A STUDY OF ENVIRONMENTAL FACTORS IN CALF HOUSING

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ABSTRACT

A STUDY OF ENVIRONMENTAL FACTORS IN CALF HOUSING

By Edward V. Hallahan

This investigation deals with the environmental temperature and relative humidity prevailing within two differently constructed and managed commercial calf houses.

These internal environments are then compared with the outside conditions of temperature and humidity. Recordings were taken and comparisons made during both winter and summer climatic conditions.

One house was of recent construction, with floor, wall, and ceiling insulation. Ventilation was provided by one 14 inch fan which was thermostatically controlled and had thermostatically controlled louvers. Supplemental heat was provided in winter by two 3-kilowatt heaters.

The second house was an old stanchion barn converted for calf rearing. It had no floor, or wall insulation, but the ceiling was insulated with baled straw. Three 19 inch two-speed fans provided ventilation. These were operated by time-clocks but also had thermostats fitted if required. The animals were the only source of heat in this house.

Hygrothermographs were used to get a continuous record

of temperatures and relative humidities inside and outside both houses. Ventilation rates were obtained by measuring the output of the fans. In the case of those operated by time-clock, the length of time each operated was recorded. From these figures the amount of air exhausted from the buildings per hour was calculated.

The amount of supplemental heat supplied during the winter was also calculated by observing and recording the time of operation of each of the heaters.

Heat and moisture production of the animals was estimated from published data and adjusted for the temperatures prevailing.

From the continuously recorded data, temperatures and relative humidities were taken at hourly intervals for one twenty-four hour period and the average for that period then computed. For those average temperatures and humidities then, enthalpies and specific volumes were determined.

A heat balance for both houses was calculated using these data to obtain a sensible heat balance and a total heat balance.

The results of these calculations were then compared and discussed.

From the heat balance calculations, and the study of these diagrams the following conclusions were drawn:

A sensible heat balance is only of practical use where no condensation, freezing, melting or evaporation of moisture takes place.

A total heat balance, using enthalpy difference, will produce an acceptable result under any combination of circumstances and is therefore the better method to use.

A combination of insulation, ventilation, and supplemental heat is required for the proper environmental control of young calf houses.

In the well insulated and ventilated building a cooling effect due to moisture evaporation occurred during the very warm summer days.

In the unheated building serious condensation and freezing occurred during winter on the cold uninsulated components of the structure.

Approved James S. Boyd
Major Professor

Approved [signature]
Department Chairman

A STUDY OF ENVIRONMENTAL FACTORS
IN CALF HOUSING

By

Edward V. Hallahan

A THESIS

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INTRODUCTION

There is very little information on the effect of climate on the growth and survival of dairy calves from birth. Yet mortality among these calves is high.

Infectious agents are probably the primary cause, but climate could well be a predisposing factor.

When dairy herds were small, it was possible to give calves individual attention, and serious losses did not occur. With herd size increasing, and consequently the number of calves, the mortality rate is also increasing. Too, due to the labor position, this individual care is no longer possible.

Table 1 (8) shows the correlation between herd size and calf mortality according to telfarm records.

TABLE 1

Herd size	No. of farms	No. of cows	Calf mortality %
<30	48	1258	11.9
30-49	119	4540	13.8
50-69	69	4053	13.4
70-99	32	2553	15.4
>100	13	1550	18.4

Exposure of newly born calves to sudden changes in temperature, cold drafts, wet and humid conditions are all major contributing causes of calf losses.

The objectives of environmental control then are to reduce the adverse effects of weather, increase growth rate, and improve management efficiency.

Optimum environment is based on the interactions of temperature, humidity and ventilation rate.

Ventilation is required in livestock buildings to remove excess moisture, control temperature and replace stale contaminated inside air with fresh air from outside.

The removal of moisture places the greatest demand on the ventilating system. Since ventilation also involves a transfer of heat, the quantity of air must be controlled to meet the combined requirements for removing moisture and controlling temperature.

In winter it is important to conserve heat produced in the building, in order to reduce the need for supplemental heat. Ventilation is therefore either a balance, or a compromise between the minimum rate necessary to remove moisture and the maximum that can be permitted to control temperature.

Calves produce heat and moisture through their metabolic and respiratory processes, and this must be considered with all other sources in designing environmental conditions.

The total heat produced by calves is in sensible and latent form. Sensible heat is that which is available to heat the buildings. Latent heat is that expelled from the respiratory system as vaporized moisture in the air. It is not available for heating the building.

This moisture does affect the humidity in the building, and must be expelled before it condenses to water.

When the amount of water vapor pressure in the house is greater than outside, there is a vapor movement outward. This movement is usually accelerated when the air temperature inside is higher than outside. Winter conditions speed up this process, and condensation may occur on or in the walls when the moisture-laden air inside comes in contact with a colder surface.

Insulation near the inner surface of the wall would keep its temperature almost the same as the inside environmental temperature, thus reducing or eliminating condensation. A vapor barrier is required on the warm side of most insulating materials to prevent vapor infiltration which would destroy their insulating properties.

Insulating walls, floors and ceilings also prevents the loss of sensible heat from the building by the common laws of heat transfer through these components.

This then reduces the requirements for supplemental heat.

OBJECTIVE

The objective of this research study is to record and analyze climatic data for two differently constructed and managed calf houses.

To show the environmental conditions prevailing outside and within these houses during winter and summer climatic conditions.

To evaluate the environmental conditions to which the calves are exposed in these buildings.

By heat balance calculations to provide information and direction for further investigation, and environmental design, and improvement of calf housing systems.

FUNDAMENTALS AND REVIEW OF LITERATURE

Calves like all higher mammals are homeothermic, and tend to come into thermal equilibrium with their environment. However, it must be remembered that their bodies must remain at an almost constant temperature. The heat loss therefore must equal heat absorption plus heat production. Thus when the environment is hot, dissipation of heat must be accelerated. On the other hand, when the environment is cold, extra heat must be produced and loss to the environment restricted.

Chemical and physical principles utilized to promote the tendency of homeotherms to come into thermal equilibrium with their environment are conduction, convection, and radiation. An animal loses heat by conduction through its skin and excreted material. Heat conduction is the property of a material that allows heat to pass through it, though it may be impermeable to air.

The amount of heat exchanged by conduction is governed by the equation (16):

$$Q = UA\ (T_1 - T_2)$$

Where:

Q = The amount of heat transferred in a given time.

A = Area of cross-section of the body through which the heat moves.

U = The heat transfer coefficient.

$T_1 - T_2$ = The temperature difference between the body and its environment.

Air can circulate around any heating body such as that of the calf, and remove heat by convection. If the heated air is removed quickly by ventilation, other heated air tends to rise. This way moving air cools the animal by convection.

The amount of heat exchanged in this manner is governed by the relation (16):

$$Q = CAV^n (T_1 - T_2)$$

Where:

Q = Heat transferred per hour.

A = Surface area of the animal.

V = Air velocity.

$T_1 - T_2$ = Temperature difference between the animal's skin and the air surrounding the animal.

C = Convection coefficient.

n = A coefficient indicating that heat transferred does not vary directly with air velocity.

Radiation is the transfer of heat by electromagnetic waves across space. A hot body is able to radiate because its electrons and atoms vibrate more rapidly, and hence produce waves which travel away from it. This heat travels from a warmer body to a cooler one. Heat will go from a warm animal to a cold wall, or from a hot wall to a cooler body.

The tendency of a body to be affected by radiation is proportional to its emissivity and this varies with the quality of the surface. Dull surfaces have a high emissivity, and polished surfaces a low. Skin emissivity is 97%. Therefore if the environment is hotter than the body, the skin will absorb 97% and reflect 3% of the radiant heat.

The relation governing the rate of radiant heat transfer is given by (16):

$$Q = ADEF\ (T_1^{\ 4} - T_2^{\ 4})$$

Where:

Q = Rate of heat exchanged.

A = Area of the surface.

D = A constant.

E = Emissivity.

F = Involves the shape of the objects.

$T_1 - T_2$ = Temperature of the bodies between which the heat transfer occurs.

In warm weather an animal's body is maintained at constant temperature by the following physiological factors:

1. The blood is diluted, increasing its volume and thus making it easier for the body heat to be carried to the surface.
2. Pulse rates increase in all sweating species, and decrease in all dry-skinned species.
3. A larger part of the body fat solidifies, reducing metabolism.
4. The adrenal and thyroid hormones stabolize metabolic rates, and nervous activity.
5. Evaporation is an important aid to the bovine animal to adjust to heat stress. Heat energy is

required for the transition of liquid water to vapor and must come from some source by the common modes of heat transfer.

The physiological adjustments for cold climatic conditions are the reverse of those outlined.

1. Blood volume decreases, thus conveying less heat to the surface for dissipation.
2. The insulating properties of the skin are increased by an increase in subcutaneous fat, and a thicker growth of hair.
3. More of the body fat is in liquid form for ready metabolism.
4. Appetite increases. Thyroxine causes more feed to be consumed and speeds the rate at which feed is used and heat produced.

Brody (9) describes the effect of meteorological factors on animals, being by way of many consecutive simultaneous chain reactions involving hormones, enzymes and nutrients. He identifies the thyroid as being directly affected by temperature, and also the pituitary. From this he concludes all other glands controlled by the pituitary to be similarily affected.

Hormones regulate the activities of enzymes, and these regulate the metabolic rates and levels of metabolites. He then concludes that meterological factors exert regulative effects on the levels of hormones, enzymes, metabolites, metabolic rates and consequently on the entire physiology, chemistry and economy of the animal including its agriculturally productive processes.

Ragsdale, Cheng, and Johnston (13) studied the effect of constant temperatures of 50°F and 80°F on the growth rate of calves. Their results showed that all calves apparently made normal growth at 50°F. At 80°F the growth rate and skeletal development of shorthorn calves was depressed. The other breeds on test were found to be more heat-resistant. The humidities during these tests were low; 62% at 50°F, and 54% at 80°F. Also the youngest calves were one month old at the commencement of the trial.

Stewart and Shanklin (14) studying the effect of growth and environmental temperatures on the surface temperatures of beef calves, found that at 50°F both hair and skin temperatures decreased with increasing weight, while at 80°F increasing body weight was associated with increasing hair temperatures but decreasing skin temperatures. Calves in this test were 8 to 10 weeks old when started on the trial.

Yeck (19) reports from his study on the heat and moisture dissipation from beef calves that at 50°F and 80°F both stable heat and moisture increased rapidly from day to day for the first three months. For the remainder of the test the increases were much smaller. He found that stable heat dissipation was almost the same at both temperatures, but stable moisture production at 50°F was only between 50% and 60% of that at 80°F. In this study the relationship of latent heat to total heat ranged from 35% to 39% at 50°F, and 67% to 71% at 80°F.

Accumulation of litter also had an effect on stable heat and moisture. At 80°F, stable heat and moisture were 20% greater on the sixth day after cleaning than they were on the first. At 50°F, this effect was reduced by about one half.

The ages of the calves at the start of this trial ranged from one to three months.

Yeck and Stewart (18) reported that metabolic heat production accounted for 95% of the stable heat dissipation at both 50°F and 80°F air temperatures. They also found that vaporization from the animals accounted for 53% of the total stable moisture dissipation at 50°F, and 72% at 80°F. Vaporization from the bedded area was about the same at both temperatures. At 25 weeks .75 pounds of water per 1000 pound's body weight per hour was given up by the bedded area at 50°F. At 80°F this figure was .83 pounds. At 65 weeks the amount had dropped to .36 and .41 pounds per 1000 pound's body weight per hour respectively.

Many experiments have shown that respiratory evaporative loss is of importance in dissipating heat at elevated environmental temperatures, and suggest that respiration rate is a sensitive indicator of thermal stress in bovine animals.

Kibler and Brody (12) conclusively demonstrated that respiration rate increases with increasing humidities at environmental temperatures greater than 30°C.

Beakley and Findlay (5, 6) suggested that rectal temperatures might be valuable indicators of the ability of animals to withstand thermal stress.

They worked with four-month-old ayrshire calves and subjected them to temperatures of 15, 20, 25, 30, 35 and 40°C at low humidity (17 mg. per litre absolute humidity) and at temperatures of 30, 35 and 40°C at high humidity (7 mg. per litre saturation deficit).

They studied the rectal, skin, ear, and scrotal temperatures of these calves, also their heart beat and respiration rate under these conditions.

They found that rectal temperatures rose with rising environmental conditions and time of exposure. Also, increasing the humidity from the low to the high figure at 30°C was equivalent to raising the temperature by 4°C. At 35°C, raising the humidity was equivalent to a rise of 9°C in environmental temperature. Increasing the humidity at 40°C caused rectal temperatures to raise at the rate of 3°C per hour.

The frequency of respiration of all calves increased with increasing temperatures and humidity. The general behavior of respiration rate at high humidity at 30°C and 35°C was similar to that at low humidity but the actual values were higher. The results showed that 30°C and 35°C at high humidity had the same effect as 33°C and 46°C at low humidity.

These equivalent temperatures are almost the same as those for rectal temperatures. High humidity at 40°C caused increased panting and profused salivation.

The heart rate of all animals increased with increased environmental temperatures above 20°C, and with increased humidity above 30°C. The effect of high humidity at 35°C was to increase the rate by 34 beats per minute. High humidity at 40°C gave increases up to 136 beats per minute.

Skin, ear, and scrotal temperatures were all found to increase with increasing temperatures, humidities and time of exposure. However, they concluded that those temperatures, and the heart rate were unreliable as indicators of heat tolerance in cattle.

All the proceeding work and in fact most of the environmental studies done with calves were found to be oriented towards the investigation of the effects of high environmental conditions on these animals.

Blaxter and Wainman (7) then, are among the very few that studied the effect of cold environmental conditions on calves.

They subjected two and a half year old steers to temperatures of -5, 5, 15, 25 and 35°C with humidities varying from 40% to 90% approximately.

From their studies they established a critical cold temperature for calves, associated with different levels of nutrition, Table 2.

TABLE 2

Plane of feeding	Critical temperature °C
Maintenance	5.7 to 6.8
Sub-maintenance	11.1 to 12.1
Fasting	17.8 to 18.4

They observed shivering in the animals at temperatures of 5°C and -5°C and respiratory distresses to occur at 35°C.

Heat production change was minimal at environmental temperatures of 15°C to 25°C, but was markedly increased at -5°C and at 35°C, Table 3.

The relationship of latent heat to total heat also increased with increasing temperatures, being 30% of the total heat at 15°C and 53% at 25°C. Total heat production at maintenance level of feeding was only 50% of that at full feeding.

They also found that rectal temperatures increased at 35°C. Trunk surface temperatures to be reduced at low temperatures, and evidence of cutaneous vaso-constriction between 5°C and 15°C.

From their observations they concluded that the animals appeared most comfortable at 25°C.

Witzel and Heizer (17) observed that calves that were adjusted to the environment showed no effect when housed in a loose-housing cow shed where the temperature dropped to

TABLE 3*

Heat emission of steers 528 Kg. (K. cal. per 24 hours)

Nutritional level	Environmental temperature °C	Total	Water vapor	Radiation convection conduction	Heat of warming food and water	Storage of heat in body
	-5	14,866	1,804	12,580	482	---
	5	13,030	2,513	9,912	605	---
Maintenance	15	12,518	3,799	8,175	544	---
	25	12,452	6,598	5,403	451	---
	35	13,319	10,542	2,119	310	348
Sub-maintenance	-5	14,620	1,896	12,401	323	
	19	10,583	2,720	7,483	380	

*Blaxter, K. L. and Wainman, F. W. 1960. Environmental temperature and energy metabolism and heat emission of steers. Journal of Agric. Science, 56:81-90.

$0^{\circ}F$ and lower.

They did however find that the ears of newly born calves froze under those conditions.

No study has been done to determine an optimum temperature for young calves.

Cargill (10) suggests $55^{\circ}F$ as being the minimum practical temperature for moisture removal, with a reasonable amount of air movement in the calf house. Colder air has very low moisture holding capacity therefore too much should be removed to prevent condensation.

Again too much insulation or supplemental heat would be required to maintain a temperature much above $55^{\circ}F$.

Weller (15) recommends a temperature of $15^{\circ}C$ ($59^{\circ}F$) for a calf rearing house.

For the first few weeks of the calf's life he suggests the temperature in the house should be up to $20^{\circ}C$ ($68^{\circ}F$).

From experimental data to date, a wide range of temperatures from $43^{\circ}F$ to $77^{\circ}F$ with moderate humidities is suitable for calves.

High humidities have the same effect as increasing temperatures and therefore have detrimental effects when associated with high temperatures.

CONSTRUCTION AND MANAGEMENT OF HOUSES

Environmental conditions were studied in two commercial calf houses. For convenience these shall be referred to hereafter as House A and House B.

House A

This house is on the farm of Mr. L. Ormston, St. John's, Michigan. It is an L-shaped house constructed within an existing barn.

The lay-out is shown in Figure 1. The outside of the walls is constructed of 3/4 inch tongued-and-grooved boards. Inside there are 3 inches of blanket insulation protected on the inside by a sheet of plastic film. The inside then is sheathed with 1/2 inch plywood.

The ceiling is reconstructed from the existing haymow floor of 1 inch boards over joists by adding 3 inches of blanket insulation underneath, putting a plastic film below this, and then sheathing the under side with 1/2 inch plywood.

