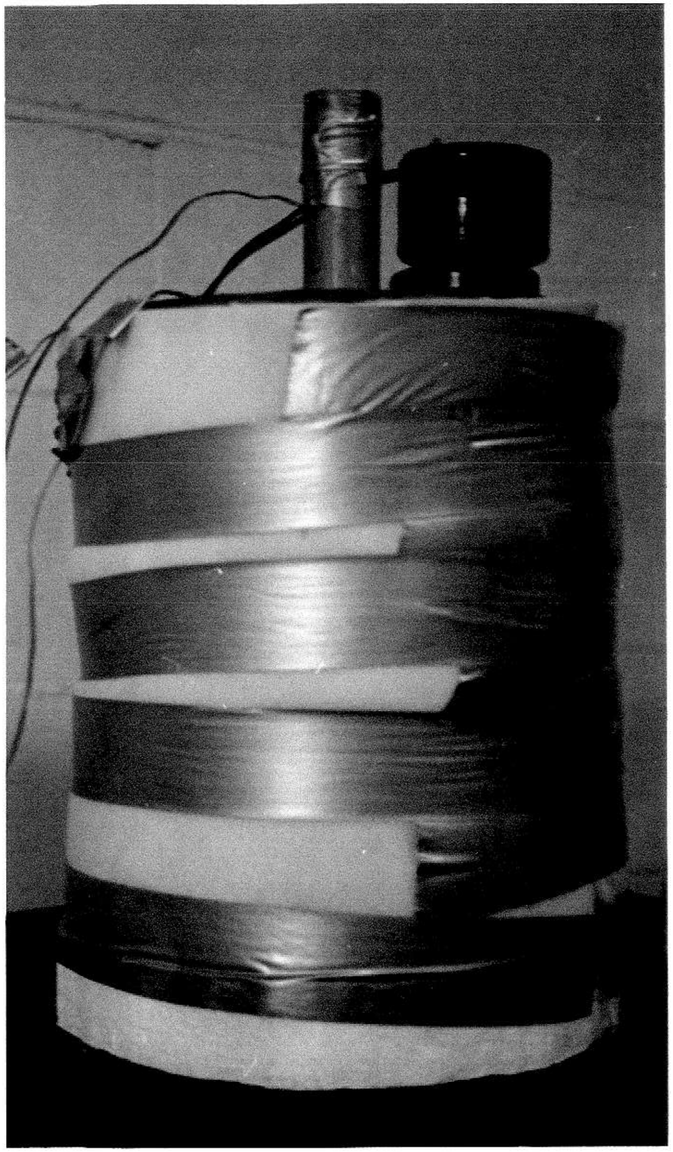


Figure 30. Psychrometer used in the investigation.

Figure 31. Top view of the psychrometer.

lities available to evaluate this.

The differences in the two averages were checked for significance by using Student's t test, and it was found that the difference was not significant at any level of confidence. This indicates that the difference was due only to chance.

TABLE 11

RESULTS OF THE PSYCHROMETER VERIFICATION TEST

Aspirated Psychrometer			Vermiculite Psychrometer		
Dry-bulb (F)	Wet-bulb (F)	Relative Humidity*	Dry-bulb (F)	Wet-bulb (F)	Relative Humidity*
69.8	54.2	.35	70.0	55.5	.39
70.0	54.3	.34	70.1	55.4	.38
69.8	54.2	.35	70.0	55.3	.38
70.0	54.5	.35	70.1	55.2	.37
70.5	55.0	.36	70.5	55.3	.37
71.0	54.9	.34	71.2	55.5	.36
71.0	55.0	.34	71.2	55.5	.36
71.4	55.1	.34	71.9	55.5	.34
71.5	55.5	.35	71.8	55.6	.34
72.0	56.0	.35	72.4	55.7	.33
72.0	56.0	.35	71.7	55.9	.36
72.3	55.7	.33	72.8	55.9	.33
72.5	56.0	.34	72.6	55.9	.33
72.0	55.5	.33	72.3	55.7	.33
72.3	55.5	.33	73.2	55.9	.32
72.5	56.0	.34	72.8	55.5	.32
72.8	56.0	.33	73.0	55.5	.31
72.5	55.5	.32	72.9	55.1	.30
Average+		.341			.345
Sum of Squares		.0016			.0118

Standard error of the difference = .00663+

* Calculated by the equations of Brooker (1967; Appendix B).

