ENVIRONMENTAL CHARACTERISTICS OF CALF HUTCHES

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I. INTRODUCTION

The calf hutch is a facility for raising calves outside and individually, and is used even during winter in severe cold areas. It has been popularly used in the U. S. A. since the beginning of the 1970's because of its excellent performance especially with respect to the improvement of high mortality rate of calves. When the calf hutch was introduced to Japan in 1977, most farmers and even researchers suspected the effectiveness because it had been common sense that calves should be raised in a warm environment at that time.

Studies on the calf hutch have been made with respect to the growth, the feed consumption, the behavior and the health of calves. However, the environment in calf hutches, which is considered to be the most improtant factor bearing on the effectiveness, has been little studied scientifically, although it was abstractly stated.

The objectives of this study are to verify the environmental characteristics of the calf hutch and to discuss what environmental factors are required for good performance of calves.

The environment in this study consists of factors controllable by practical environmental managements, namely ventilation, insulation and heating.

The environment in the calf hutch was investigated from various viewpoints. Thermal environment will be discussed first to show the severe conditions during a cold winter and modifications of thermal environmental factors by the calf hutch. Behavior of calves in calf hutches will then be described to understand the role of the hutch as the facility for modifying thermal environment. An air exchange rate study will also be presented to show how much fresh air can be introduced into calf hutches in various

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conditions. Bacterial aerosol concentrations in calf hutches will then be discussed in comparison with those in the other facilities including conventional dairy barns.

Depending on the data obtained from the investigation of the environment, the discussion is made on what are important environmental factors for raising calves. The rearrangement of environmental factors will also be discussed.

II. LITERATURE REVIEW

The portable pen, which is the origin of the calf hutch, was first tried in 1943 to control diseases of calves (DAVIS, 1952). It was made of four 0.9×3.0 m wooden panels and was just an enclosed facility without a roof. It was modified in 1947 and provided the basic concept for calf hutches which can be seen today.

Studies of environmental effects on calves will be first reviewed as a background of the calf hutch studies. The history of the calf hutch studies will then be presented and the research area little investigated will be pointed out. The calf hutch studies in Japan will also be presented.

Although plenty of data concerning thermal environemental effects on cattle are available (ASHRAE, 1981a ; CLARK, 1981 ; RECHCIGL, 1982 ; ASAE, 1982 ; CURTIS, 1982), cold environmental effects on calves, which is deeply related to the calf hutch, have been studied more recently. GONZALEZ-JIMENEZ and BLAXTER (1962) reported on the metabolism and thermal regulation of calves. The critical temperatures of calves estimated were 12.8°C on the third day of life and 8.2°C on the 20th day. They also recommended that the temperature, inside calf house should not be allowed to fall below 13°C. Since then, environmental temperatures recommended for calves had been near this temperature for a long time, for example, from 10°C to 26°C as an acceptable temperature range by HAHN (1974) ; from 5°C to 30-32°C as a range of production environment by MIMURA and MORITA (1980). More recently intensive studies have been made by WEBSTER (1970, 1976 and 1978) and these results have been reviewed (WEBSTER, 1974 and 1981). He presented the calculated lower critical temperatures of 9°C for a new born calf and 0°C for a one-month-old calf, and stated that cattle have a very marked ability to adapt to cold environment. Including these studies, thermal environment has been a main concern for a long time when the livestock environment is investigated (HAHN, 1982).

On the other hand, BATES (1974) proposed the consideration of air purity for calf health and recommended continuous exhaust for reducing

aerosol contamination, from a stand point that "Ventilation for animal health is more than a thermo-dynamic process for moisture and temperature control (ANDERSON, BATES and JORDAN, 1978)." He also recommended using an air exchange rate instead of a ventilation rate since "one pathogene shedding animal can produce a higher density concentration of pathogenes than a number of healthy animals (ANDERSON, BATES and JORDAN, 1978)."

Webster also stated the importance of the quality of fresh air, since "cold has negligible effects on growth and food conversion efficiency in young calves until air temperature falls below 5°C (Webster, 1978)."