All through the year there was some 15 feet of baled straw on the mow floor giving extra insulation to this ceiling. The floor is of 4 inch poured concrete on the ground. It has 2 inches of perimeter insulation, extending down two feet from the floor level.

There are four small single pane windows on the two external walls, and one door that opens into the outer barn.

Two fans are situated in the west wall for ventilation. One is 14 inches in diameter and runs both winter and summer. The second is a large fan designed for summer ventilation. Both fans are thermostatically controlled and have thermostatically controlled louvers. The thermostats for these are centrally located in the house.

Supplemental heat is supplied by two 3 kilowatt electric heaters, placed in opposite corners of the house. Operation of these heaters is also controlled by thermostats.

Light is provided by seven 100 watt bulbs, in addition to the windows.

The floor area of this house is 826 square feet. It has four individual pens for newly-born calves, and two large group pens.

Straw is used for bedding and is allowed to accumulate in the two large pens for several months.

During the winter test period there were 11 calves in the house; 2 in the individual pens, 4 in one large pen, and 5 in the other.

For the summer test period there were 15 calves in the house; 2 in the individual pens, 6 in one large pen, and 5 in the other.

The aim is to maintain the temperature in this house at 50°F at all times. A low ventilation rate was maintained all through winter for moisture removal. One louver on the inside of the small fan is manually controlled. In summer

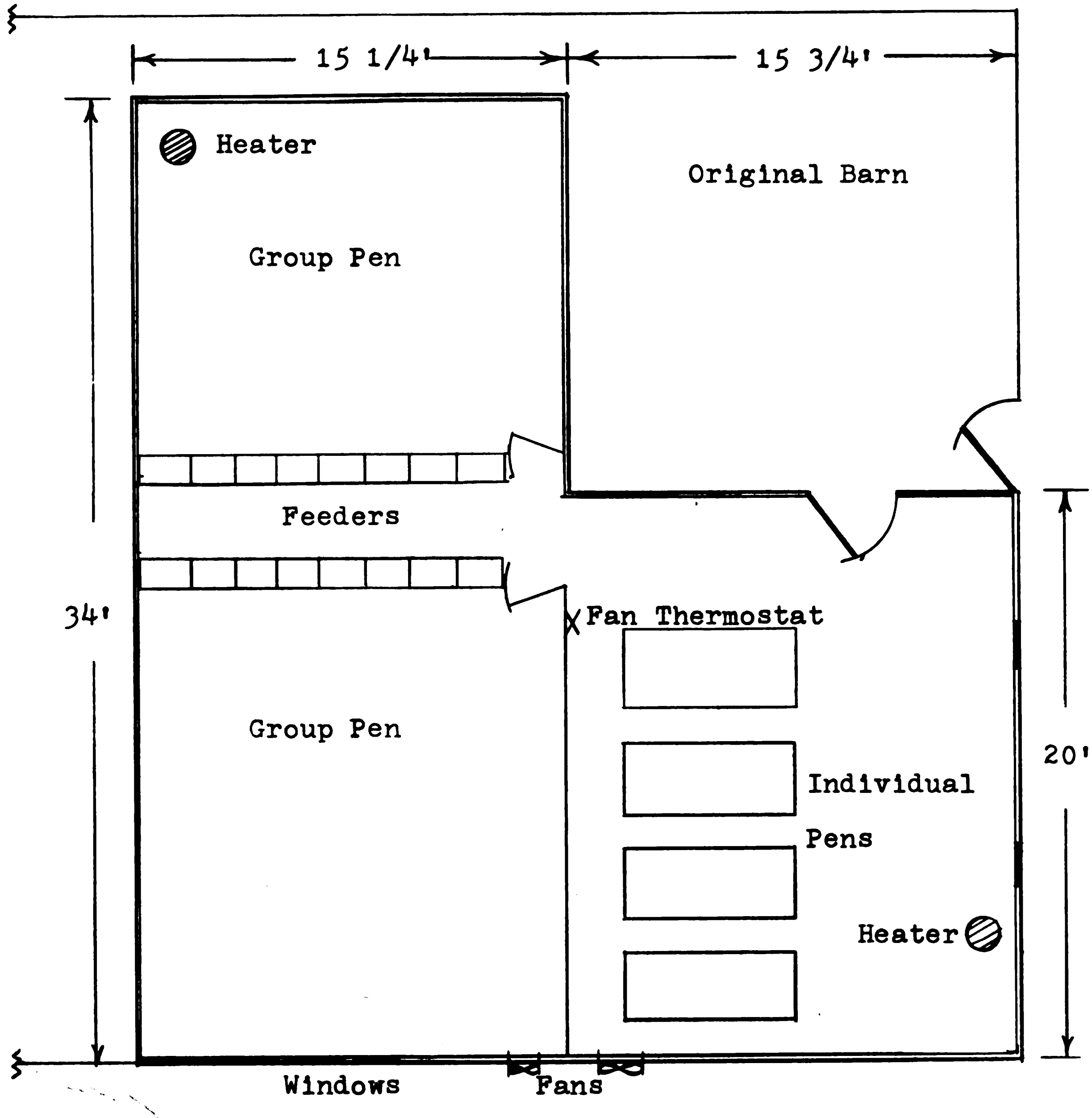


Figure 1. Layout of House A Showing Position of Heaters, Fan Thermostats and Fans.

Figure 2. Exterior View of Barn Surrounding House A.

Figure 3. Interior View of House A.

all the other fan louvers operate from the thermostat for temperature control.

There is an automatic waterer in both of the large pens.

House B

This house is on the farm of Mr. Green at Elsie, Michigan. It is an old stanchion type barn, with hay-mow overhead, converted for calf rearing. The floor is of poured concrete, with no insulation.

The base of the walls is also of concrete construction one foot thick. This extends up to two feet above the floor level. On top of this the regular wall is constructed of 3/4 inch drop siding, studs, building paper, and sheathed inside with 3/4 inch tongued-and-grooved boards.

The ceiling in this house is again the hay-mow floor, that is 1 inch boards on joists. The only insulation in this case was some 15 feet of baled hay on this, throughout the winter.

There are 28 single-pane windows in the house, amounting to 161 square feet of glass.

There are six doors, one large one on each end of the building and four small ones, two of which open into milk and meal stores off the main building.

Light in addition to the windows is provided by twenty 100 watt bulbs.

Winter ventilation in this house is supplied by three

19 inch two-speed fans. All three are placed in the east wall of the building. Operation of these fans can be controlled by thermostats or time-clock. During winter, operation was on a time basis to provide ventilation for moisture removal regardless of the temperature.

The air is drawn into the building through eight ventilators, five of these are on the west side of the house, and three on the east.

In summer all windows, and doors are opened in addition to the fans for ventilation purposes.

Most of the calves are in individual pens in this house. These pens are 4½ feet by 2½ feet with slatted floors about 9 inches off the concrete floor.

There are also four large group pens at one end of the building for the older calves. Straw is used for bedding all calves, even those on the slats in the individual pens.

During the winter test period there were 78 calves in the house. This number was up to 121 for the summer.

The only heat in this house is that produced by the calves and a small amount from the light bulbs.

The internal layout and fan positions in this house are shown in Figure 4.

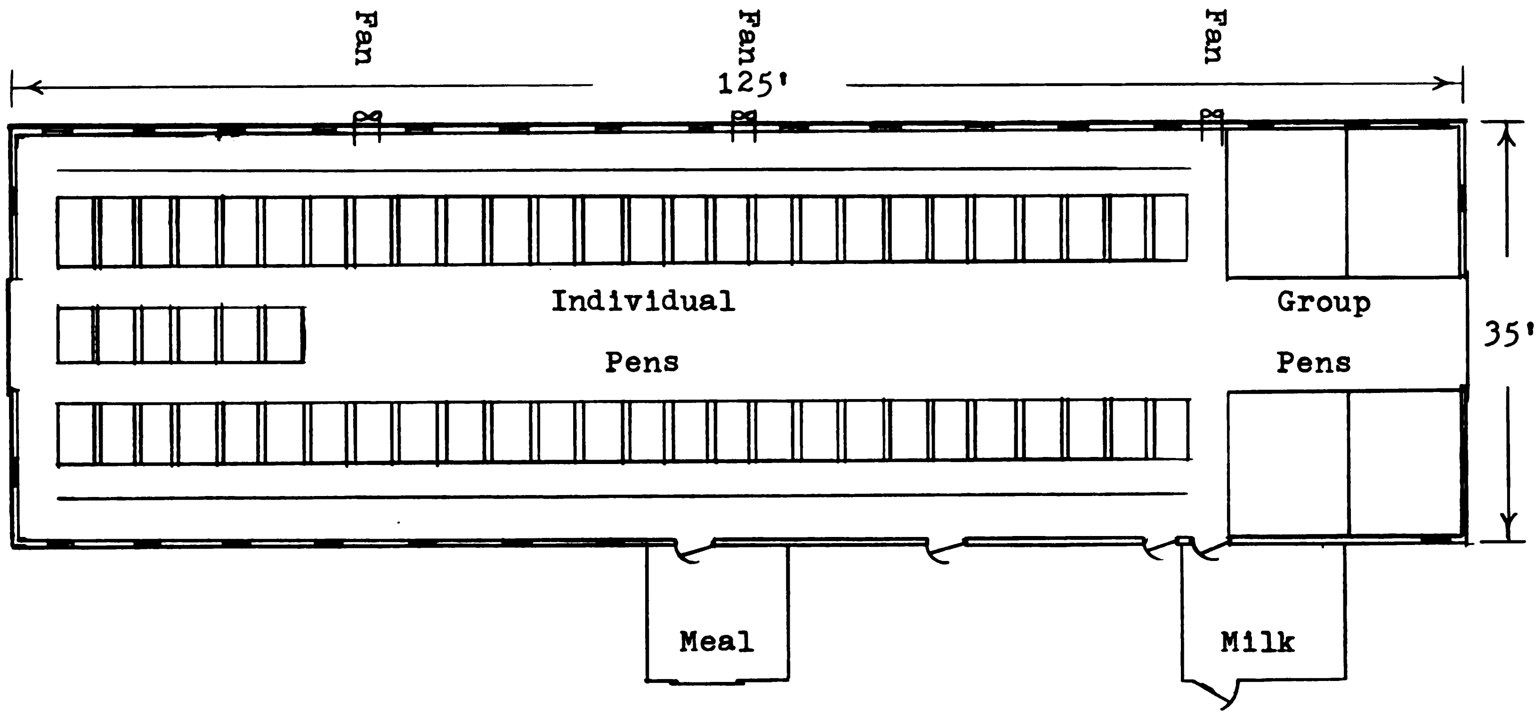


Figure 4. Layout of House B Showing Individual and Group Pens, and Fan Positions.

Figure 5. Exterior View of House B.

Figure 6. Interior View of House B Showing Individual Calf Pens.

INSTRUMENTATION

Temperature and Relative Humidity

Hygrothermographs were used inside and outside the houses to provide a continuous record of both temperatures and relative humidities.

In the case of House A a third instrument was placed in the shed surrounding two sides of the calf house. This was done to record the conditions there and then check the variation if any between those and the outside conditions.

Two hygrothermographs were used inside House B due to its size to record any differences that might occur from one end to the other.

All instruments, when taken out on the farm locations were put in the one place recording the same conditions for the first twenty-four hours. During this period the calibration of each instrument was checked a number of times to ensure that all were recording the same.

A certified thermometer was used to check temperatures, and a sling psychrometer to check the relative humidity.

Daily charts were used during all the recording periods to get a detailed continuous record of the environmental conditions. When the charts were changed each day, the instruments were again checked with the thermometer and psychrometer. This was necessary as it was found at the start that any sudden movement could alter the pen setting on these instruments.

Inside the houses instruments were placed about four to five feet high. This was out of reach of the calves, and corresponded to the level of the exhaust fans approximately.

Outside, they were placed in an open shed and about six to seven feet high. In this they were protected from the weather in winter and from the direct rays of the sun in summer. They were also roughly on the same level as the air inlets to the buildings though some distance away.

Ventilation

Air flow through the houses was arrived at by measuring the output of the fans.

Both a vane annemometer and a velometer were used for this. This was found necessary as in some circumstances one or other of them could not be operated. Where it was possible both were used as a check on the accuracy of the instruments and the readings.

Using the grill on the face of the fan as a guide, sixteen independent readings were taken on each fan, Figure 7. The average output in feet per minute was then computed and this multiplied by the effective area of the fan gave the output of air in cubic feet per minute (C.F.M.). This method was used for the three fans in House B and for the fan in House A in the summer.

In winter there was only ½ inch opening underneath the lower louvre of the fan in House A. The other louvres which were thermostatically controlled were all closed. With this situation and such a low ventilation rate it was impossible to get an accurate reading on the outside of the fan. The output in this case then was obtained by attaching a suitable probe to the velometer and placing this in the ½ inch opening from the inside. The area of this opening was then used to calculate the output in cubic feet per minute from the building.

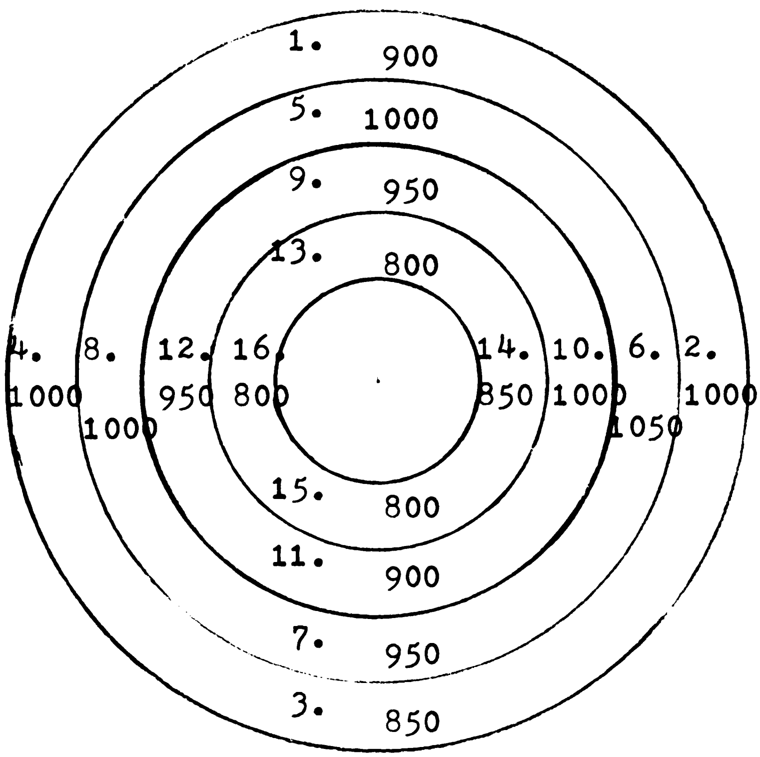


Figure 7. Air Velocities at Various Points on Outside of Fan.

CALCULATIONS

Housing for young calves should be designed to provide a comfortable environment inside the house through varying outside climatic conditions. This should also be possible with varying stocking densities within the house.

To achieve this in a building economically usually requires a combination of insulation and ventilation. It also requires supplemental heat in many cases.

Balancing insulation and ventilation requirements is achieved by solving heat and moisture equations for the particular conditions. The ventilation rate to remove the moisture produced in the house is based on a moisture balance. That is, the rate of moisture removal by ventilation air must equal the rate of moisture production within the structure.

When a building is ventilated, there is heat lost through the ventilating air. To compensate for this, insulation can be put in the walls, floor, ceilings, etc. to reduce the heat loss through these components. The problem resolves itself then into a balance between insulation and ventilation requirements.

In many cases particularly that of young stock, it is not practical to achieve this balance without the addition of supplemental heat. A heat balance gives the required information on heat loss, heat produced, and heat required for a particular set of conditions.

This type of balance is calculated in this study for both houses under winter and summer conditions.

There are two methods of computing a heat balance, viz:

(a) Calculating a total heat balance using enthalpy change

(b) Calculating a sensible heat balance using temperature change only.

In this investigation both methods will be used and the results compared. The calculations are made on average hourly temperatures for a twenty-four hour period during winter and summer. Temperatures and relative humidities were recorded each hour from 8 a.m. one day to 8 a.m. the next day, by continuous hygrothermograph recordings, and the average computed for the twenty-four hour period.

Where supplemental heat was supplied, the heat added for the same twenty-four hour period was recorded and an hourly average heat production calculated. The fan outputs were measured to get the ventilation rate or the air exhausted from the buildings.

Winter House A

Heat and Moisture Production

The environmental temperature in this house throughout the winter period is almost constant at 50°F. Based on the work done by Yeck (19), already mentioned, the following figures for heat and moisture production by calves at this temperature were used in computing the heat balance.

Total stable heat production at 50°F per 1000 lb. body weight	4700 BTU/hr.
Latent heat production at this temperature, per 1000 lb. body weight	2200 BTU/hr.
Sensible heat production per 1000 lb. body weight	2500 BTU/hr.

This figure for latent heat is the equivalent of 2 lb. of water per 1000 lb. body weight.

As the bedding is allowed to accumulate in the house for a considerable period of time, stable heat and moisture figures are used, rather than those for animal heat and moisture production.