\+ No significant difference between the two means.

During experiment 1, the unit performed satisfactorily until the latter stages of the experiment. When checked with the aspirated psychrometer, the vermiculite unit was found to be somewhat in error. Apparently dust in the air coupled with an inability to maintain the correct water level caused poor response. During experiment 1 no external water supply was used, and it was difficult to maintain the correct water level. At the end of experiment 1 the unit was removed from the building, cleaned, and verified for experiment 2.

For experiment 2, an external water supply was used so that the proper water level could be maintained at all times. The external water supply consisted of two one-gallon bottles connected to a level control (Figure 28). The level control was a small plastic container with a styrofoam float. This small container was located remotely from the psychrometer but at the same elevation as the psychrometer. The water level in the small container was maintained at the same level as the water level in the psychrometer. These were then connected by a continuous column of water. The correct water level in the small container was maintained by the styrofoam float. Connected to the float was a flexible 1/4 inch diameter rubber tube, which was connected to the water supply. As the water level fell below the correct level, the float lowered, causing the rubber tube to extend, which released water from the supply. When the correct level was reached, the float would rise, pinching the rubber tube, which would stop the flow of water from the supply. An air filter was also constructed for the intake pipe for experiment 2.

APPENDIX B

PSYCHROMETRIC EQUATIONS

PSYCHROMETRIC EQUATIONS

Using wet-bulb and dry-bulb temperatures, psychrometric data can be obtained from a psychrometric chart. When a large number of data are being analyzed, using a psychrometric chart can become very tedious and many errors may result. For this reason Brooker (1967) has presented a mathematical model of the psychrometric chart. Using the equations presented by Brooker, any of the desired psychrometric properties may be obtained. For this study, dew-point temperature, relative humidity, and specific humidity were needed.

Using the wet- and dry-bulb temperatures, the following equations were used to solve for the desired properties.

$$Ps = \exp(54.6329 - \frac{12301.688}{Tdp} - 5.16923 \text{ Ln } Tdp) \qquad (6)$$

$$Pswb = \exp(54.6329 - \frac{12301.688}{Twb} - 5.16923 \ln Twb) \qquad (7)$$

$$Hfg = 1075.897 + 0.56983\ (491.69 - Twb) \qquad (8)$$

$$B = 0.2405\ (14.6996 - Pswb)/(0.6219\ Hfg) \qquad (9)$$

$$Pv = Pswb - B(Tdp - Twb) \qquad (10)$$

$$RH = Pv/Ps \qquad (11)$$

Use Pv in equation 6 to solve for the dew-point temperature.

$$Tdp = \frac{12301.688}{(54.6329 - 5.16923 \text{ Ln } Tdp - \text{Ln } Pv)} \quad (12)$$

Since Tdp cannot be solved for explicitly, an iterative technique must be used. The computer program subroutine used to solve for the dew-point temperature is:

```
      SUBROUTINE DEWPT(T,DP,P)
C
C     THIS CALCULATES THE DEW-POINT TEMPERATURE.
C
      DIMENSION C(25)
C
C     ASSUME THAT THE DEW-POINT TEMPERATURE IS EQUAL TO THE WET-BULB
      TEMPERATURE.
      C(I) = T
      A1 = T
      DO 100 I = 1, 25
      C(I) = 12301.688/[54.6329 - 5.16923*ALOG(A1) - ALOG(P)]
      IF(I.GT.1) GO TO 102
      GO TO 100
  102 A1 = C(I-1)
      DEL = C(I) - A1
C
C     TEST FOR CONVERGENCE.
C
      IF[ABS(DEL).LT. .000001] GO TO 101
      A1 = C(I)
  100 CONTINUE
C
C     CONVERT TO FAHRENHEIT
C
  101 DP = C(I) - 459.69
      RETURN
      END
```