Studies on air quality in calf facilities have been made rather recently. PRICHARD (1981) reported the effects of air filtration on respiratory disease. Balance of viable and non-viable aerosols in calf barns was attempted by JONES *et al.* (1982), WICKLEN *et al.* (1982) and WATHES *et al.* (1984). However, data are still very limited and more studies related to air quality need to be made.

In regard to the practical performance of calves, a survey of dairy calves in South Carolina showed a death loss of 7% to 20% (JENNY *et al.*, 1983). Much of this is caused by pneumonia and other respiratory diseases. In Japan, NAKANE (1979) reported the mortality rate of 24.4% for dairy beef calves and more than half of it (13.2%) was due to respiratory diseases.

The calf hutch was first studied by DAVIS (1952, 1954). He concluded that the portable pen was effective in controlling diseases even under severe cold conditions from a ten-year study compared with four other raising systems. Since then various studies were made on growth, health, nutrition, behavior and management of calves raised in portable pens, or calf hutches.

JORGENSON *et al.* (1970) reported no significant difference in dairy gain between a conventional indoor housing system and an outdoor calf rearing system (calf hutches) in South Dakota, U. S. A., where the temperature varied from a low of −23°C in January to a high of about 35°C in July. Similar results with respect to growth of the calves were presented by APPLEMAN and OWEN (1969) and WILLET and ALBRIGHT (1970). MCKNIGHT (1978) showed no difference in the weight gain between hutch housing and traditional housing but slightly high feed consumption in hutch housing.

MCKNIGHT (1978) indicated that hutch calves required less medical treatment than calves housed indoor. HOLMS *et al.* (1983) also showed that calves raised in cold environment tended to have fewer health problems and fewer deaths than those raised in a warm environment.

WARNICK (1977) reported in regard to calf behavior in a hutch that hutch calves tended to spend a greater percentage of the time in recumbency

compared with calves in other facilities.

Various extension materials also have been published, for example, by MWPS (1983), BATES *et al.* (1985) and HOARD'S DAIRYMAN (1973, 1978 b).

Responses of farmers using calf hutches were described in magazines. For example, one farmer in Wisconsin, where the minimum temperature drops easily below −20°C, decided to use calf hutches although he thought he might lose the calf. After this trial, he found his calves could be raised with much lower mortality (HOARD'S DAIRYMAN, 1973). This example shows how the calf hutch system was beyond the common sense in calf raising at that time.

Although many reports concerning calf hutches were published as listed above, data with respect to the environmental characteristics of calf hutches were very limited. The environmental characteristics of calf hutches are considered to be the most important factor bearing on the effectiveness. Only the data of wind velocity and temperature inside cald hutch (HARTMAN and GWAZDAUSKAS, 1982) can be seen.

The calf hutch was first officially introduced to Japan by Prof. Bates in 1977 (HOSHIBA, 1980 a) and Dr. DOHKOSHI extended it. The first research project on use of calf hutches in Japan was started at the Shintoku Animal Husbandry Experiment Station in 1977 (Shintoku Animal Husbandry Experiment Station, 1982) including the author as one of the member of the project, and the results were presented including environmental characteristics of calf hutches (OKAMOTO, SONE and HOSHIBA, 1983 ; HOSHIBA *et al.*, 1985 a ; 1985 b ; 1985 c ; and SONE *et al.*, 1985).

Since then various studies have been made as calf hutches came into use on farms (KINOSHITA, 1981 ; IKETAKI *et al.*, 1983 ; NISHIGAI *et al.*, 1983).

III. ENVIRONMENT IN CALF HUTCHES

A. THERMAL ENVIRONMENT IN CALF HUTCHES

When the calf hutch was introduced to Japan, what people were most anxious about was that calves were exposed to severe cold environment in winter. Thus, it should be useful to verify how low the actual inside temperature in winter is, and how the calf hutch can modify the thermal environmental factors.

Objectives of the study of thermal environment in calf hutches were to :

(a) verify the actual temperature inside calf hutches during winter in the Tokachi district as a representative of cold areas in Hokkaido.

(b) describe wind protection effects and reduction of cold stress provided by calf hutches.

In this study, no calf was housed in calf hutches except when the actual inside temperature in winter was measured so as to make measurements possible. Only the thermal environmental characteristics of the calf hutch itself was investigated.