Stable heat is that dissipated by the animals and their bedded area. It does not include heat from lights, personnel, or equipment.

Stable moisture refers only to the moisture dissipated by the animals, their bedded area, and their watering devices.

There were eleven calves in the house during this test period.

The total average weight . . . . 2,000 lb.

The total animal heat production . . . . 9,400 BTU/hr.

Total sensible heat production . . . . 5,000 BTU/hr.

Supplemental Heat

Supplemental heat is supplied in this house by two 3 kilowatt electric heaters.

The total heat produced by heaters for the twenty-four hour period . . . . 56.88 K.W. x 3413

The average heat production then is:

$$\frac{56.88 \times 3413}{24} \; . \; . \; . \; . \; . \; . \; . \; . \; . \; . \; . \; . \; . \; . \; . \quad 8{,}060 \text{ BTU/hr.}$$

Typical operation pattern of these heaters for one morning and one afternoon period is shown in Figure 8.

Heat from Light Bulbs

Light is provided in the house by seven 100 watt bulbs, and one meter recorded the total electricity used by these bulbs. From the yearly use of electricity the average hourly heat added by the light bulbs is calculated as follows:

Total electricity used for year . . . . 331 K.W.

Average hourly heat added is:

$$\frac{331 \times 3413}{365 \times 24} \; . \; . \; . \; . \; . \; . \; . \; . \; . \; . \; . \; . \; . \; . \quad 130 \text{ BTU/hr.}$$

As the house is relatively dark inside due to the small window area, the average heat production from the lights is assumed similar all year around.

Heat Loss from the House

Heat is lost from the building according to the known principles of heat transfer through structural components, by ventilation, and by air leakage. Air leakage can be regarded as part of the ventilation and so no further heat loss need be calculated for this.

Heat loss through the walls, ceiling, doors and windows is theoretically calculated when the overall heat transmission coefficient of these components is known (Appendix A) and the inside and outside temperatures. The average temperature in the shed surrounding two walls of this house was only 1°F higher than outside. The outside temperature is then used in computing heat loss through all the components of the building.

The variation in relative humidity was found to be small so the outside conditions are used.

The equation (10) used to calculate the heat loss through the building components is:

$$q = U.A.\Delta T.$$

Where:

q = The heat loss in BTU per hour.

U = The overall heat transmission coefficient of the component.

A = The area of the component in square feet.

ΔT = The temperature difference between inside and outside.

Heat loss through the floor is more difficult to measure when the temperature underneath the floor is not known.

A reasonable approximation can be made however using the formula (3):

$$q = F \times L \times \Delta T + 2A$$

Where:

q = Heat loss in BTU per hour.

F = Factor for floor heat loss included within a three-foot border along the exposed edge in BTU per hour.

L = Length of exposed edge in feet.

ΔT = Temperature difference between inside and outside.

A = Total floor area less an area included within a three-foot border along the exposed edge.

For the outside design temperature the average outdoor temperature for the two weeks prior to the day on which the calculation is made, is used. This is considered a more accurate figure due to the large mass of soil involved. Also, in computing the formula, while the actual outside temperature for the day was used, it happened to be the same as the average for the nine preceding days.

Ventilation Heat Loss

The heat lost by ventilation can be reliably calculated when the rate of air exhausted from the building and the physical characteristics of the air both inside and outside are known.

Knowing the inside temperature and relative humidity, and the outside temperature and relative humidity the enthalpy change and the specific volume of the air is determined from the psychrometric chart. Having this data, the amount of heat removed by the ventilating air is then computed by the formula:

$$q = \frac{CFM \times 60 \times \Delta E}{Vs}$$

Where:

q = Heat removed in BTU per hour.

CFM = Ventilation rate in cubic feet per minute.

ΔE = Enthalpy difference between inside and outside air.

Vs = Specific volume of inside air.

In calculating a sensible heat balance for a building only temperature change between inside and outside air is used.

The formula for calculating the amount of heat removed by the ventilation in this case is then:

$$q = \frac{CFM \times 60 \times .24 \times \Delta T}{Vs}$$

Where ΔT is the temperature difference between the inside and outside air.

As there was only one fan operating at a constant rate all through the winter in this building, the ventilation rate measured as fan output is the total air exhausted from the house.

1. Total Heat Balance

Inside environmental conditions:	Temperature	$50^{o}F$
	Relative humidity	68%
Outside environmental conditions:	Temperature	$12^{o}F$
	Relative humidity	66%

Structural Heat Loss

Structural Component	Area sq. ft.	U Value	ΔT	Heat Loss BUT/hr.	
Wall	927	.075	38	2640	
Door	20.1	.61	38	466	
Windows	16.8	1.13	38	720	
Fan (idle)	2.75	.66	38	69	
Ceiling	824	.0032	38	100	
Floor	.32 x 130 x 30 + 2 x 474			2196	
				Total	6191

Ventilation Heat Loss*

$$\frac{154 \times 60 \times 13.7}{12.95} \ldots\ldots\ldots\ldots \quad 9800$$

Total heat loss 15,991

Heat Production in House

	BTU/hr.
Animal total heat	9,400
Electric heaters	8,060
Light bulbs	130
Total heat production	17,590

*Formula, page 34.

2. Sensible Heat Balance

	BTU/hr.
Structural heat loss	6,191
Ventilation heat loss*	
$\frac{154 \times 60 \times .24 \times 38}{12.95}$	6,500
Total heat loss	12,691

Heat Production

	BTU/hr.
Animal sensible heat	5,000
Electric heaters	8,060
Light bulbs	130
Total heat production	13,190

*Formula, page 34.

Winter House B

Heat and Moisture Production

As the environmental temperature drops below 59°F, sensible heat production increases rapidly, and latent heat production decreases. There is also an increase in total heat production but this is not significant until the temperature drops below 32°F.

The average environmental temperature in House B for the winter test period was 36°F. Total heat production at this temperature is for all practical purposes the same as that at 50°F. Latent heat production however is lower at 36°F, so the sensible heat is higher at this temperature than at 50°F.

Animal heat and moisture production used in calculating the heat balances for this house under these conditions are:

Total stable heat production per 1000 LB body weight	4700 BTU/hr.
Latent heat production per 1000 LB body weight	2000 BTU/hr.
Sensible heat production per 1000 LB body weight	2700 BTU/hr.

The latent heat production for this temperature is equivalent to 1.8 LB of water per 1000 LB body weight.

During this test period there were 78 calves in the house.

Total weight of these	14,500 LB
Total animal heat production in this house is therefore	68,150 BTU/hr.
Sensible heat production under these conditions	39,150 BTU/hr.
Latent heat production	29,000 BTU/hr.
Total moisture production as water	26.1 LB

Heat from Light Bulbs

Average heat production from the twenty 100 watt light bulbs is computed to be 500 BTU/hr. This is assuming the lights are on one hour morning and evening during chore time.

Heat Loss from the House

Structural heat losses from this building are calculated as for House A, again using the standard formula for heat flow through the individual components.

The overall heat transmission coefficients computed for the separate components of this house are shown in Appendix B.

Floor heat loss is again calculated using the same formula as for House A but in this case the F factor has a different value due to the absence of floor insulation.

Ventilation Heat Loss

Ventilation heat loss in this case is also calculated from the amount of air exhausted by the fans. There were three fans operating in this house for the duration of the study. The output of these was measured as previously indicated and the average output calculated to be 1327 C.F.M.

Operation of these fans was controlled by a time clock to maintain a certain ventilation rate regardless of temperature. The time of operation of each one was recorded and then the air exhausted from the building calculated.

Fan No. 1 operated for 3 minutes every 10 minutes.
Fan No. 2 operated for 2.75 minutes every 10 minutes.
Fan No. 3 operated for 4 minutes every 10 minutes.

Typical operation pattern of these fans over a period of time is shown in Figure 9.

Total air exhausted from this house is then:

1327 x 6 x 3 + 1327 x 6 x 2.75 + 1327 x 6 x 4

. . . . 76,300 C.F.H.

Using recorded inside and outside environmental temperatures and relative humidity the enthalpy difference and the specific volume of the inside air, is read from the psychrometric chart. The same equations for heat removal by ventilation are used as in the previous case for both total and sensible heat balance calculations.

1. Total Heat Balance

Inside environmental conditions:	Temperature	36°F
	Relative humidity	70%
Outside environmental conditions:	Temperature	16°F
	Relative humidity	93%

Structural Heat Loss

Structural Component	Area sq. ft.	U Value	ΔT	Heat Loss BTU/hr.	
Wall base	574	.55	20	6310	
Wall upper	1405	.22	20	6182	
Doors	245	.61	20	2990	
Windows	161	1.13	20	3640	
Ceiling	4320	.0033	20	285	
Floor	.8 x 319 x 14 + 2 x 3395			10,360	
				Total	29,767

Ventilation Heat Loss*

$$\frac{76{,}300 \times 6.3}{12.55} \ldots\ldots\ldots\ldots \quad 38{,}250$$

Total heat loss 68,017

Heat Production in House

	BTU/hr.
Total animal heat	68,150
Total from light bulbs	500
Total heat production	68,650

*Formula, page 34.

2. Sensible Heat Balance

	BTU/hr.
Heat loss from structure	29,767
Ventilation heat loss*	
$\frac{76{,}300 \times .24 \times 20}{12.55}$	29,150
Total heat loss	58,917

Heat Production

	BTU/hr.
Animal sensible heat	39,150
Production from light bulbs	500
Total heat production	39,650

*Formula, page 34.

Summer House A

Heat and Moisture Production

Environmental temperatures during the summer test period were high both inside and outside. For the twenty-four hour period used for calculating the heat balance the recorded environmental temperature inside was 75°F.

Again from the work done by Yeck (19) and that of Blaxter et al. (7) it is shown that as the environmental temperature increases, total stable heat also increases. In this case the latent heat production increases rapidly, while the sensible heat production decreases slightly.

From the results of this experimental work the heat and moisture production for this house under summer conditions is:

Total animal heat production at
75°F per 1000 LB body weight . . . . 5,000 BTU/hr.

Latent heat production per
1000 LB body weight . . . . 3,500 BTU/hr.

Sensible heat production per
1000 LB of animal weight . . . . 1,500 BTU/hr.

The latent heat production is equivalent to 3.25 LB of water per 1000 LB of body weight.

During this period the house contained 15 calves.

Total average weight . . . . 3,000 LB

Total animal heat production . . . . 15,000 BTU/hr.

Latent heat production . . . . 10,500 BTU/hr.

Total sensible heat . . . . 4,500 BTU/hr.

Total moisture production
as water . . . . 9.75 LB.

Heat from Light Bulbs

Average heat production from the light bulbs is assumed the same as for winter, that is 130 BTU/hr.

Heat Loss from the House

Heat loss from the structure is again calculated according to the common principles of heat transfer. The equation for this and the overall heat transfer coefficients of the components being the same as those used for the winter calculations.

Ventilation Heat Loss

The heat removed by the ventilation air is also computed as before from the fan output. The air exhausted from the building being the same as the fan output, as only the one operated. Due to the high temperature inside it ran at full speed.

Total air exhausted as
measured by fan output for
these conditions . . . . 2,296 C.F.M.

The average inside and outside temperatures and relative humidities were taken from the continuous hygrothermograph recordings of the summer conditions. The enthalpy difference between the inside and outside and the specific volume of the inside air were then read from the psychrometric chart. From these figures the ventilation heat loss is computed for both total and sensible heat balances using the appropriate equations.

1. Total Heat Balance

Inside environmental conditions:	Temperature	75.7°F
	Relative humidity	76.5%
Outside environmental conditions:	Temperature	75°F
	Relative humidity	70.3%
Average temperature for previous 12 days		71.2°F

Structural Heat Loss

Structural Component	Area sq. ft.	U Value	ΔT	Heat Loss BTU/hr.	
Wall	927	.075	.7	48.6	
Door	20.1	.61	.7	8.6	
Windows	16.8	1.12	.7	13.2	
Fan (idle)	2.75	.66	.7	12.7	
Ceiling	824	.0032	.7	1.9	
Floor	.32 x 130 x 4.5 + 2 x 474			1134	
				Total	1219

Ventilation Heat Loss*

$$\frac{2296 \times 60 \times 1.4}{13.8} \;.\;.\;.\;.\;.\;.\;.\;.\;.\;.\; 13{,}950$$

Total heat loss 15,169

Heat Production in House

	BTU/hr.
Total animal heat	15,000
Light bulb production	130
Total heat production	15,130

*Formula, page 34.

2. Sensible Heat Balance

	BTU/hr.
Structural heat loss	1,219
Ventilation heat loss*	
$\frac{2296 \times 60 \times .24 \times .7}{13.8}$	1,675
Total heat loss	2,894

Heat Production

	BTU/hr.
Animal sensible heat	4,500
Light bulbs	150
Total heat production	4,650

*Formula, page 34.

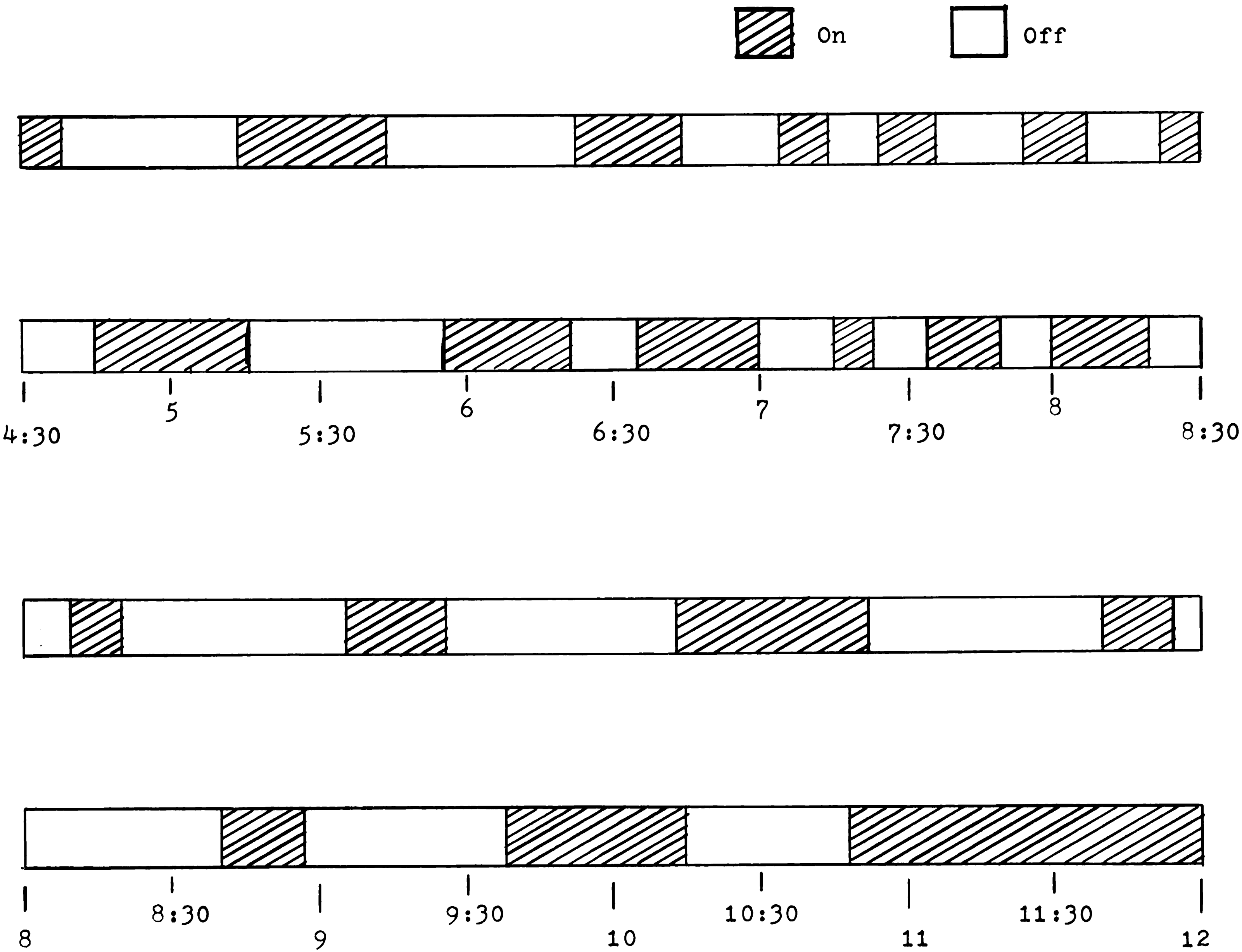


Figure 8. Typical Operation Pattern of the Two Heaters for an Afternoon Period Above, and a Morning Period Below, House A.