$$X = 0.6219 \frac{Pv}{14.696 - Pv} \quad (13)$$

TABLE 12

SYMBOLS USED IN THE EQUATIONS

Symbol	Definition	Units
Tdp	Dry-bulb temperature	deg R
Twb	Wet-bulb temperature	deg R
Tdp	Dew-point temperature	deg R
Ps	Saturation vapor pressure at Tdp	Psi
Pswb	Saturation vapor pressure at Twb	Psi
Pv	Vapor pressure	Psi
Hfg	Latent heat of vaporization at Twb	Btu/lb
B	Slope of the constant wet-bulb temperature line	
RH	Relative humidity	Decimal
X	Specific humidity	$\frac{\text{lb water}}{\text{lb dry air}}$

APPENDIX C

ANIMAL PERFORMANCE DATA

TABLE 13

ANIMAL PERFORMANCE DATA

Winter	1968-69[*2]			1969-70[†3]		
	Daily Gain lb/da	Daily Feed lb/da	Feed[1] Eff	Daily Gain lb/da	Daily Feed lb/da	Feed[1] Eff
	1.39	4.60	3.31	1.73	5.35	3.10
	1.47	5.11	3.38	1.81	5.41	2.99
	1.36	4.34	4.70	1.61	5.15	3.20
	1.35	4.40	3.21	1.68	5.34	3.18
	1.44	3.17	3.21	1.64	5.02	3.06
	1.47	4.47	2.92	1.66	4.98	3.00
Winter	**1970-71[4]**			**1971[5]**		
	Daily Gain lb/da	Daily Feed lb/da	Feed[1] Eff	Daily Gain lb/da	Daily Feed lb/da	Feed[1] Eff
	1.68	5.05	3.00	1.61	5.78	3.59
	1.60	5.22	3.27	1.69	5.93	3.53
	1.65	5.01	3.04	1.86	5.81	3.13
				1.66	5.69	3.42

* Koch and Hines, 1969

† Koch and Hines, 1970

1 lb feed/lb gain

	Avg beg wt, lb	Avg end wt, lb
2	60	185
3	80	201
4	75	191
5	112	214

APPENDIX D

THERMAL ENVIRONMENTAL DATA

Table 14. Daily average temperatures of experiment 1.