The Shintoku Animal Husbandry Experiment Station will be abbreviated as SAHES.

1. PROCEDURES

a. Actual Inside Temperature in Winter

The actual inside temperatures of calf hutches with calves being housed were measured at the SAHES in winter (January 15 to April 4), 1980. Three fiber reinforced plastic (FRP) calf hutches shown in Fig. 1 were used for this measurement as well as for the behavior observation which will be described in the next section. A Cu-Co thermocouple thermometer covered with a protective case made of a polyvinyle chloride tube was set at inner roof surface of each calf hutch. Temperatures were recorded every hour by a digital recorder.

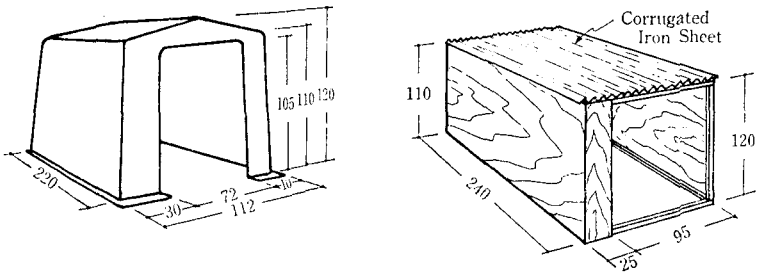
b. Environmental Modification in Winter

1) Wind Protection Effects

The investigation of wind protection by a calf hutch was made using an actual size plywood calf hutch as shown in Fig. 1 at the Agricultural Experiment Farm, Hokkaido University in May to July, 1979. Wind velocities were measured using small three cup anemometers (Rikoken-type) at points from A to G at a height of 60 cm as shown in Fig. 2. The point A was set far enough from the calf hutch so that the wind velocity at A might not be influenced by it. Wind velocity data were obtained by calculating averages for 5 minutes. To evaluate the influence of wind direction the calf hutch was set at clockwise angles of 0°, 45°, 90°, 135° and 180° toward wind direction as shown in Fig. 2. The angle of 0° indicates that wind blows toward the front opening of the calf hutch. The wind tunnel experiment was also made to verify the field experiments using an open-circuit wind tunnel with cross-section of 170×170 cm and a scale model of 1/12 in regard to two different wind velocity levels, since the wind velocity and direction are not steady in the field and also the wind velocities inside the hutches were sometimes below the measurable range of the anemometer used in the field. A hot wire anemometer was used in the wind tunnel experiment.

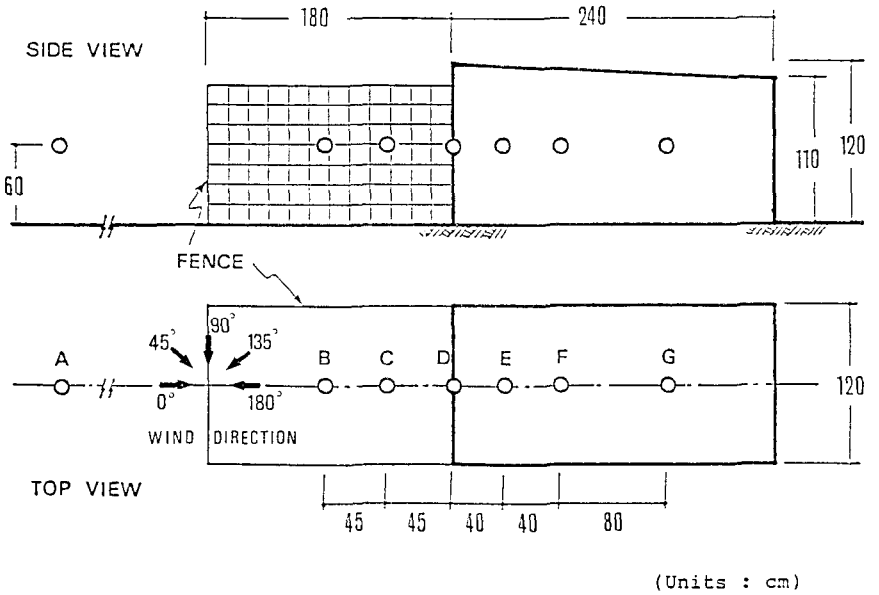
2) Reduction of Cold Stress

In order to estimate the reduction of cold stress by the calf hutch the wind chill index (WCI) was used. The WCI indicates rate of heat loss and



(a) FRP calf hutch (b) Plywood calf hutch

Fig. 1. Calf hutches used for measuring thermal environment.