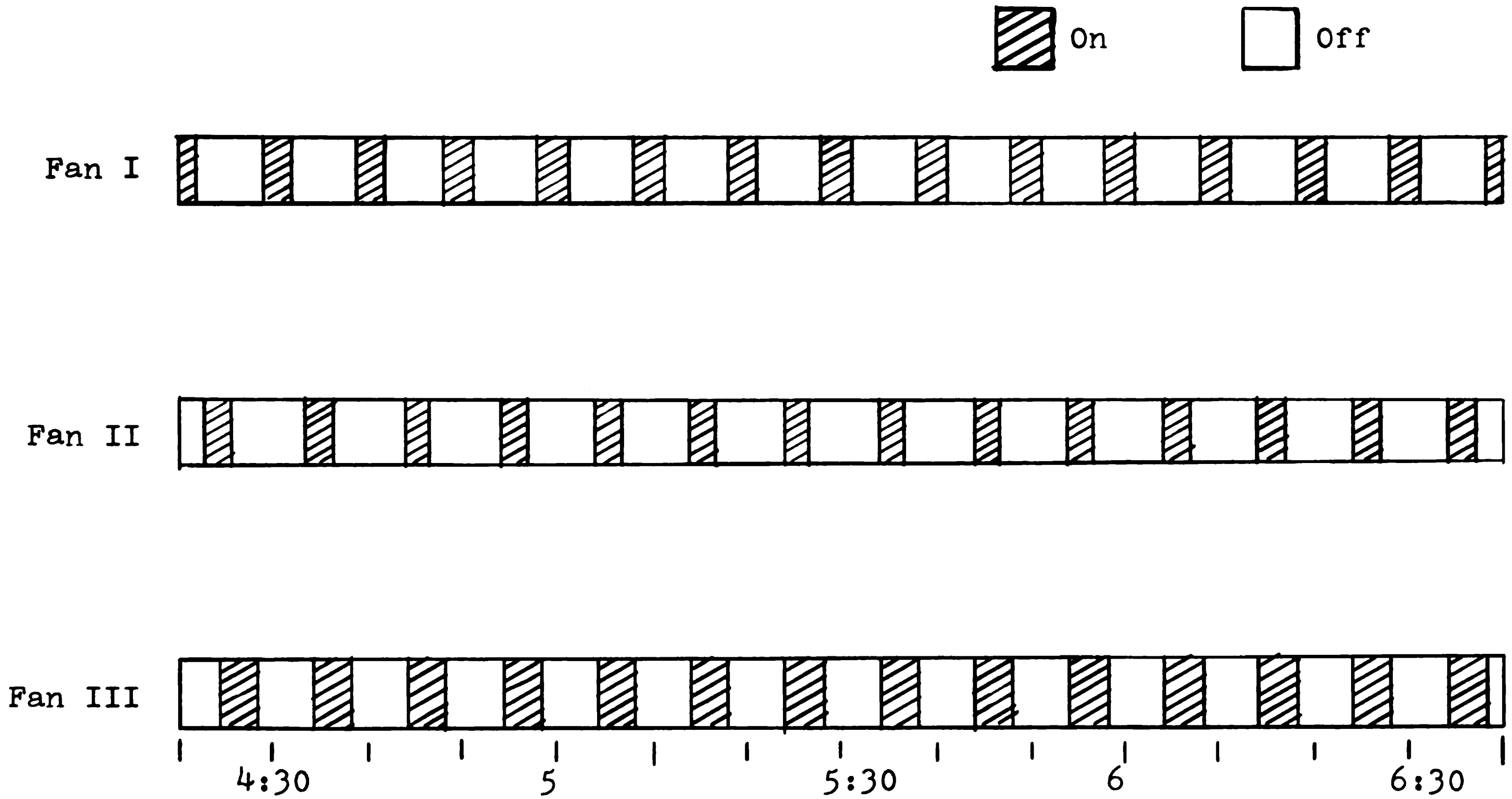


Figure 9. Typical Operation Pattern of the Three Fans When Controlled by Time-Clocks, House B.

DISCUSSION OF HEAT BALANCE CALCULATIONS

In both houses the total heat balance calculations were within an acceptable degree of accuracy for the three different sets of conditions calculated.

Absolute accuracy is not expected in computing heat balances of this type, as the formulas used and the heat production figures are estimates. They are however very acceptable for farm livestock building calculations.

The sensible heat balances unlike the total, only produced an acceptable result in the case of one house under one set of climatic conditions.

A separate discussion on each of the buildings, under the different sets of environmental conditions prevailing is given here to explain why this might occur.

House A (Winter)

Both the total and the sensible heat balance calculations for this house are accurate to an acceptable degree for winter conditions.

Working with the total heat production and enthalpy change the heat loss and heat production figures are within 9% of each other. Using sensible heat and temperature change only the results are within 3.7 percent.

This is apparently due to the excellent conditions in this house during this period. There was no apparent condensation, and no freezing inside. It is assumed then that all the moisture produced was removed by the ventilation.

The only changes in the building therefore were those caused by the sensible heat produced by the animals, and the supplemental heat. All of these are included in the calculation of both the sensible and total heat balances.

It is to be expected then that under these conditions an acceptable balance should be got from both methods.

House B (Winter)

In this house the total heat balance is accurate to a remarkable degree, while the sensible heat balance shows some 19,267 BTU per hour more heat removed than produced.

The explanation for this appears to be condensation and ice formation.

From observations during the test period there was estimated to be ± 1/8 of an inch of ice on the windows. The area of window glass in this house was 161 square feet.

There was also condensation noticed on the concrete forming the bottom two feet of the wall.

The ventilation rate required for moisture removal from a livestock building is calculated according to the equation (9):

$$CFH = \frac{Wp\ Vs}{(We - Wi)}$$

Where:

CFH = Ventilation rate in cubic feet per hour.

Wp = Weight of water produced in LB.

Vs = Specific volume of inside air.

We = Specific humidity of exhaust air.

Wi = Specific humidity of incoming air.

Substituting the conditions prevailing within and outside this house for this period, the ventilation rate required is:

$$\frac{26.1 \times 12.55}{.0012} \; . \; . \; . \; . \; 273,000 \text{ C.F.H.}$$

The actual ventilation rate as computed from the fan outputs . . . . 76,300 C.F.H.

This then is only 27% of what is required for moisture removal. Thus only 27% of the 26.1 LB of water produced is being removed by the ventilation air. This leaves 19.05 LB of water still in the building to cause condensation. Some or all of this may also freeze.

Every pound of water vapor that condenses in this building releases 1074 BTU of heat, Appendix C.

If this pound of water then freezes, it releases a further 144 BTU of heat. Assuming that all the water vapor not removed by ventilation condensed it would release 20,200 BTU of heat per hour. If it all froze also, the total heat production would be 23,200 BTU per hour. This figure would then account for some of the heat imbalance in sensible heat.

The extra heat removed coming from a combination of condensation and freezing of water vapor. This illustrates one shortcoming of calculating using sensible heat production and loss alone. Using this method no account is taken of the moisture present in the air. This can condense and even freeze in some circumstances exchanging latent for sensible heat.

In farm livestock buildings there is always water vapor present. There is also almost always some condensation, or evaporation taking place.

It appears then that only under very ideal conditions within a building is a sensible heat equation likely to balance.

House A (Summer)

Under summer conditions the total heat balance is within the accepted degree of accuracy, while the sensible heat equation is not.

The sensible heat equation in this case shows much more heat being produced than removed. This is the opposite of what appeared under winter conditions in House B.

The actual deficit on the heat loss side being 1750 BTU per hour. While this amount is small, it is however 38% of the total in this case. This deficit may be explained by evaporation.

There is in this case only .7°F difference between inside and outside air temperatures. With the calves producing heat inside, there must be some form of cooling taking place in addition to the ventilation.

Evaporation of water would absorb heat, thus converting to latent form some of the sensible heat produced by the calves which would otherwise raise the inside temperature.

The air flow required to remove the moisture from this house is:

$$\frac{9.75 \times 13.8}{.0011} \quad \ldots\ldots\ldots\ldots\ldots \quad 122{,}000 \text{ C.F.H.}$$

Actual ventilation rate . . . . 137,760 C.F.H.

Amount of ventilation air available for water evaporation is then . . . . 15,760 C.F.H.

This amount of air could evaporate

$$\frac{15{,}760 \times .0011}{13.8} \quad \ldots\ldots\ldots\ldots\ldots \quad 1.25 \text{ LB of water}$$

The amount of sensible heat converted to latent form by evaporation of this amount of water is

1.25 x 1050 . . . . 1315 BTU/hr.

This figure added to the total heat loss figure computed in the sensible heat equation would bring the balance within 10%.

Another complication in this case is that the temperatures inside and outside the house are almost the same. In Figure 18 it is seen that the outside temperatures are 8°F higher than inside for part of each day. Under these circumstances the heat transfer would be in the opposite direction. That is, into the building. Thus each day during this hot summer weather the building is losing heat during the night and early morning and gaining heat during the rest of the day. It is difficult under these circumstances to expect a high degree of accuracy in computing a heat balance.

House B (Summer)

No heat balance calculations were possible for this house during the summer, as all windows and doors were opened in addition to the fans making ventilation measurements impossible. Therefore no figure could be calculated for air exhausted from the building.

Only observations of the temperatures and relative humidities are made from the hygrothermograph records. These are discussed in connection with Figures 22 through 25 inclusive.

TEMPERATURE AND HUMIDITY OBSERVATIONS

Winter House A

Recording started in this house on January 14th at 4 p.m. and continued to 12 noon on January 19th. The instruments were then moved to House B and were returned again on February 10th. Further data was then recorded from 8 p.m. on the 10th to 12 noon on the 12th of February.

A continuous low ventilation rate of 154 C.F.M. was used throughout the winter. Two 3 kilowatt heaters thermostatically controlled provided supplemental heat.

There were 11 calves in this house throughout the recording period; total average weight of those was 2000 pounds.

The heater thermostats were set to maintain a temperature of 50°F at all times. Figure 10 shows how well this was achieved. Only from 12 a.m. to 12 noon on the 17th of January did the temperature vary more than 2°F from this setting. This coincided with a severe storm on that morning, with winds of 45 m.p.h. from the west.

The ventilators in this building also opened to the outside on the west wall.

Outside temperatures varied from -4°F to 34°F for the recording period. The inside temperature appears to settle around 48°F when the outside temperature is very low. This is the only indication of any correlation between the inside and outside temperatures.

The relative humidity inside for this period however shows more of a relationship to the outside humidity, Figure 11. The inside humidity follows roughly the same pattern as the outside but does not fluctuate to nearly the same degree.

Outside humidity for the period varies from 52% to 81% while inside humidity varies from 54% to 77%. However only for approximately 12 hours in the seven days is the inside humidity greater than 70%. Where this occurs on February 11th it follows a period of very high outside humidity. This could be the position at the start also, which is the only other time it exceeds 70% inside, but this is prior to the start of recording.

The fluctuations in outside humidity within any one day, or from day to night conditions is much greater than inside.

Maintaining an inside humidity between 54% and 70%, with reduced short term fluctuations, and a temperature of 50°F indicates very acceptable conditions for the calves.

Figure 12 shows the conditions of temperature and humidity prevailing outside during the test period. Apart from one twenty-four hour period from 12 noon on the 16th to 12 noon on the 17th of January when the humidity varied considerably, both temperature and relative humidity follow the expected pattern. As the temperature increases, the humidity decreases and as temperature decreases, humidity increases.

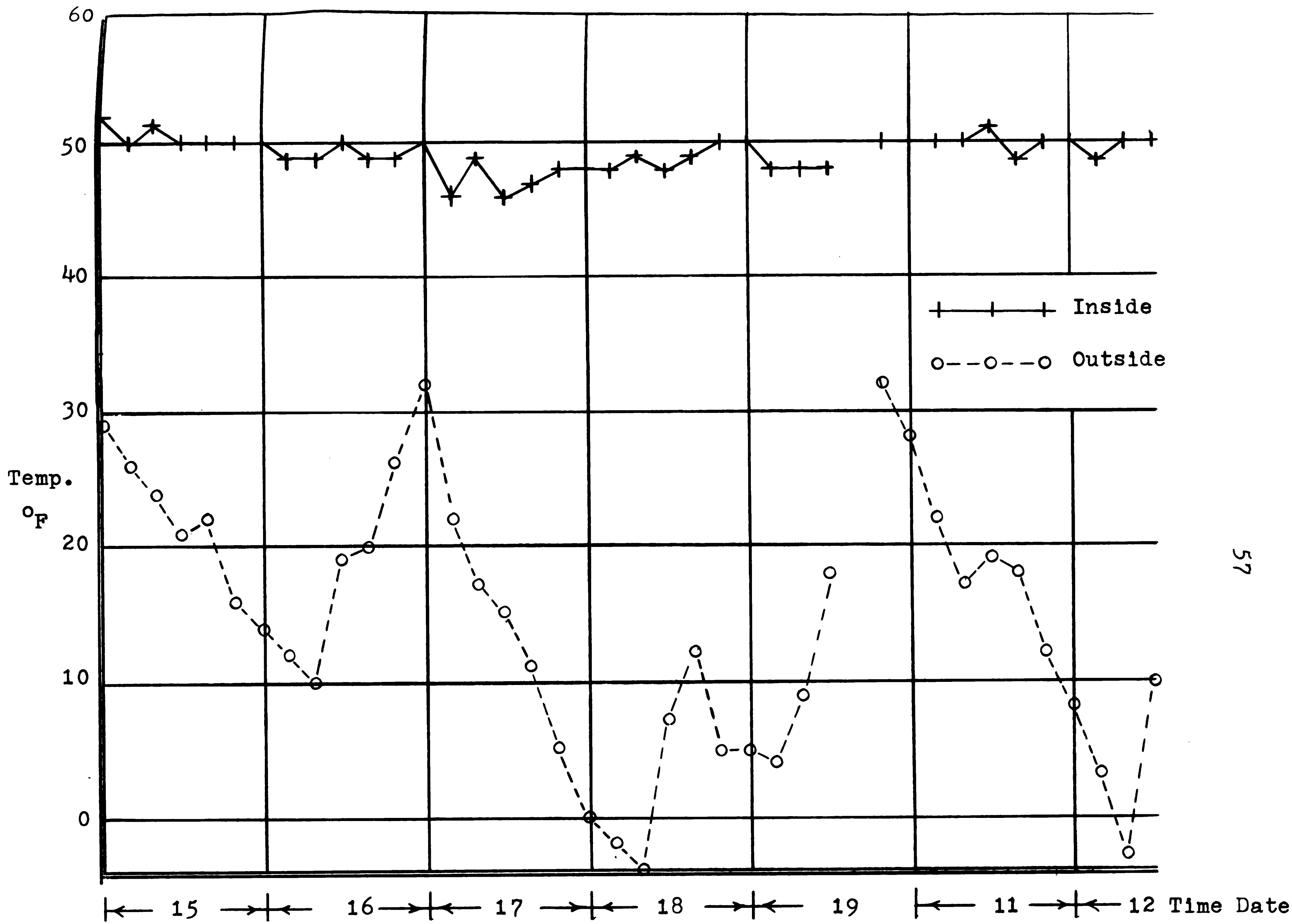


Figure 10. Curves Showing the Temperature Inside and Outside From January 15th to 19th and on February 11th and 12th, House A.

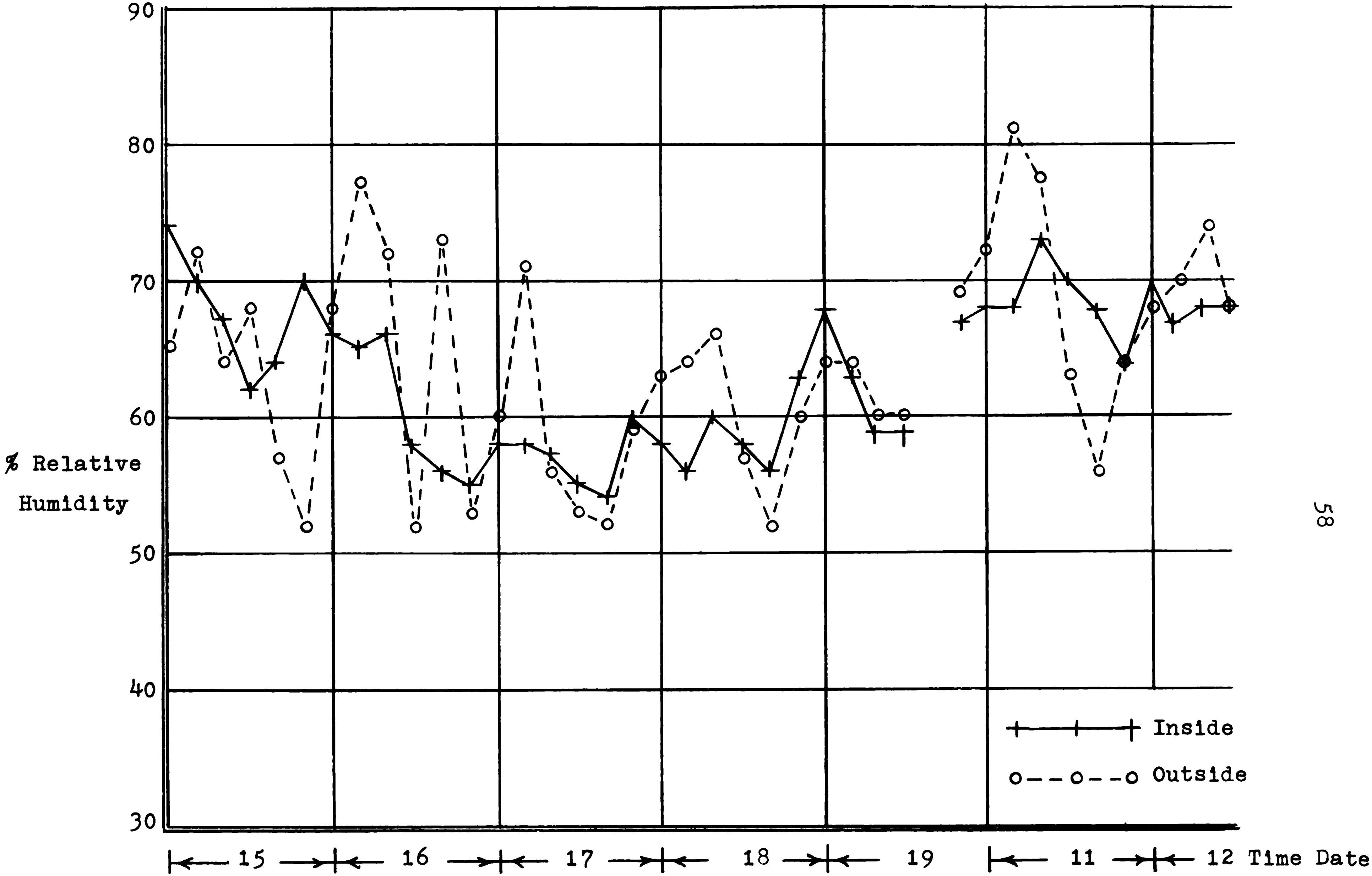


Figure 11. Curves Showing the Relative Humidity Inside and Outside From January 15th to 19th and on February 11th and 12th, House A.