DATE	OUTSIDE AIR	OUTSIDE BLACK GLOBE	POLYETHYLENE FILM	PLYWOOD FRONT	FLOOR	MID-PEN	TOP OF PEN PARTITION	INSIDE DRY-BULB	INSIDE WET-BULB	INSIDE BLACK GLOBE	ROOF FAN	WEST WALL FAN (Thermostat control)	EAST WALL FAN (Timer control)	PIT
11-26-70	37.6	38.8	43.6	43.1	51.3	58.1	54.3	52.8	46.0	61.1			54.9	
27	31.2	31.4	38.8	38.7	47.3	54.2	50.8	49.3	44.0	57.0			51.2	
28	35.5	35.7	42.8	40.3	49.7	56.3	53.5	52.5	47.4	61.3			54.2	
29	46.0	50.2	57.0	52.8	56.7	65.3	61.6	60.4	51.5	68.2			61.6	
12- 1-70	58.7	61.0	62.2	60.8	67.1	73.8	68.6	67.6	56.4	74.8	66.4	68.6	66.0	
2	48.2	49.4	54.6	54.4	62.7	68.2	65.6	64.4	57.7	71.3	59.6	65.4	62.2	
Time Period 2														
6	44.7	47.0	53.4	52.0	58.8	66.1	59.9	58.7	53.2	68.7	57.6	59.4	60.6	
7	31.3	32.4	41.7	42.0	51.8	58.3	52.6	52.5	47.6	61.7	51.0	46.4	54.0	
8	41.7	42.2	48.6	46.9	53.2	59.8	55.7	54.5	50.0	65.1	52.6	56.7	55.9	
Time Period 3														
9	45.6	47.3	52.6	51.1	58.0	65.5	60.1	58.8	55.1	69.1	57.7	60.2	61.2	61.0
10	44.2	44.8	49.4	48.5	58.2	64.7	59.5	58.8	54.2	69.2	56.3	58.9	61.0	61.6
11	23.4	23.6	31.0	33.0	46.6	51.5	44.9	42.6	40.2	55.2	45.5	36.3	46.2	58.3
12	28.2	30.5	36.5	35.5	41.9	48.0	44.7	43.2	40.7	54.5	43.0	43.5	44.7	50.6
13	34.5	36.6	44.5	42.9	50.0	58.2	53.6	51.9	47.3	63.8	51.2	52.4	53.5	57.1
14	39.4	41.6	48.2	46.2	52.0	60.2	55.6	54.5	47.9	66.2	52.3	55.9	55.4	57.6
Time Period 4														
15	40.1	39.8	45.9	45.0	54.6	61.0	57.2	56.0	52.3	66.6	53.4	57.5	57.2	56.6
16	31.6	33.2	39.8	39.4	51.3	56.6	52.8	51.0	47.9	62.0	49.4	52.8	52.0	56.0
17	39.5	42.1	48.9	45.6	54.9	62.5	58.6	56.3	52.9	67.3	54.9	58.0	57.9	56.4
18	28.7	28.4	36.4	37.0	49.9	55.5	50.9	47.9	45.8	59.7	47.2	49.0	49.7	56.4
19	24.3	26.8	36.4	36.2	48.1	54.6	49.9	47.2	43.1	58.6	45.4	44.0	48.8	54.7
20	24.6	24.7	34.5	33.0	46.3	50.7	48.8	47.6	43.8	56.3	44.6	46.7	49.7	53.4
21	29.6	29.8	38.1	36.9	49.0	54.6	50.8	48.8	45.5	59.0	47.5	49.6	50.9	53.9
22	35.0	36.3	42.3	41.5	51.1	57.3	54.1	52.1	47.3	63.9	51.3	52.0	53.1	55.1
23	24.5	27.0	34.1	35.4	46.9	52.6	49.3	46.9	41.7	57.7	45.4	44.4	46.2	54.6
24	30.3	31.5	38.7	37.7	47.9	54.8	50.7	49.1	42.7	61.6	48.4	49.1	47.7	53.9
25	24.2	27.6	34.5	34.6	45.4	53.3	48.5	46.2	39.9	58.9	44.7	43.0	44.4	53.1