(Units : cm)

Fig. 2. Dimensions of tested calf hutch, wind directions and measuring points of wind velocity.

expresses combined effects of wind and temperature. The indexes were calculated from the data of wind protection effects, using a following equation (ASHRAE, 1981 b):

$$\begin{aligned} WCI &= (10.45+10\sqrt{V}-V)\ (33-ta) \quad kcal/hr\cdot m^2 \\ &= 1.163\times(10.45+10\sqrt{V}-V)\ (33-ta) \quad W/m^2 \end{aligned} \qquad (1)$$

where WCI=Wind chill index
V=Wind velocity (m/sec)
ta=Air temperature (°C)

2. RESULTS AND DISCUSSION

a. Actual Inside Temperature in Winter

The actual inside temperature of a calf hutch at the SAHES in winter, 1980 was −2.1°C in average with the minimum daily mean of −10.5°C and the maximum daily mean of 10.3°C. In the same period, the outside air temperature was −4.6°C in average with the minimum and maximum daily mean of −13.2°C and 8.8°C respectively. The difference in air temperature between inside and outside of a hutch was only 2.5°C in average. Thus, calves in calf hutches are exposed to lower temperatures than the lower critical temperature, which was reported as 0°C for onemonth-old calves (WEBSTER, 1974). Since calf hutches are recommended to use in areas where the average temperature is −10°C, calves are exposed to the cold environment far below the critical temperature.

b. Environmental Modification in Winter

1) Wind Protection Effects

Wind velocity distribution in the calf hutch for various wind directions is shown in Fig. 3. The Y-axis indicates a wind velocity ratio of each point to a point A where no influence of the calf hutch is observed. Wind velocities decreased drastically inside the calf hutch regardless of wind direction, and it was nearly calm at point G. Result similar to Fig. 3 was obtained from the wind tunnel experiment, although a little more wind protection effects were shown in the wind tunnel experiment than in the field

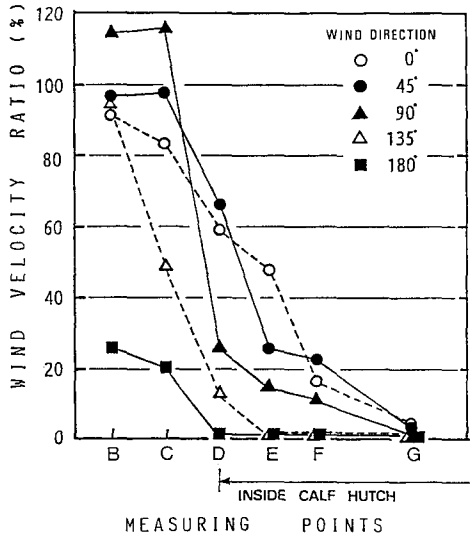


Fig. 3. Wind velocity distributions of calf hutch for various wind directions. Wind directions are shown in Fig. 2.

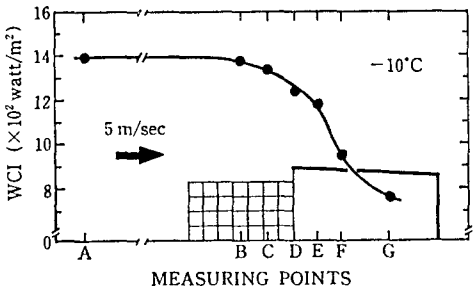


Fig. 4. Estimate of wind chill indexes (*WCI*) for air temperature of −10°C, wind velocity of 5 m/sec and wind direction toward open front at point A.

experiment. Similar results with respect to wind protection effects were reported by HARTMAN and GWAZDAUSKAS (1982) although their measurements were not made in detail.