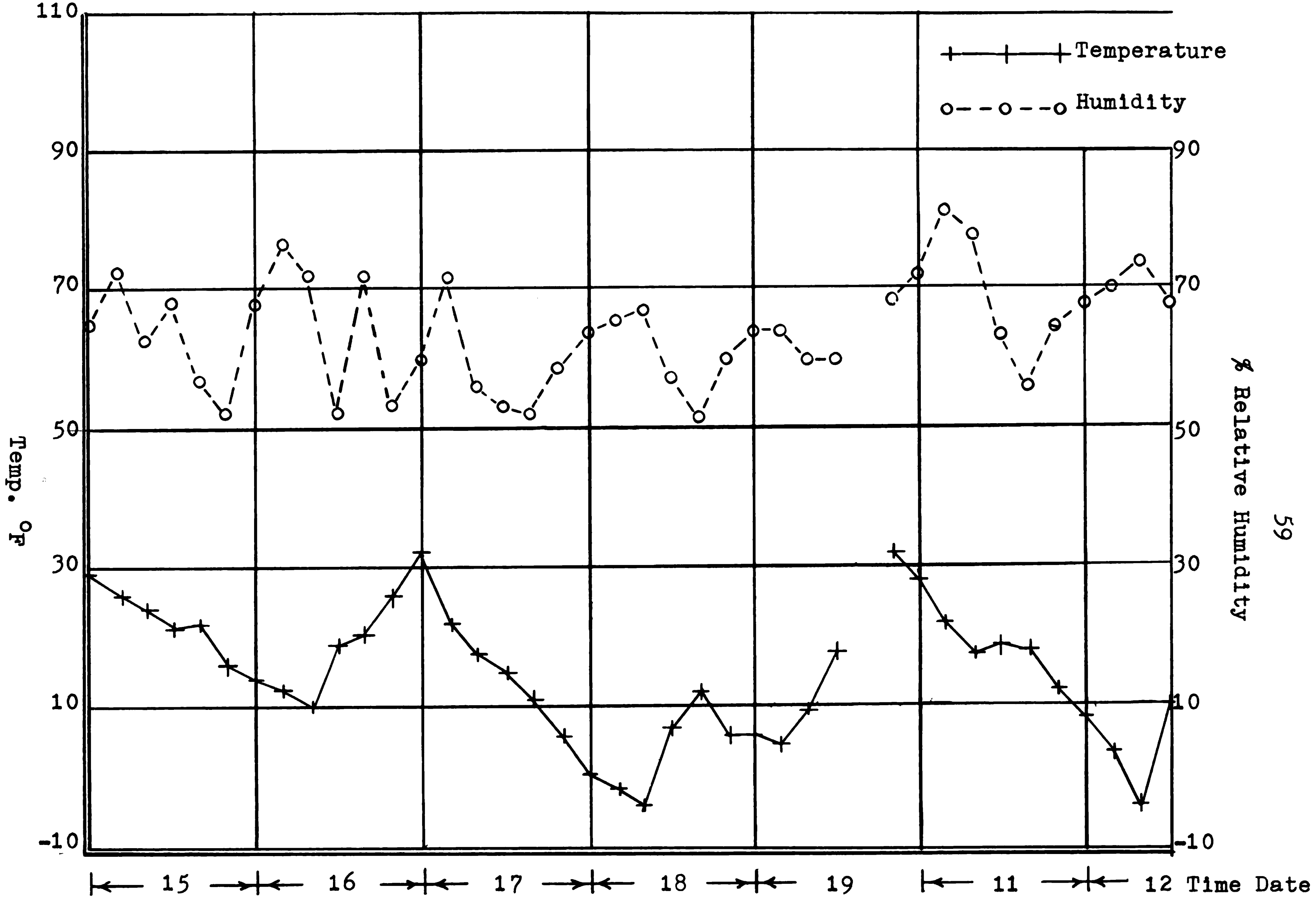


Figure 12. Curves Showing the Temperature and the Relative Humidity Outside From January 15th to 19th and on February 11th and 12th, House A.

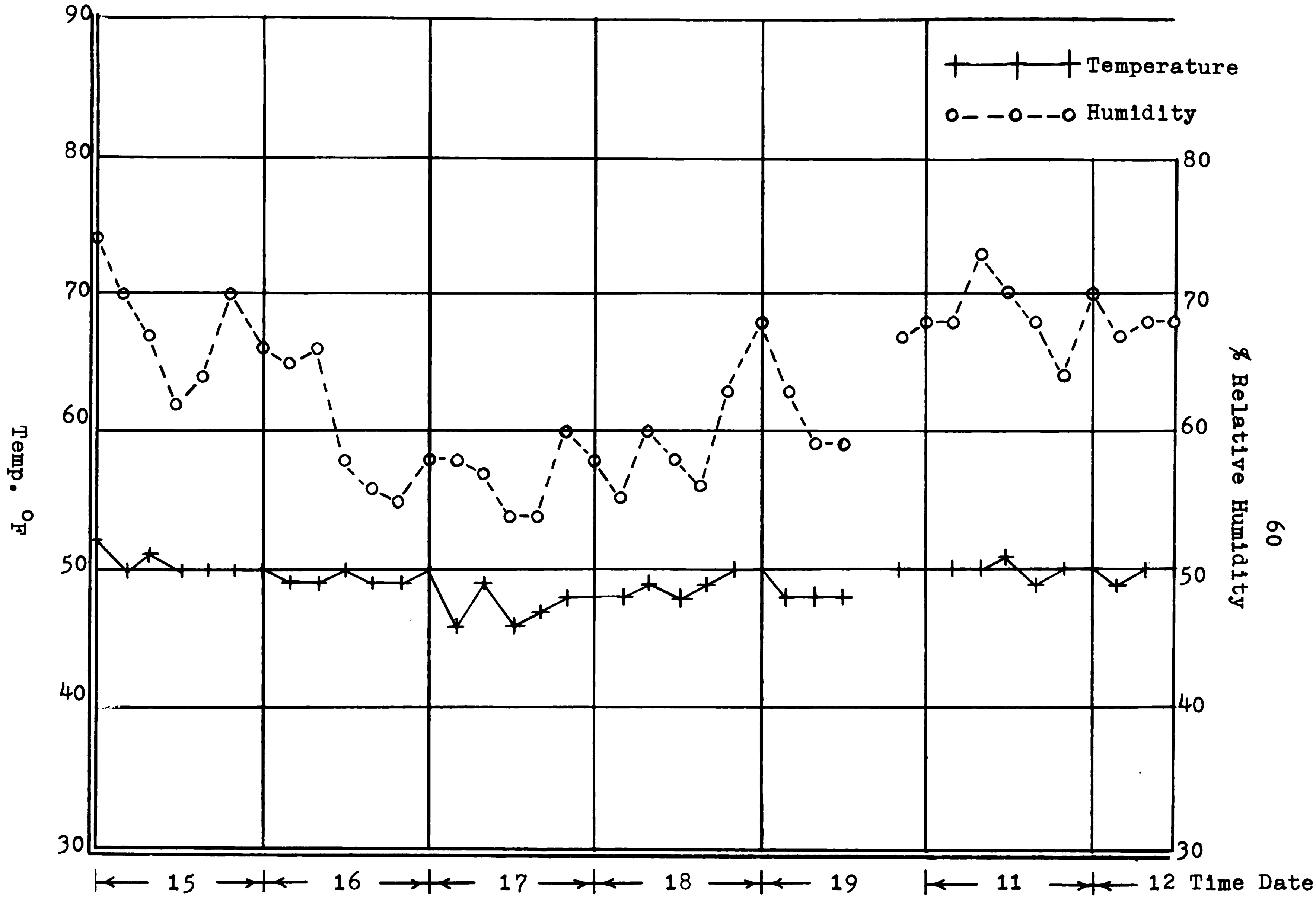


Figure 13. Curves Showing the Temperature and Relative Humidity Inside From January 15th to 19th and on February 11th and 12th, House A.

The period of severe fluctuation in the humidity occurred in the 12 hour's prior to and during the storm of January 17th.

Inside temperature and humidities bear very little relationship to one another, due to the very steady temperature maintained inside, Figure 13. There is a slight indication that the humidity follows the temperature directly rather than inversely. When the temperature is 52°F, the relative humidity is highest and when the temperature is down to 48°F, the humidity is at its lowest. This humidity trend however is due to a correlation with the outside humidity condition, rather than inside temperatures.

The inside temperature change is so small it would scarcely effect the humidity to this extent. Also there is no evidence of an inverse humidity change inside coinciding with the temperature change however small it is.

Winter House B

Environmental temperatures and relative humidity recordings were taken in this house for winter, from January 22nd at 4 p.m. to noon on January 26th.

A heavy snowfall interrupted data collection from January 26th to February 7th. The instruments were relocated on that date at 8 p.m. and data collection continued to 8 a.m. on February 10th.

The three fans operated in this house on a time clock control for moisture removal during this test period.

The only heat provided in this house was that produced by the calves plus a small amount from the light bulbs.

During the recording period there were 78 calves in the house; 58 of these were in individual pens and 20 in the four large pens. This amounted to only 60% stocking density for the house.

Figure 14 shows how the temperature in this house followed the pattern of the outside temperature, but with much less variation. Over the period the outside temperature varies from 2°F to 54°F, while inside the variation is from 32°F to 56°F.

In all cases where the outside temperature drops very low the inside remains some 6°F to 30°F above it. The lower the outside temperature drops the greater is the difference between the inside and outside conditions. When the outside temperature reaches 2°F, the inside is just at freezing. A temperature of 2°F or less was recorded on ten days during the months of January and February 1967.

Even at 15°F outside, which is about average winter conditions for Michigan, the inside temperature is only one or two degrees above freezing.

According to Blaxter et al. this is well below the critical cold temperature for young calves. The house it must be remembered could hold approximately 40% more calves; however it did have good ceiling insulation.

The relative humidities recorded inside and outside this house for winter climatic conditions are shown in Figure 15. While both follow in general a similar pattern, an increase in humidity inside appears to occur more slowly than outside, while a decrease outside is followed very closely by a similar decrease inside.

There is much greater fluctuations in both inside and outside humidities during the January period when temperatures were high, than during February when environmental temperatures were much lower.

The practice in this house was to increase the ventilation rate during periods of warm weather and reduce it when the weather got cold. Such a change may have been made in the period January 26th to February 7th. This would account for the difference in the internal humidity pattern from one recording period to the other.

The outside environmental conditions of temperature and humidity are shown in Figure 16 for the entire winter test period. The characteristic temperature humidity mirror image appears here also. Humidity variation outside in this case is from 59% to 100%.

Conditions of temperature and humidity prevailing inside appear in Figure 17. An unusual effect appears in this case in that the relative humidity curve follows that of the temperature directly instead of being the opposite of it. This is not the usual happening and cannot be readily explained here. The time lag mentioned earlier between the

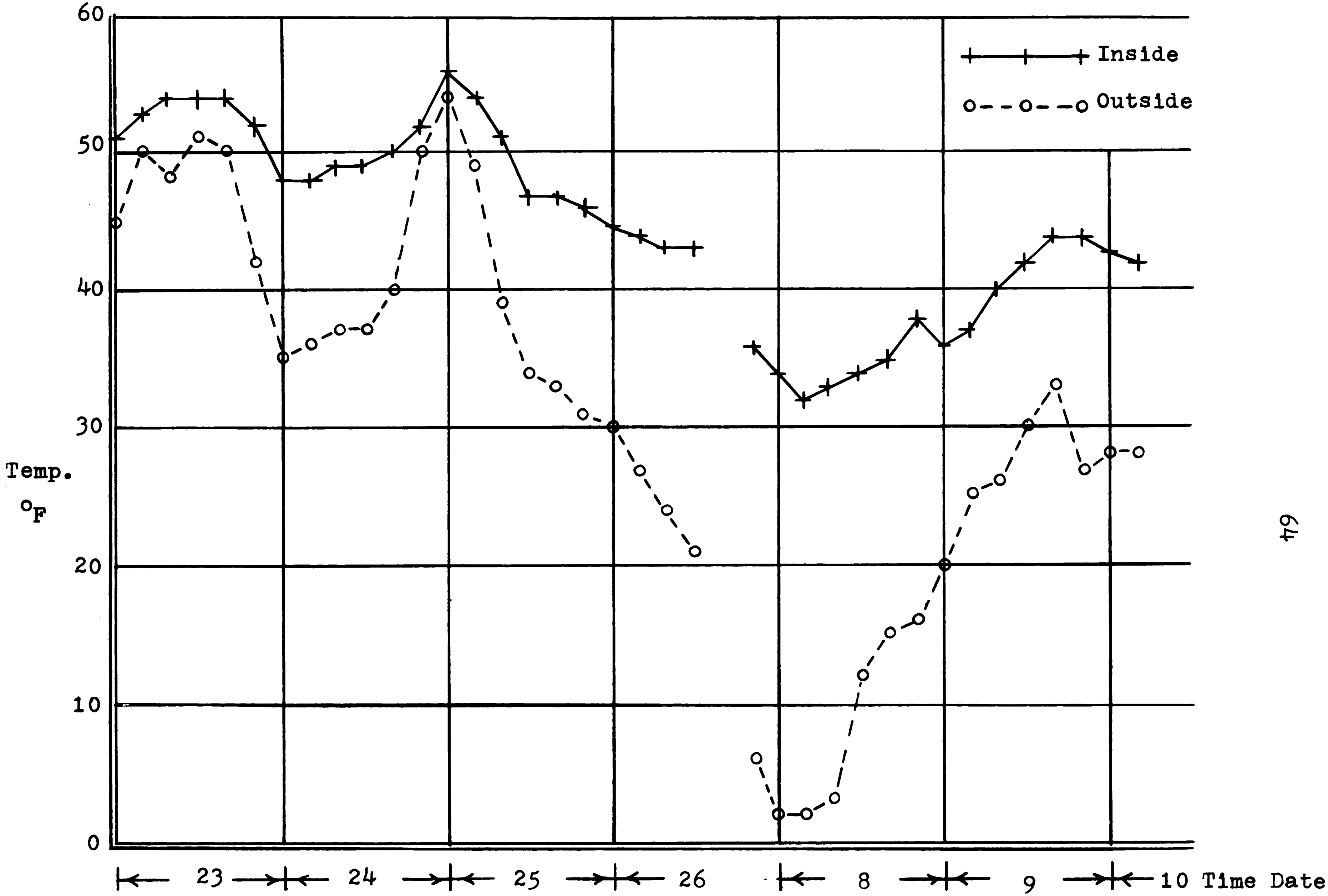


Figure 14. Curves Showing the Temperature Inside and Outside From January 23rd to 26th and February 8th to 10th, House B.