26	33.7	35.5	41.9	41.3	48.5	56.1	53.6	51.6	46.2	63.2	50.0	51.6	50.7	53.4
27	30.6	31.5	38.9	38.4	48.2	55.8	53.0	51.6	48.3	62.9	49.8	51.5	51.9	54.3
28	29.1	32.5	40.5	39.4	50.5	56.2	51.2	51.7	47.7	61.4	48.3	50.9	50.4	53.3
Time Period 5														
29	30.9	34.7	41.5	40.8	47.4	57.2	52.5	51.3	47.8	61.9	49.4	51.3	51.4	52.7
30	34.6	34.0	40.2	39.4	48.3	53.6	51.1	50.0	46.9	60.6	49.8	51.7	50.4	53.8
31	33.0	34.6	41.1	40.5	47.1	52.9	52.1	51.5	47.2	62.3	50.5	51.5	51.0	54.9
1- 1-71	41.1	43.2	48.7	47.2	52.4	58.6	57.0	55.6	49.6	66.1	54.5	57.1	56.2	56.9
2	32.0	31.9	37.7	38.5	47.4	54.2	50.5	48.7	43.5	58.8	49.0	48.0	51.8	57.5
3	22.1	22.3	27.5	29.7	40.6	44.3	41.6	40.2	36.6	50.0	41.5	36.0	41.7	56.4
4	11.8	13.9	23.0	25.0	36.6	40.2	36.8	35.5	32.0	44.3	35.1	28.2	34.0	52.4
5	7.1	13.4	23.3	24.1	32.2	40.5	37.4	37.7	34.4	44.7	34.5	32.4	34.9	49.2
6	5.7	11.4	21.4	21.0	29.4	37.1	36.4	35.3	32.4	45.6	32.1	31.5	27.1	45.8
7	14.4	19.7	26.5	25.3	29.9	39.6	41.0	38.8	34.8	48.4	34.8	36.1	34.8	45.2
8	24.6	28.6	32.0	27.8	36.5	41.8	40.6	40.4	36.6	50.6	41.1	40.6	38.6	47.6
9	31.8	37.5	41.9	38.2	42.3	49.9	49.5	48.3	42.2	58.7	47.2	48.6	47.1	50.2
10	26.6	30.9	37.3	37.9	44.1	51.2	49.7	48.4	42.0	57.7	46.9	47.0	47.5	53.1
11	18.6	18.8	27.1	29.2	38.6	42.4	40.3	40.5	37.1	45.1	40.1	34.9	42.1	53.5
12	7.0	8.1	19.8	21.6	29.5	34.8	34.4	34.8	31.6	41.6	34.1	29.4	33.6	49.6
13	18.1	21.0	29.2	28.1	33.2	40.7	41.5	41.0	36.9	49.3	38.1	38.6	37.8	47.3
14	13.9	16.3	25.6	26.7	32.5	29.4	39.7	39.1	35.5	46.3	36.2	34.9	35.8	46.0
15	16.1	22.3	29.2	28.0	33.8	41.3	40.6	40.8	35.9	48.6	37.2	35.9	39.4	44.9
16	29.0	30.4	35.9	36.0	40.5	49.1	47.1	46.8	41.4	56.3	43.9	45.8	44.9	46.2
17	29.9	32.1	36.6	37.1	43.1	50.4	48.1	46.9	41.8	56.1	44.8	45.6	47.1	48.0
Averages for each time period														
Time Period														
1	45.5	47.1	52.0	50.6	58.1	64.7	61.0	59.8	52.1	67.4	63.0	67.0	59.7	
2	39.2	40.6	47.9	47.0	54.6	61.4	56.1	55.2	50.3	65.2	53.7	54.2	56.9	
3	39.5	37.4	43.7	42.9	51.1	58.0	53.0	51.9	47.5	63.0	51.0	51.2	53.7	57.7
4	30.4	31.9	39.3	38.7	49.5	55.8	52.1	50.3	46.1	61.4	48.6	50.5	50.8	54.7
5	22.4	25.1	32.3	32.1	39.3	46.0	44.4	43.6	39.3	52.6	42.0	41.2	42.4	50.6