2) Reduction of Cold Stress

Supposing it is a windy day in Tokachi district, Hokkaido, where air temperature is $-10°C$ and wind blows toward open front at the velocity of 5 m/sec, wind velocities at each point were obtained from Fig. 3. WCI's were calculated using Eqn. 1, and illustrated in Fig. 4.

Although estimated WCI is 1400 W/m^2 at point A far from a calf hutch, it drastically decreases as the measuring point goes inside the hutch and finally becomes about 800 W/m^2 at point G. The value of WCI does not present a true heat loss from calves since it was developed for humans, but would somewhat indicate the degree of cold stress in calves.

Calves in calf hutches are still exposed to cold stress due to the low temperature itself, although they are protected from the cold stress due to wind.

From the results above, calf hutches should be set in winter so that the prevailing wind blows from behind the hutches. Tight construction of calf hutches is also required in winter.

B. BEHAVIOR OF CALVES HOUSED IN CALF HUTCHES

In the previous section, The modification of undesirable thermal environment by the calf hutch was measured. However, this modification effects are not evaluated from the calves' point of view.

The objective of this study is to investigate how calves use the "boxes" (calf hutches) in relation to thermal environmental factors in winter by observing their behavior.

The role of the "boxes", in other words, the difference in environment for calves between outside and inside a calf hutch will be verified through this investigation.

1. PROCEDURES

a. Observation Period, Site and Calves

The observation of calf behavior was made in 81 days from January 15th to April 4th in 1980 in the SAHES. Three calves born at the SAHES were housed in FRP calf hutches respectively at the day of the birth. Slatted boards made of rafters (4.5×4.5 cm) were set inside calf hutches as a floor, and straw was spread on the boards. The calf could move freely both inside and outside the calf hutch within a wire fence (Fig. 5).

b. Method of Observing Calf Location

Automatic devices observing calf location were developed and installed on both sides of the hutch walls (Fig. 5). The device consists of two pairs of photo switches. The positions of the devices were determined by trial and error so as to most effectively sense the location of the calf. The on-off signals from the devices were recorded by an electromagnetic oscillograph. The location of the calf was judged from the response curves as shown in Fig. 6. The occupancy ratio (ratio of time animal spent inside a calf hutch to 24 hours) was then obtained.

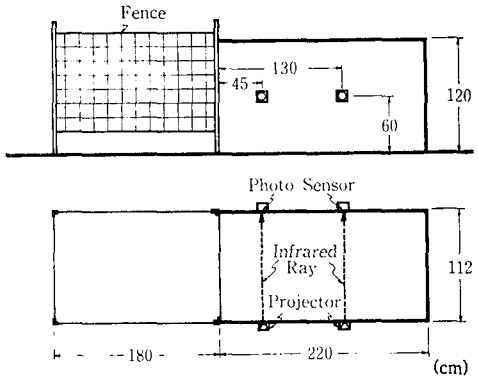
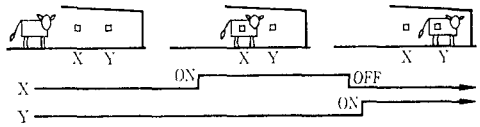
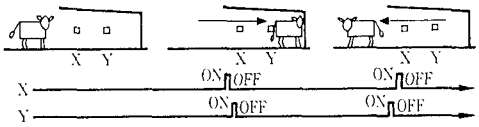


Fig. 5. Calf hutch and automatic device observing calf location.



(a) Response when calf moves slowly into back portion of calf hutch.



(b) Response when calf moves quickly into and out of calf hutch.

Fig. 6. Calf movement and response of recorder.

The advantages of the device are: the behavior of the calf is not disturbed because an infrared ray (950 nm in wave length) is used; and lighting at night is not needed. On the other hand, reading the response curves is tedious and sometimes difficult when the calf moves quickly into and out of a calf hutch or move around the photo switches. Therefore, the reliability of the device was tested by comparison with manual observation which was made at intervals of 15 minutes for 24 hours.

c. Measurement of Thermal Environmental Factors

Measured thermal environmental factors were temperatures inside and outside calf hutches, duration of sunshine, amount of insolation, and wind velocity. Temperatures were measured with thermocouples and recorded by a digital recorder every hour. Wind velocity was measured with a small three cup anemometer (Rikoken-type) at a height of 150 cm from the ground above the wire fence. Wind chill indexes were calculated from outside temperature and wind velocity using Eqn. 1. Duration of sunshine and amount

of insolation were measured at the weather station in the SAHES.