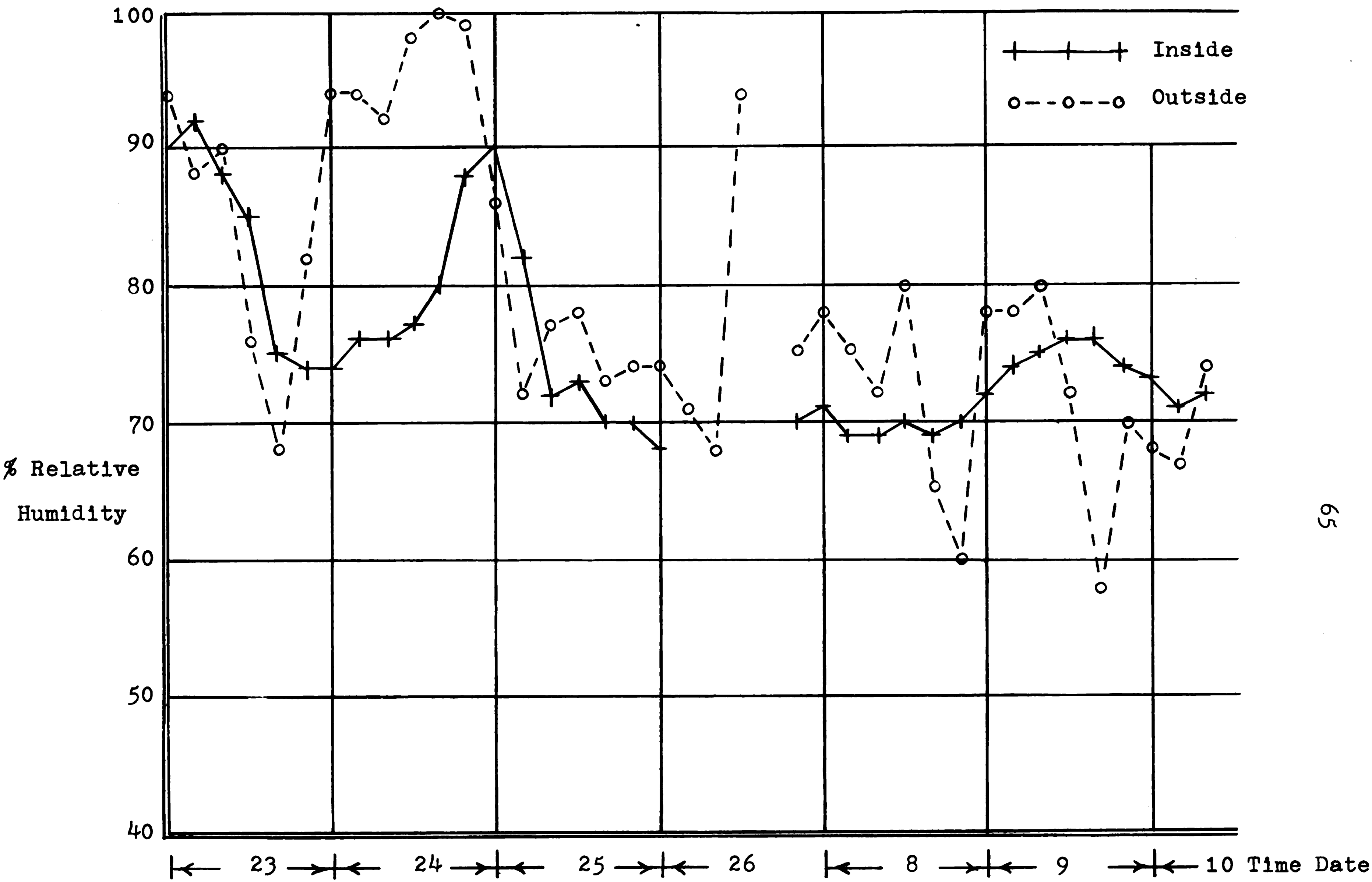


Figure 15. Curves Showing the Relative Humidity Inside and Outside From January 23rd to 26th and February 8th to 10th, House B.

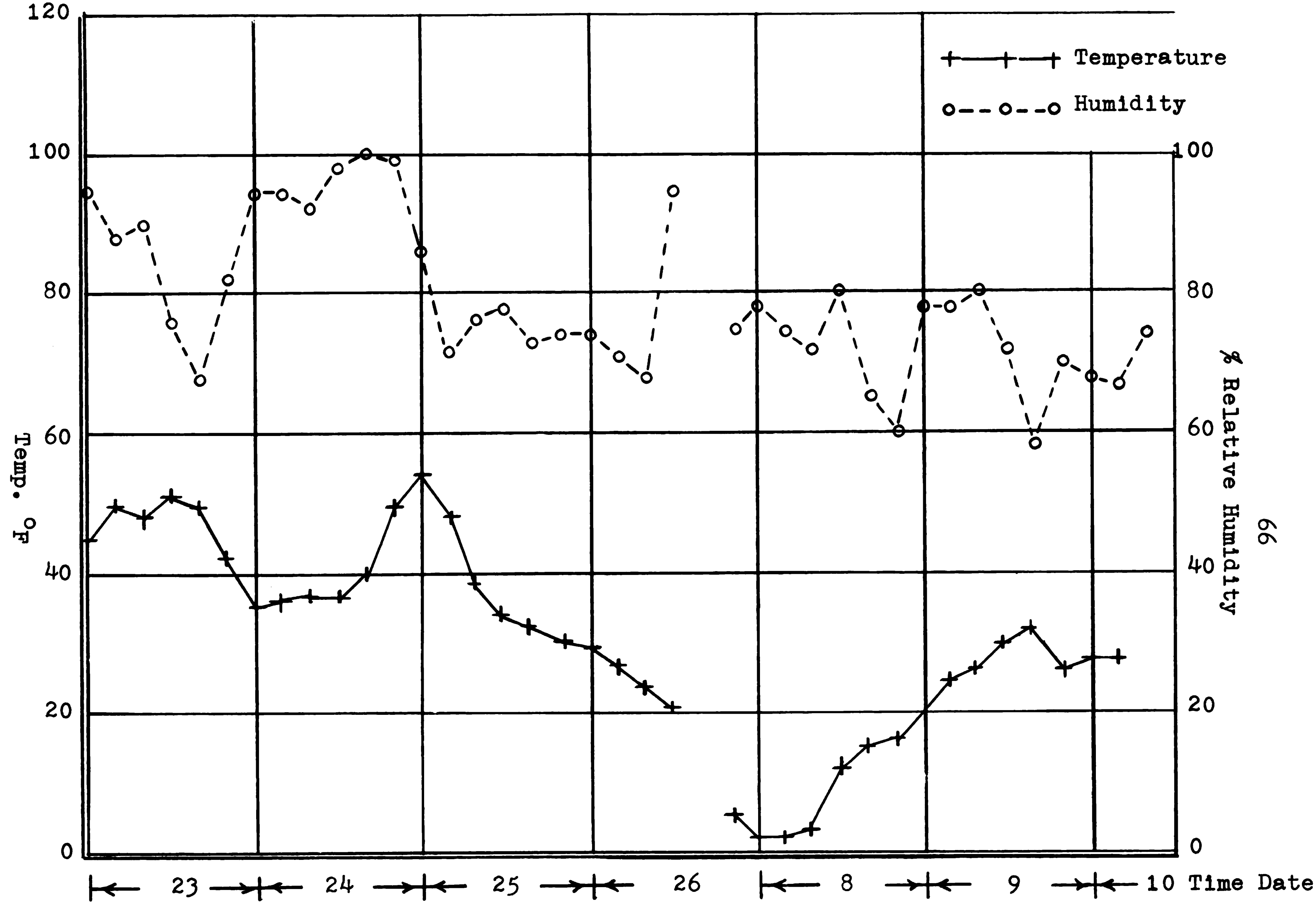


Figure 16. Curves Showing the Temperature and the Relative Humidity Outside From January 23rd to 26th and February 8th to 10th, House B.

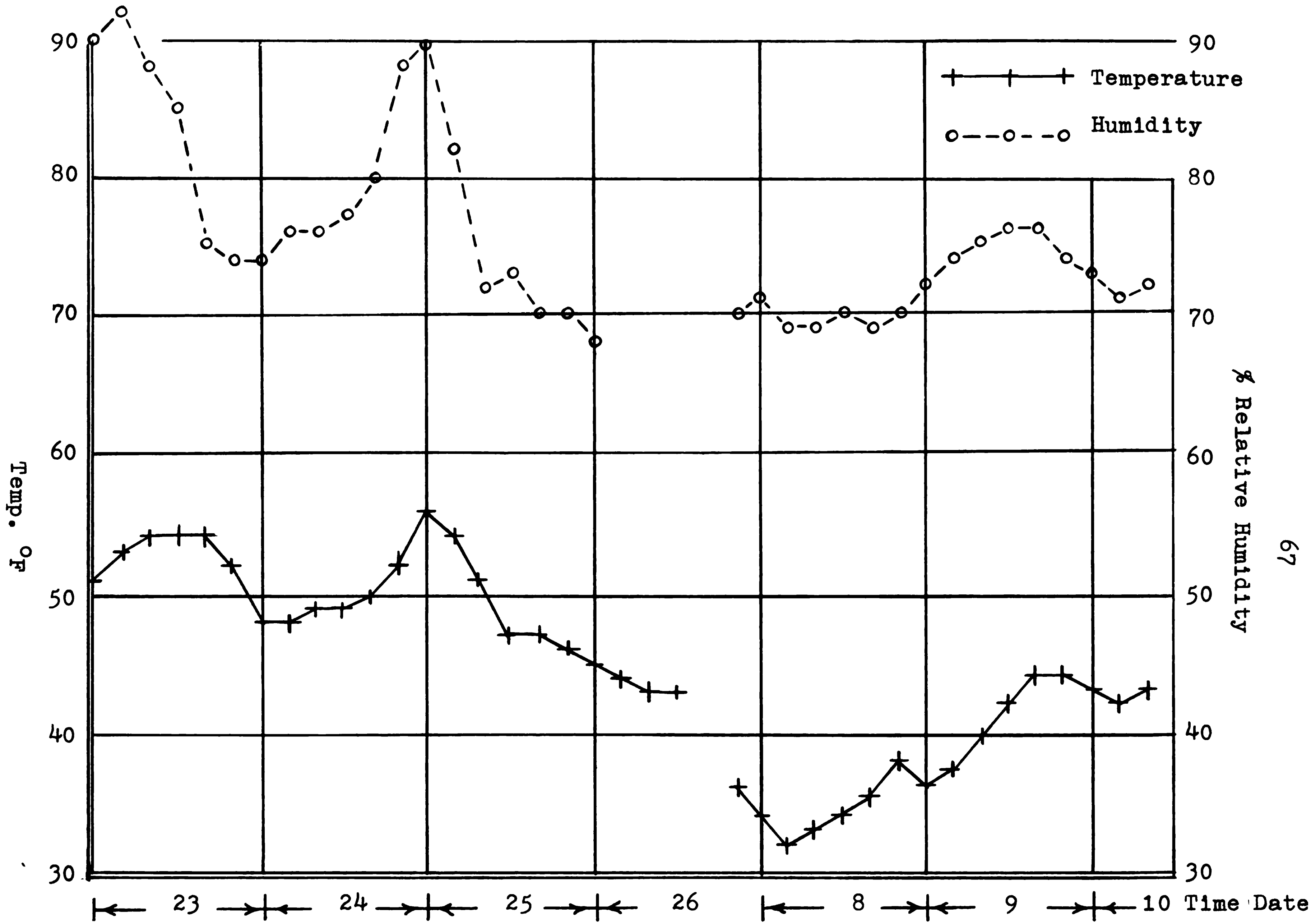


Figure 17. Curves Showing the Temperature and the Relative Humidity Inside From January 23rd to 26th and February 8th to 10th, House B.

inside humidity increase following an increase in outside humidity would to some extent produce this effect. However it would be expected that the inside temperature, fluctuating to the extent it did, should have more of an effect on the inside humidity.

Summer House A

Summer recordings of environmental temperatures and relative humidities commenced in this house on June 12th at 8 p.m. Data was then collected continuously to 12 noon on June 19th.

The only air movement through the house during this time was that moved by the fan. Only the 14 inch fan was in operation, but with all the louvres, which are thermostatically controlled fully open.

There were 15 calves in the building during this week, giving a total weight of 3000 pounds.

The temperature variation in the house during this test period is from 60°F to 84°F. Outside temperatures vary from 53°F to 89°F.

Figure 18 shows how the inside temperature curve corresponds with the outside. While both follow the same general pattern the inside maximum is never as high as the outside.

In this house there is some cooling taking place when the outside daytime temperatures are very high. This is explained in calculating the heat balance as being due to the evaporation of moisture in the house. That is after all the water vapor is removed the excess ventilation air evaporates water. This water may come from the bedding, and the drinking bowls. This process of evaporation is simply an exchange of sensible heat into latent heat as required to vaporize water. This loss of sensible heat then causes a lowering of the environmental temperature in the house.

When the outside temperature drops at night, the insulation in the building is able to slow down, and prevent loss of a considerable amount of the sensible heat produced by the animals. In this way the environmental temperature is maintained at a higher level than outside at night.

In this type of building while the inside temperature follows the outside fairly close, the day to night inside fluctuations are much less.

The sudden drop in outside temperature at 4 p.m. on June 13th and a similar drop at the same time on June 16th is due to the occurence of a thunderstorm at both those times. This also causes abrupt changes in the outside humidity. The variation in outside relative humidity for this period is from 49% to 99%. Inside the variation is much less, being from 58% to 84%, Figure 19. Only on two days did it exceed 80% inside and then only for a short duration of time.

As in the case of temperature, the day to night humidity fluctuations are also much less inside the house,

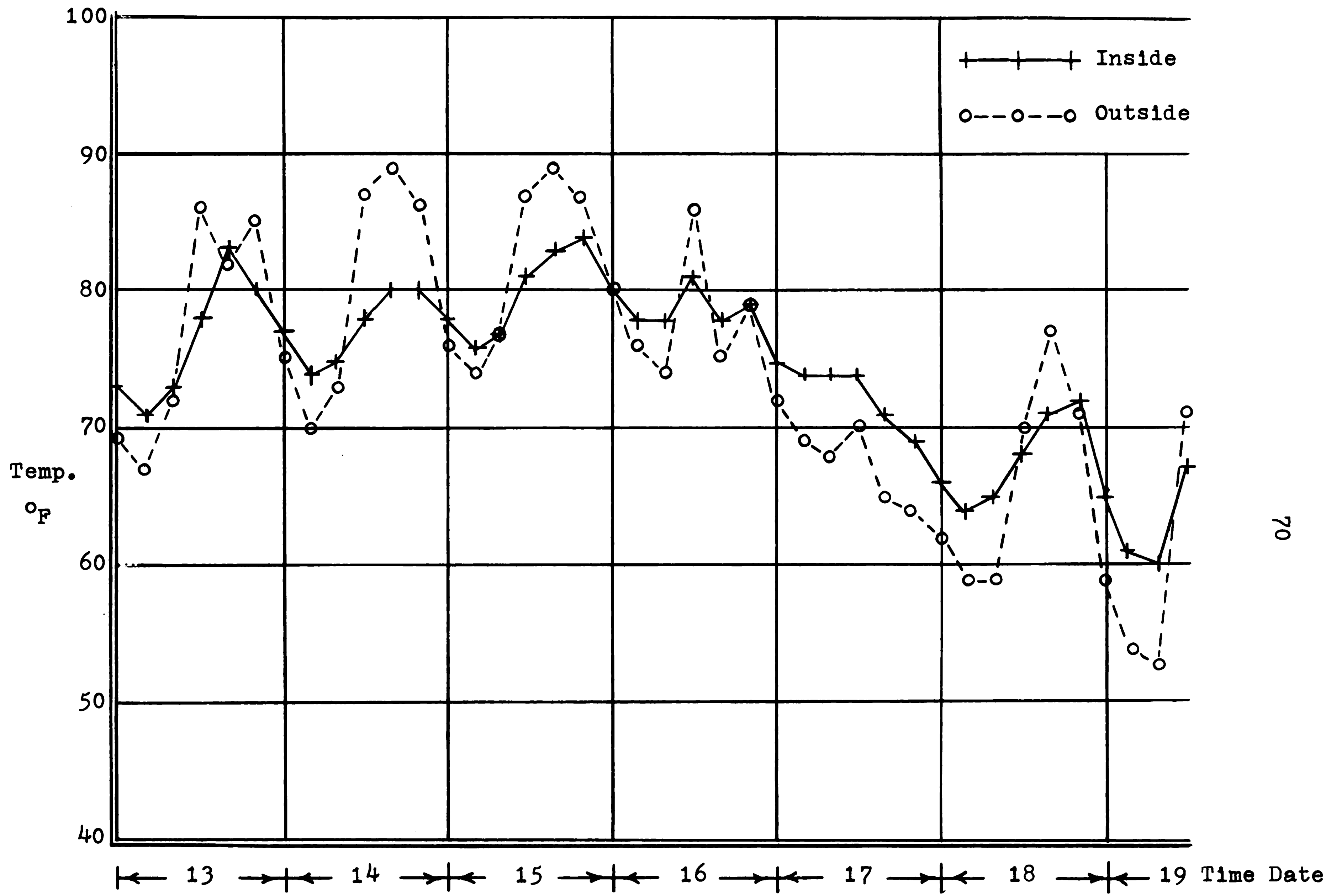


Figure 18. Curves Showing the Temperature Inside and Outside From June 13th to 19th, House A.