Table 15. Daily average temperatures for experiment 2.

DATE	OUTSIDE AIR	OUTSIDE BLACK GLOBE	POLYETHYLENE FILM	PLYWOOD FRONT	FLOOR	MID-PEN	TOP OF PEN PARTITION	6 ft FROM FLOOR	INSIDE DRY-BULB	INSIDE WET-BULB	AIR TEMP AT THE INSIDE BLACK GLOBE	INSIDE BLACK GLOBE	WEST WALL FAN (Thermostat control)	ROOF FAN	PIT
Time Period 1															
2-23-71	21.9	25.7	46.7	41.3	52.5	60.8	56.8	57.3	57.3	49.9	59.9	69.6	45.7	46.1	49.6
24	30.8	37.2	51.5	41.8	53.2	60.5	57.7	59.4	59.3	55.1	61.4	71.9	54.7	57.3	53.9
25	39.0	43.4	53.0	43.6	57.5	61.3	59.3	60.9	60.3	53.2	62.2	72.6	61.1	53.8	55.9
26	35.1	38.0	51.1	41.2	56.0	64.1	58.1	59.4	58.5	49.8	61.3	71.9	57.9	52.7	56.7
27	32.4	35.1	51.4	41.3	55.5	65.4	59.1	60.0	59.3	49.1	62.4	72.9	54.5	52.0	56.6
28	30.5	32.3	45.7	37.4	55.3	61.0	55.5	56.4	56.9	48.2	59.2	69.3	53.7	49.7	55.2
3- 1-71	27.9	29.9	44.6	37.8	55.1	60.3	56.0	57.1	56.7	48.4	59.4	69.5	50.4	49.7	55.2
2	20.7	25.5	41.8	37.0	48.5	56.2	52.8	53.2	52.5	44.6	55.4	66.0	40.5	44.7	50.4
3	26.9	35.2	47.5	38.9	51.8	57.4	55.9	57.2	56.2	47.3	59.3	69.8	51.2	48.0	50.7
Time Period 2															
4	39.4	42.3	51.6	43.0	57.0	62.6	56.9	59.0	58.2	49.5	60.2	71.6	56.3	52.7	53.0
5	38.3	43.1	51.6	46.2	57.6	65.3	59.2	60.0	59.2	50.3	61.8	72.4	53.3	53.2	55.1
6	30.8	32.4	46.8	43.5	53.2	63.6	57.8	57.8	57.3	48.1	60.1	70.7	47.0	49.2	54.3
7	29.7	32.5	49.4	42.9	54.5	62.7	58.9	59.1	58.4	48.3	61.2	71.9	43.3	48.9	54.1
8	35.7	40.9	51.8	42.4	57.5	63.9	58.5	60.4	60.0	48.8	61.9	72.9	56.8	52.2	54.7
9	33.1	35.3	48.8	43.7	55.2	62.3	59.3	59.5	59.0	50.6	62.8	73.0	52.4	50.9	54.8
10	46.5	52.5	57.2	49.7	61.5	66.5	62.7	64.2	63.1	52.4	65.3	75.4	64.1	56.5	55.9
11	53.8	60.9	64.6	56.9	64.5	71.3	67.6	68.5	68.0	54.5	69.5	78.0	68.3	60.7	58.0
Time Period 3															
12	57.9	62.7	65.2	59.1	67.1	72.1	66.7	68.3	67.1	54.8	68.6	76.4	68.0	63.2	59.9
13	62.6	65.0	67.5	64.3	72.2	76.3	71.6	72.3	71.2	58.7	72.5	79.1	71.0	67.1	62.4
14	44.6	46.5	54.7	48.6	61.6	67.8	60.6	61.2	60.2	51.1	62.2	72.3	58.0	55.0	59.7
15	43.1	47.4	55.2	49.8	59.9	66.7	61.3	62.0	61.0	49.8	63.7	73.2	58.0	55.1	57.0
16	42.0	45.2	54.9	48.5	59.3	65.0	61.9	62.4	61.8	51.6	64.0	73.1	58.7	54.4	53.5
17	52.8	50.1	56.5	53.9	62.3	66.4	61.0	61.6	60.9	48.7	61.2	69.7	60.7	58.5	57.1
18	33.6	--*	45.7	42.8	55.0	60.9	54.8	54.6	53.9	46.2	56.6	67.8	47.4	47.3	54.5
19	31.9	--	46.9	41.1	53.5	60.3	55.4	56.0	55.3	46.1	57.8	69.2	50.7	48.9	52.7
20	48.1	--	56.4	50.7	61.0	67.2	60.7	61.8	61.0	47.4	63.0	72.4	60.7	56.2	53.8
21	38.5	--	50.5	46.3	59.2	65.8	59.8	59.9	59.2	49.3	61.9	71.8	55.3	53.4	55.6
22	32.0	--	48.1	45.3	45.3	54.5	63.3	57.9	58.6	58.1	48.0	61.4	72.3	50.2	54.3
23	29.0	--	45.1	39.4	53.8	61.2	56.9	57.3	57.1	47.5	60.6	71.1	52.2	47.6	53.0
24	27.3	--	41.8	37.6	48.6	52.0	50.8	52.2	52.3	45.6	55.0	63.8	48.9	44.4	52.2
Averages for each time period															
Time Period															
1	29.5	33.6	48.1	40.0	53.9	60.8	56.8	57.9	57.5	49.5	60.1	70.4	52.2	50.5	53.8
2	38.4	42.5	52.7	46.1	57.6	64.8	60.1	61.1	60.4	50.3	62.9	73.2	55.2	53.0	55.0
3	41.8	--	53.0	48.3	59.1	65.0	60.0	60.6	59.9	49.6	62.2	71.7	57.2	53.9	55.8

* Outside black globe was blown off of its mounting by a high wind.

Table 16. Daily average psychrometric conditions for experiment 1.