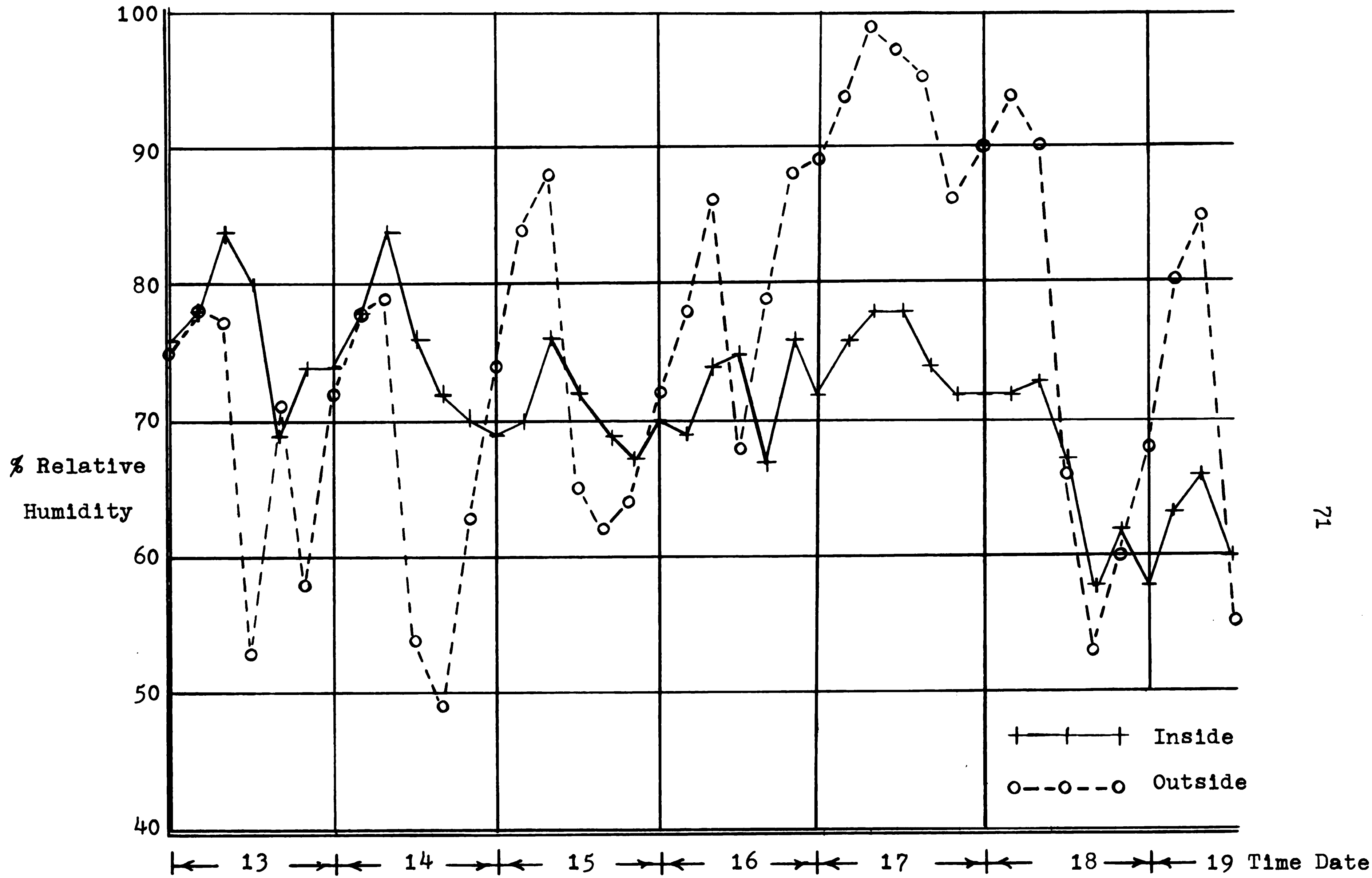


Figure 19. Curves Showing the Relative Humidity Inside and Outside From June 13th to 19th, House A.

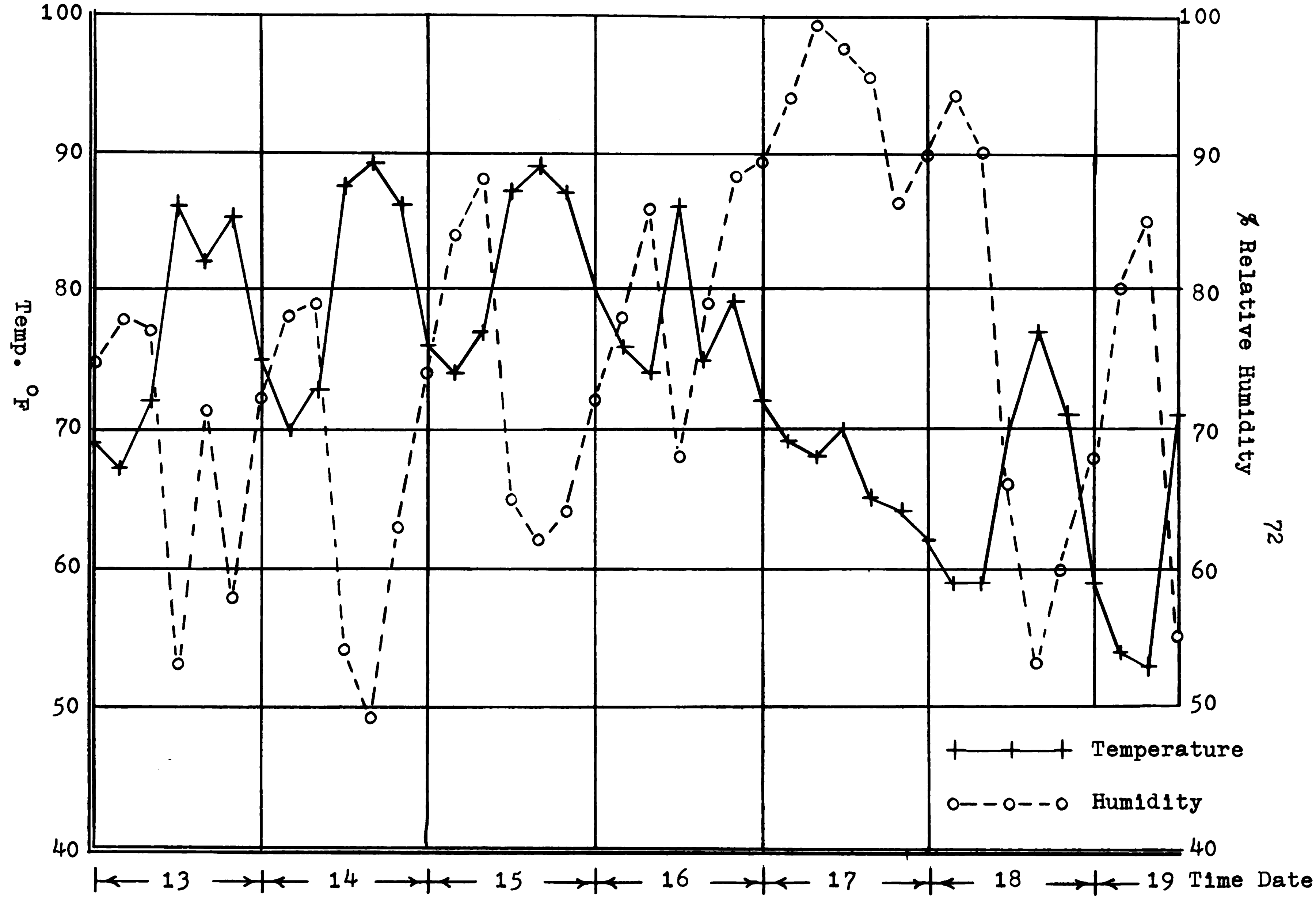


Figure 20. Curves Showing the Temperature and the Relative Humidity Outside From June 13th to 19th, House A.

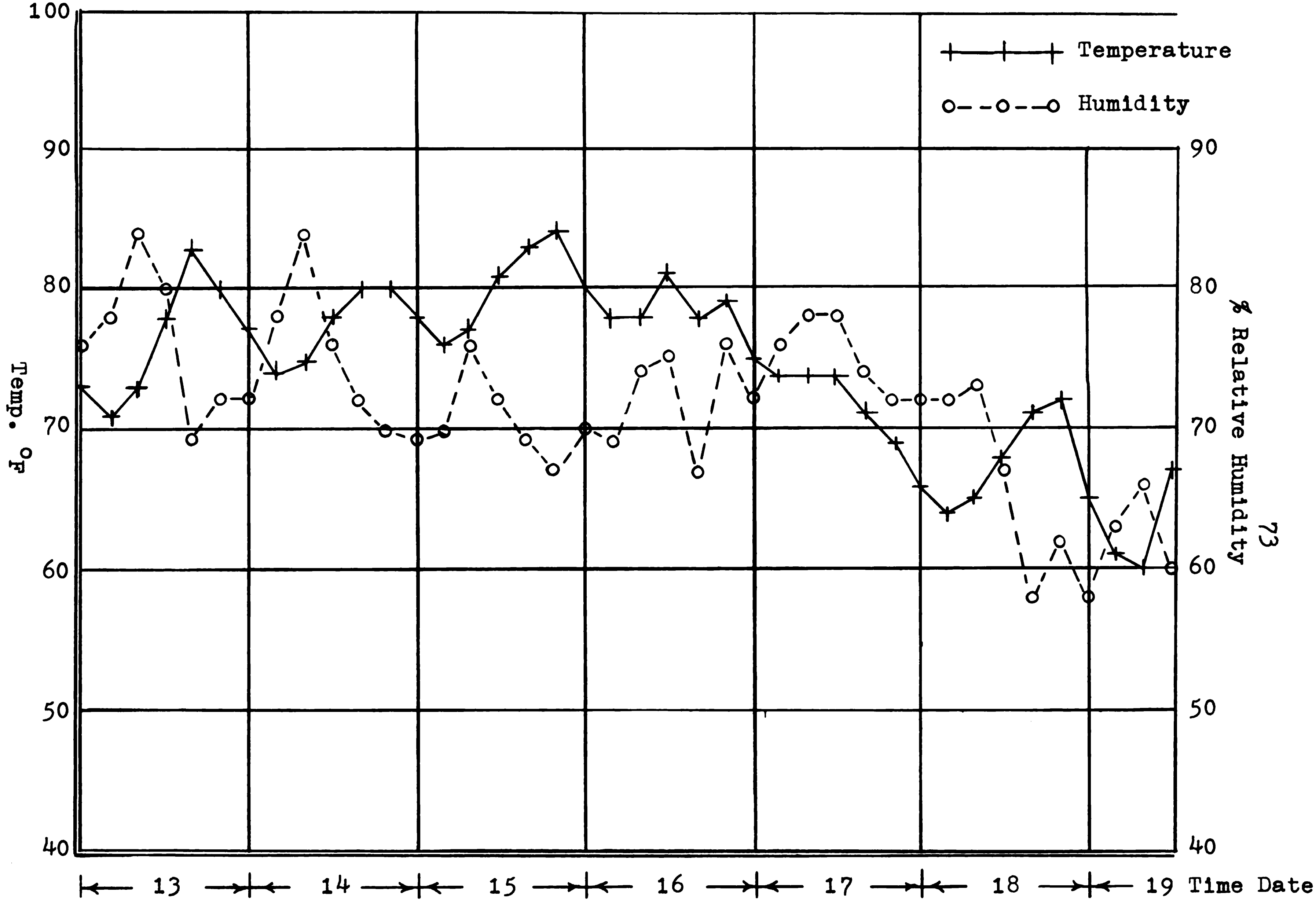


Figure 21. Curves Showing the Temperature and Relative Humidity Inside From June 13th to 19th, House A.

giving more uniform conditions for the animals.

The outside day to night fluctuations in both temperature and relative humidity are much greater, Figure 20. This shows very clearly the mirror image formed by changes in temperature and relative humidity. The sudden changes due to the thunderstorm on June 13th and 16th are also clearly visible.

Figure 21 shows the temperature and humidity pattern within the building for the week. The average temperature for the duration of the test is 75°F, and the average humidity is 70%. Those are very comfortable conditions, considering this week included the four warmest days for the month of June, that is the 13th through 16th.

The house had the effect of modifying the external temperature extremes while also reducing the humidity fluctuations, thus providing reasonably stable conditions for the calves during summer weather extremes.

Summer House B

The temperature and relative humidity recordings from 4 p.m. on June 20th to 4 p.m. on June 26th represent the summer conditions for this house.

For the duration of these recordings there were 121 calves in the house. This is approximately 100% stocking rate and amounted to a total weight of 21,200 pounds.

The three exhaust fans were operating during this period, but in addition all doors and windows were opened, making it impossible to calculate any ventilation data.

Another management practice was to close some of the doors and windows at night and open them during the daytime. It was expected that conditions inside and outside in this case should be very similar.

The inside and outside temperature curves are compared in Figure 22. The variation in outside temperature is from 51°F to 83°F, while inside conditions vary from 61°F to 78°F. This shows how closely the inside temperature follows the outside. However during the night it remained from 4°F to 10°F warmer inside. This may be accounted for by the closing of the windows and doors at this time, thus conserving more of the animal heat.

During the day there is less difference between inside and outside temperatures. The outside maximum was from 1°F to 3°F higher only. It appears however from this that some cooling is taking place in this house also when the outside temperatures are very high. The amount of cooling is much less than that recorded for House A, even at slightly lower temperatures.

The day to night fluctuations in temperature inside is only about 50% of that occurring outside.

Relative humidity fluctuations both inside as well as outside in this case are very great, both from day to day, and from daytime to nighttime, Figure 23. The outside humidity varies from 39% to 90% and the inside variation is from 51% to 94%.

The inside humidity is almost constantly higher than that occurring outside. This is expected as during the day both temperatures are very close, thus the animal's latent heat would tend to increase the humidity inside the building. At night closing the windows and doors lowers the ventilation rate which in turn would allow the humidity inside to build up, resulting in a higher reading.

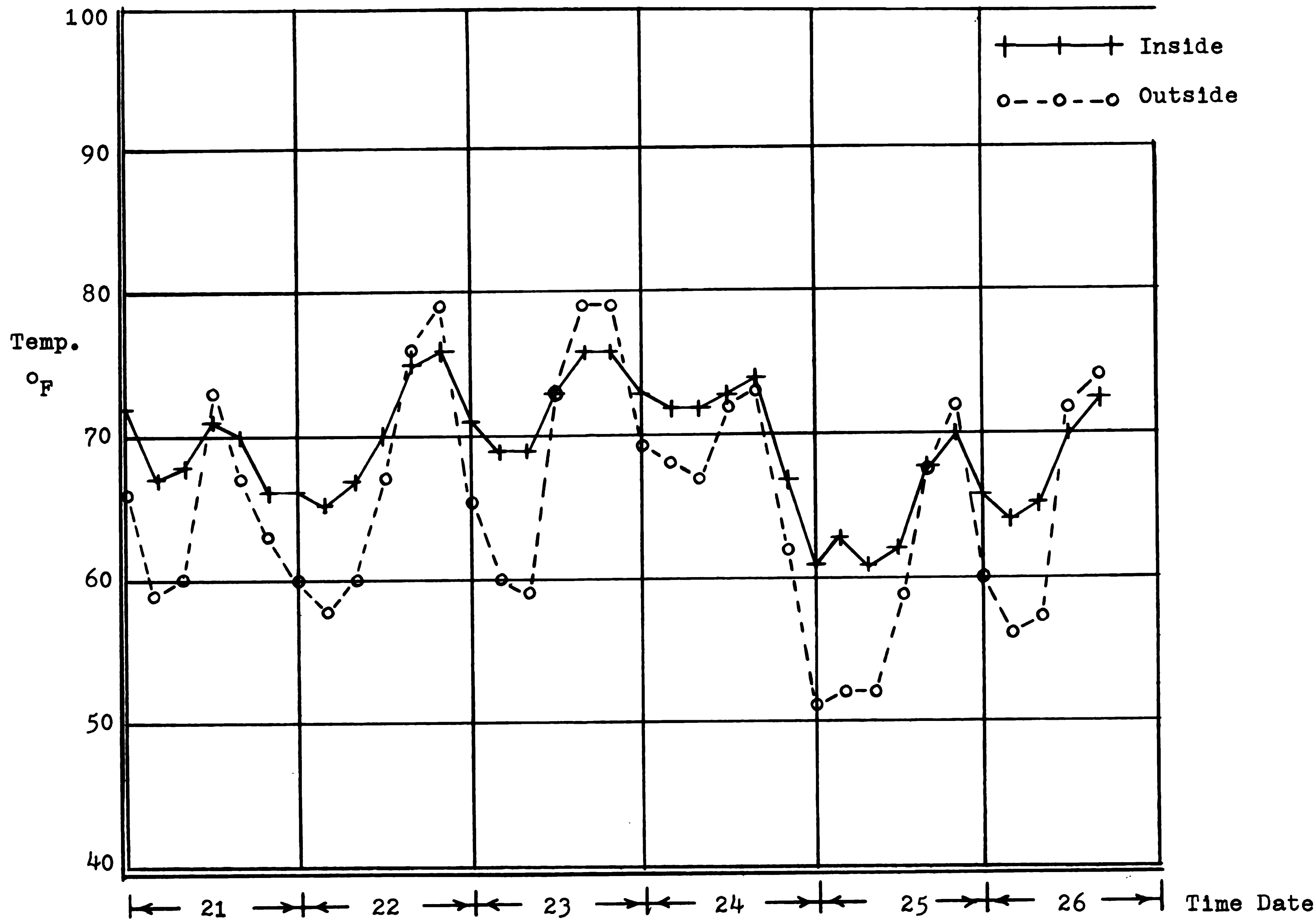
The environmental conditions of temperature and humidity prevailing outside at the time of this recording are shown in Figure 24. The expected temperature humidity pattern is very much in evidence here, also the very great temperature and relative humidity fluctuations that occurred during this period.

In contrast to this the variation in temperature and humidity within the house are much less, Figure 25.

The inside temperature for this period is very acceptable for calves being 70°F average for the week, with not too great a variation from day to night.