DATE	DRY-BULB (F)	WET-BULB (F)	DEW-POINT (F)	RELATIVE HUMIDITY (PERCENT)	SPECIFIC HUMIDITY lb water / lb dry air
Time Period 1					
11-26-70	52.8	46.0	40.5	59.6	.0050
27	49.3	43.9	39.3	65.6	.0048
28	52.4	47.4	43.5	69.5	.0058
29	60.3	51.4	45.7	56.2	.0061
12- 1-70	67.6	56.4	48.5	49.5	.0073
2	64.4	57.7	53.7	66.9	.0090
Time Period 2					
6	58.7	53.2	49.8	70.3	.0074
7	52.5	47.6	44.1	71.8	.0059
8	54.5	50.0	46.8	75.2	.0068
Time Period 3					
9	58.8	55.1	53.0	79.8	.0084
10	58.8	54.2	51.2	74.7	.0079
11	42.6	40.2	38.0	81.9	.0047
12	43.2	40.7	38.8	83.8	.0052
13	51.9	47.3	43.9	72.4	.0059
14	54.5	47.9	43.0	62.5	.0057
Time Period 4					
15	56.0	52.3	50.1	78.9	.0075
16	51.0	47.9	45.7	80.3	.0064
17	56.3	52.9	50.9	80.7	.0080
18	47.9	45.8	44.1	85.6	.0060
19	47.2	43.1	39.7	73.0	.0050
20	47.6	43.8	40.6	74.3	.0051
21	48.8	45.4	42.9	78.0	.0057
22	52.1	47.3	43.6	70.9	.0059
23	46.9	41.7	36.9	64.9	.0044
24	49.1	42.7	37.0	60.0	.0044
25	46.2	39.9	32.7	58.5	.0038
26	51.6	46.2	41.6	66.2	.0055
27	51.6	48.3	46.0	79.6	.0065
28	51.7	47.7	44.9	76.9	.0062
Time Period 5					
29	51.3	47.8	45.3	78.3	.0064
30	50.0	46.9	44.7	80.2	.0061
31	51.5	47.2	44.0	73.9	.0060
1- 1-71	55.6	49.6	45.5	66.4	.0062
2	48.7	43.5	39.1	66.4	.0048
3	40.2	36.6	32.4	73.1	.0038
4	35.5	32.0	27.6	70.2	.0031
5	37.7	34.4	30.6	74.7	.0035
6	35.3	32.4	28.9	76.5	.0032
7	38.8	34.8	30.1	70.1	.0034
8	40.4	36.6	32.2	69.9	.0038
9	48.3	42.2	36.4	60.9	.0044
10	48.4	42.0	35.8	59.1	.0042
11	40.5	37.1	33.4	73.5	.0039
12	34.8	31.6	27.4	72.5	.0030
13	41.0	36.9	32.3	68.2	.0037
14	39.1	35.5	31.6	72.0	.0036
15	40.8	35.9	30.2	63.3	.0034
16	46.8	41.4	36.3	63.6	.0043
17	46.9	41.8	37.2	65.9	.0045
Averages for each time period					
Time Period 1	59.8	52.1	46.7	60.5	.0067
Time Period 2	55.2	50.3	46.9	72.5	.0067
Time Period 3	51.6	47.5	43.1	75.8	.0063
Time Period 4	50.3	46.1	42.6	73.4	.0057
Time Period 5	43.6	39.3	35.1	69.9	.0042

Table 17. Daily average psychrometric conditions for experiment 2.

DATE	DRY-BULB (F)	WET-BULB (F)	DEW-POINT (F)	RELATIVE HUMIDITY (PERCENT)	SPECIFIC HUMIDITY lb water / lb dry air
Time Period 1					
2-23-71	57.3	49.9	44.6	59.9	.0059
24	59.3	55.1	52.3	79.5	.0083
25	60.3	53.2	48.8	63.3	.0070
26	58.5	49.8	43.5	54.0	.0056
27	59.3	49.1	41.3	47.8	.0051
28	56.9	48.2	41.3	53.2	.0051
3- 1-71	56.7	48.4	42.2	54.7	.0053
2	52.5	44.6	37.7	53.0	.0044
3	56.2	47.3	40.1	50.8	.0049
Time Period 2					
4	58.2	49.5	42.6	53.8	.0056
5	59.2	50.3	44.1	54.1	.0057
6	57.3	48.1	40.9	50.7	.0050
7	58.4	48.3	40.4	47.6	.0049
8	60.0	48.8	40.0	43.7	.0048
9	59.0	50.6	44.6	55.5	.0059
10	63.1	52.4	45.3	49.0	.0059
11	68.0	54.5	46.0	42.6	.0060
Time Period 3					
12	67.1	54.8	47.1	46.5	.0063
13	71.2	58.7	51.8	48.1	.0076
14	60.2	51.0	44.6	53.6	.0059
15	61.0	49.8	41.4	45.0	.0050
16	61.7	51.6	44.5	50.9	.0058
17	60.9	48.7	38.8	40.5	.0045
18	53.9	46.2	39.7	55.3	.0048
19	55.3	46.1	38.2	49.3	.0045
20	61.0	47.4	35.1	33.9	.0038
21	59.2	49.3	41.9	49.0	.0052
22	58.1	48.0	39.9	46.9	.0048
23	57.1	47.5	39.6	48.2	.0047
24	52.3	45.7	40.3	60.4	.0050
Averages for each time period					
Time Period 1	57.5	49.5	43.5	57.4	.0057
Time Period 2	60.4	50.3	43.0	49.6	.0055
Time Period 3	59.9	49.6	41.8	48.7	.0052

WINTER PERFORMANCE AND THERMAL ENVIRONMENT
OF SWINE IN A MODIFIED OPEN-FRONT HOUSE

by

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The objectives of this study were: (1) to compare the performance of swine raised in a modified open-front building during the winters of 1969-70 and 1970-71 to the performance of swine raised in an unmodified building during the winter of 1968-69, and (2) to investigate and report the thermal environment of the modified building during the winter 1970-71.

Animal performance data were obtained from the department of Animal Science for the three winters in question. During the winter of 1970-71 two similar experiments were conducted in the south and north wings of the growing and finishing unit of the Kansas State University swine research facility to investigate the thermal environment of the modified building.

The winter of 1968-69 was the first winter that the unit was used and pig performance was very poor. The liquid manure oxidation ditch often froze which prevented proper operation. For the winters of 1969-70 and 1970-71, the open front of the building was enclosed with a polyethylene film and sheets of plywood. Radiant heaters located over the pigs' sleeping area were thermostatically controlled so that they operated only when the temperature fell below 50 F.

The first experiment was conducted in the south wing and ran from November 26, 1970, to January 18, 1971. The second experiment ran from February 23, 1971, to March 12, 1971, and was conducted in the north wing. The outside air temperature and inside temperatures were recorded. The inside temperatures were at the oxidation pit under the floor, floor level, fourteen inches from the floor, top of the pen partition, at the three exhaust fans, dry and wet-bulb five feet over the center of the pen, black-globe temperature over the pigs' sleeping area, polyethylene film, and plywood front.

It was found that the average daily weight gain was significantly better for swine housed in the modified building (winters of 1969-70, 1970-71) than those housed in the unmodified building (1968-69). Total feed consumption was also less for swine housed in the modified building than those housed in the unmodified building. The swine housed in the modified building required fewer days to reach the final weight than those in the unmodified building. During experiment 1 the average dry-bulb temperature was 52.1° F while the outside temperature was 37.2° F. The average floor temperature was 50.5° F. The temperatures at the exhaust fans were nearly the same as the dry-bulb temperature. The pit temperature was 54.3° F. Average relative humidity was 70.4 percent and the average specific humidity was .0059 $\frac{\text{lb water}}{\text{lb dry air}}$.

During experiment 2 the average dry-bulb temperature was 59.2° F while the outside temperature was 37.7° F. The average floor temperature was 56.9° F and average pit temperature was 54.9° F. The average relative humidity was 51.9 percent and the specific humidity was .0055 $\frac{\text{lb water}}{\text{lb dry air}}$.

This study has shown that growing and finishing swine may be successfully produced in open-front buildings with total slotted floors when modified by enclosing them with clear polyethylene and plywood sheets and installing radiant heaters over the pigs' sleeping areas. Satisfactory operation of the oxidation pit was also achieved in the modified building.