The relative humidity however is very high being over 80% for almost two-thirds of the time, and over 90% on a few occasions.

These high readings are associated with very high outside humidities at the time. It does appear however that more ventilation is required in this building at night when high humidities occur.



Fegure 22. Curves Showing the Temperature Inside and Outside From June 21st to 26th, House B.

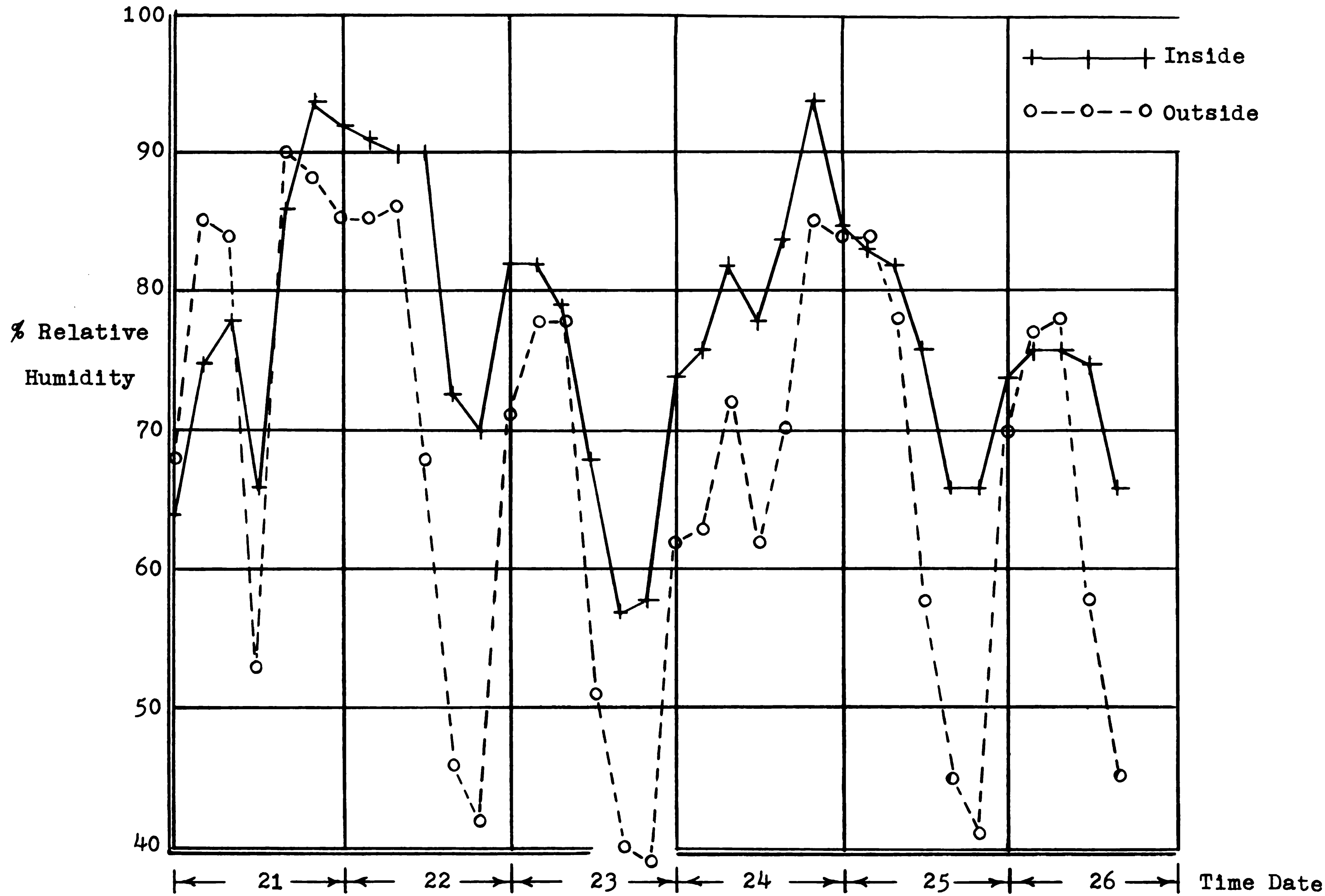


Figure 23. Curves Showing the Relative Humidity Inside and Outside From June 21st to 26th, House B.

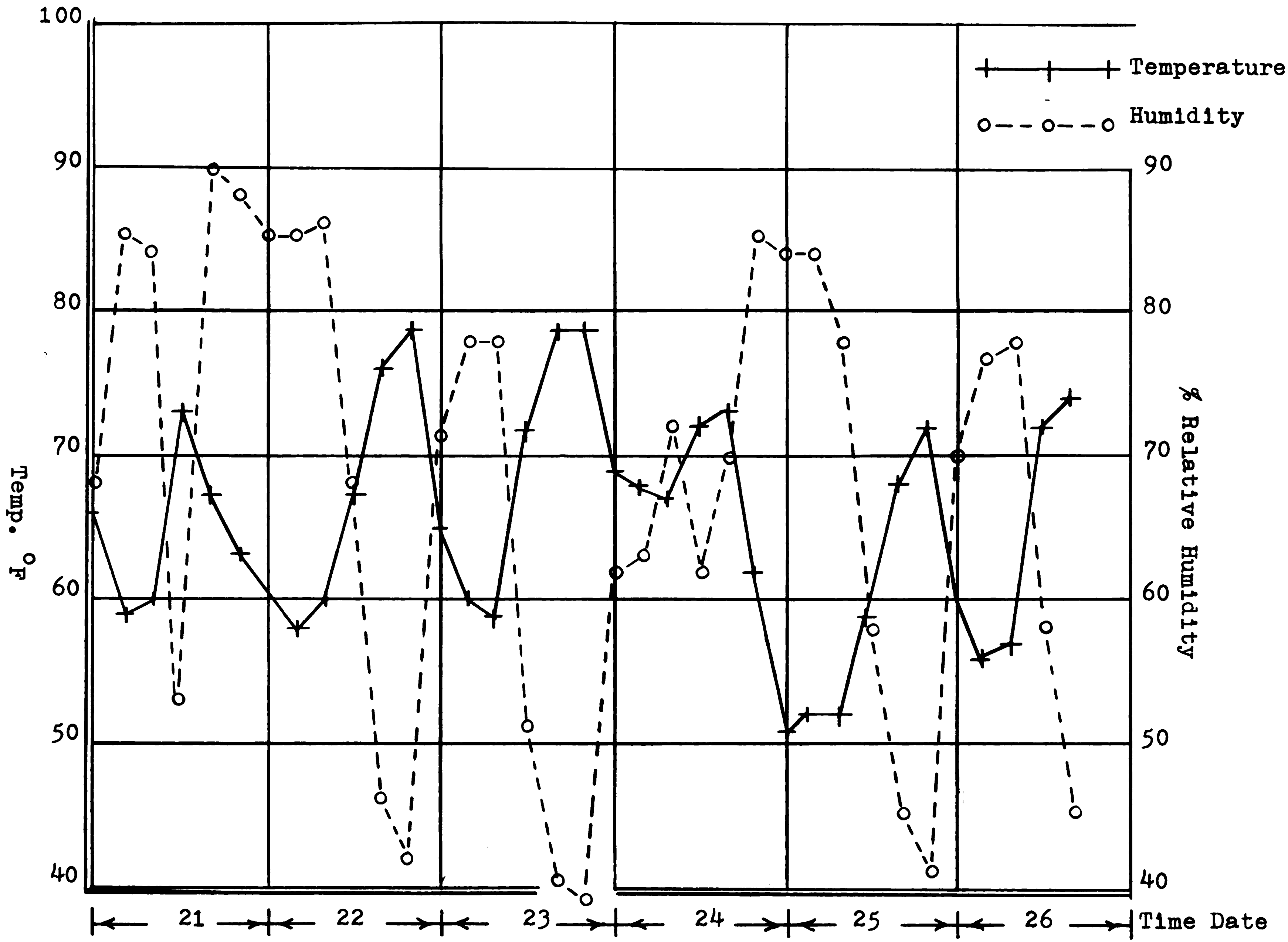


Figure 24. Curves Showing the Temperature and Relative Humidity Outside From June 21st to 26th, House B.

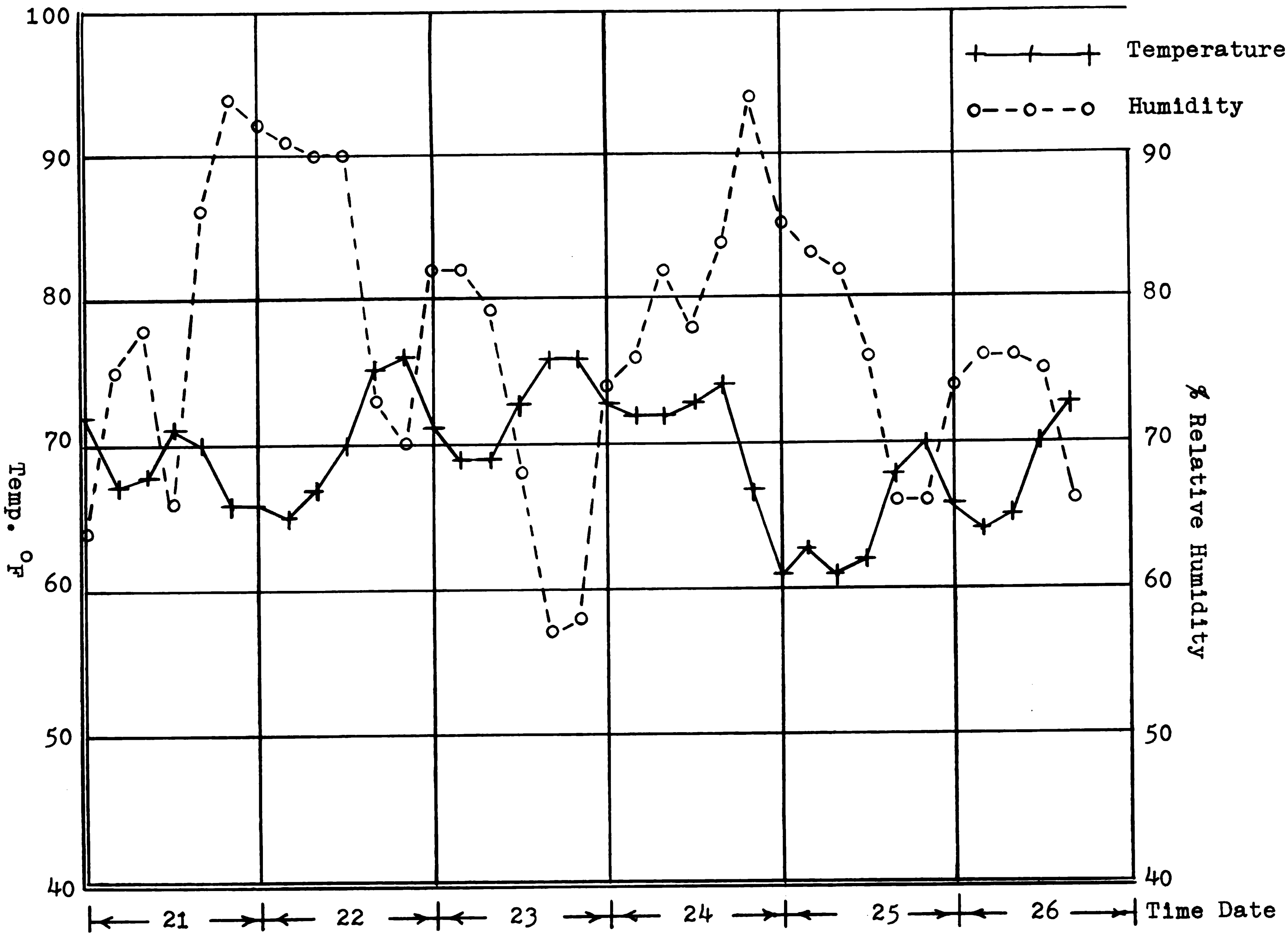


Figure 25. Curves Showing the Temperature and the Relative Humidity Inside From June 21st to 26th, House B.

SUMMARY AND CONCLUSIONS

The following conclusions are made from the data recorded during this investigation, which was concerned with the environmental conditions inside and outside existing calf houses during winter and summer climatic conditions.

Calculations show that the ventilation rate for moisture removal in House A in winter should be approximately 50 C.F.M. more than that recorded. While there was no obvious condensation in this house, the extra air movement would give better humidity control, with less fluctuation in the humidity curve.

It would however increase the amount of supplemental heat required for temperature control in the house.

Some extra heat could be conserved by double glazing the windows, and insulating the large fan.

House B was not capable of providing comfortable conditions for calves in winter. It was too cold and had an excess of condensation.

It would be impractical to improve such a house with insulation and ventilation alone. The air at winter temperatures has too low water holding capacity, thus without a temperature rise the amount required for moisture removal would be too great. Insulation of the walls and double glazing the large window area would improve conditions considerably.

The stocking density could also be increased. However while this would increase the animal heat production, it would also increase the water vapor production. The extra ventilation required for removal of this vapor then would reduce greatly the effect of the extra heat produced.

In the analysis of House A, with a ventilation rate of 77 C.F.M. and 3000 cubic feet per 1000 pounds of animal, and House B with a ventilation rate of 87 C.F.M. and 2250 cubic feet for the same weight of animals, it would appear impossible to control the environment without supplemental heat.

A combination of insulation, ventilation and supplemental heat appears to be necessary for environmental control of young calf housing during winter climatic conditions.

Under summer climatic conditions House A again is ideal. The ventilation rate removed all the latent heat, giving very acceptable humidity conditions.

There was also enough air surplus to evaporate other moisture, giving a very desirable cooling effect during the very warm summer days.

From the calculations it appears that only 1½ extra calves of the same average weight would tax the 14 inch fan to the limit, for moisture removal.

It is expected then for higher stocking densities in this house the larger fan would be needed for summer ventilation.

The summer temperatures in House B were comfortable for calves at 70°F average. The humidity in this house was too high, especially at night when temperatures dropped.

This indicates the need for a higher ventilation rate during this time.

A sensible heat balance is only of practical use where conditions are such that no condensation, freezing, melting or evaporation of moisture is taking place.

Rarely in animal housing are conditions so ideal that one or more of these processes are not taking place to some extent. Evaporation can be taking place without being noticed unless actually measured. Also hygroscopic materials, like dry hay, and meals could be absorbing condensed moisture rendering it unnoticable.

A total heat balance using enthalpy change takes account of any varying amounts of heat that is produced, or absorbed by such processes as condensation, evaporation, etc. This then appears to be the more reliable method on which to calculate a heat balance for the environmental design of livestock buildings.

SUGGESTIONS FOR FUTURE STUDY

1. To carry out full scale experiments to determine the optimum conditions of environmental temperature and relative humidity for calves from birth to a few weeks of age.
2. A large scale study to determine the correlation between specific environmental conditions and young calf mortality.
3. Study the effect of average and ideal (in the present knowledge) environmental conditions on the growth rate and feed consumption of calves.
4. Further investigate the phenomenon of evaporative cooling in insulated and ventilated livestock buildings under extreme summer conditions, using accurate instrumentation.

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APPENDIX A

Overall Heat Transfer Coefficient (U) of Components, House A

Component		R Value[1, 2]
Wall	Outside Surface	.17
	Siding 1"	.79
	Blanket Insulation 3"	11.10
	Plywood ½"	.64
	Inside Surface	.68
	Total Resistance	13.38
	U = 1/R = 1/13.38 =	.075
Door	Outside Surface	.17
	Wood 1"	.79
	Inside Surface	.68
	Total Resistance	1.64
	U = 1/R = 1/1.64 =	.61
Windows	Single Pane	U = 1.13
Fan (Idle)	Outside Surface	.17
	Fan and Shutters	.66
	Inside Surface	.68
	Total Resistance	1.51
	U = 1/R = 1/1.51 =	.66
Ceiling	Outside Surface	.68
	Baled Straw 15 ft.	300.00
	Boards 1" on Joists	2.22
	Blanket Insulation 3"	11.10
	Plywood ½"	.64
	Inside Surface	.68
	Total Resistance	315.32
	U = 1/R = 1/315.32 =	.0032

APPENDIX B

Overall Heat Transfer Coefficient (U) of Components, House B

Component		R Value[1, 2]
Wall Base	Outside Surface	.17
	Concrete 12"	.96
	Inside Surface	.68
	Total Resistance	1.81
	U = 1/R = 1/1.81 =	.55
Wall Upper	Outside Surface	.17
	3/4" Siding, Building Paper, Studs, 3/4" Tongued-and-Grooved Boards	3.70
	Inside Surface	.68
	Total Resistance	4.55
	U = 1/R = 1/4.55 =	.22
Door	Outside Surface	.17
	Wood 1"	.79
	Inside Surface	.68
	Total Resistance	1.64
	U = 1/R = 1/1.64 =	.61
Windows	Single Pane	U = 1.13
Ceiling	Outside Surface	.68
	Baled Straw 15'	300.00
	Boards 1" on Joists	2.22
	Inside Surface	.68
	Total Resistance	303.58
	U = 1/R = 1/303.58 =	.0033

APPENDIX C

Heat Required to Vaporize Water[4]

Temperature	Latent Heat (BTU/LB. Water)
32	1076
40	1071
60	1061
80	1048
100	1036