2. RESULTS AND DISCUSSION

a. Thermal Environment During Observation

Average, maximum and minimum values of each measured thermal environmental factor are shown in Table 1. The average outside temperature was −4.5°C (From −12.7 to 8.8°C) and 2.5°C lower than the average temperature inside calf hutches. Since the reliable wind velocity range of the anemometer was more than 0.7 m/sec according to the calibration before the observation, the data less than 0.7 m/sec were eliminated. Therefore average wind velocities of 53 days were used.

b. Comparison between Automatic Devices Observing Calf Location and Man Observation

Table 2 shows the periods of time calves spent inside calf hutches obtained from both the automatic devices observing calf location and man observation. As the total difference in the periods between the two methods for three calves was very little (3 minutes to 18 minutes), the occupancy ratios calculated from the data obtained by the automatic devices observing calf location are considered satisfactory.

c. Average Occupancy Ratios of Calves

Average occupancy ratios of three calves as well as maximum and

TABLE 1. Thermal environmental factors during winter observation

Thermal environmenial factors	Mean	Min. daily mean	Max. daily mean	No. of data
Outside ambient temp. (°C)	−4.6	−13.2	8.8	75
Ambient temp. inside hutch (°C)	−2.1	−10.5	10.3	76
Wind velocity (m/sec)	1.4	—	3.3	53
Duration of sunshine (hr)	5.5	0.1	9.9	79
Amount of insolation (MJ/m^2)	10.88	2.22	18.93	79
WCI (W/m^2)	924	536	1136	50

TABLE 2. Comparison of occupancy time between man observation and photo sensor (Units : min)

	No. 1	No. 2	No. 3
Man observation (15 min. interval)	1275	1305	1205
Photo sensor & automatic recorder	1272	1287	1195
Difference	3	18	5

minimum values are shown in Table 3. Because of troubles in the electromagnetic oscillograph, many of the occupancy ratios could not be obtained, especially for the calf No. 3. On an average for the whole winter observation period, calves spent from 85% to 90% of a day inside the hutch, which is similar to the results for winter (84.9%) reported by IKETAKI *et al.* (1983). The minimum occupancy ratio was 71%, while the maximum was 99%.

d. Relation between Occupancy Ratio and Thermal Environmental Factors

The correlation coefficients between occupancy ratios and various thermal environmental factors were calculated and tabulated in Table 4. Little cor-

TABLE 3. Average, minimum and maximum occupancy ratios in winter

	No. 1	No. 2	No. 3
Average occupancy ratio (%)	89.8	85.6	87.8
Maximum occupancy ratio (%)	99.3	98.5	97.8
Minimum occupancy ratio (%)	74.3	70.9	77.7
Number of data	64	49	20

TABLE 4. Correlation coefficients between occupancy ratios and various meteorological environmental factors

Meteorological Factors	Calf No.	No. of data	Correlation Coefficient	Regression formula
Outside ambient temp.	No. 1	60	−0.071	
	No. 2	46	−0.020	
	No. 3	19	0.192	
Ambient temp. inside calf hutch	No. 1	61	−0.262*	$Y=-0.364X+89.1$
	No. 2	47	−0.211	
	No. 3	20	−0.146	
Wind velocity	No. 1	42	0.781**	$Y=11.3X+75.2$
	No. 2	34	0.682**	$Y=13.3X+68.4$
	No. 3	17	0.781**	$Y=10.9X+72.4$
Duration of sunshine	No. 1	62	−0.181	
	No. 2	47	−0.281	
	No. 3	20	0.099	
Amount of insolation	No. 1	62	−0.210	
	No. 2	47	−0.301*	$Y=-0.0259X+92.2$
	No. 3	20	0.008	
Wind Chill Index	No. 1	39	0.433**	$Y=0.0219X+70.1$
	No. 2	31	0.317	
	No. 3	16	0.316	

*: $P<0.05$, **: $P<0.01$

relation was observed between outside temperature and occupancy ratio, as shown in Fig. 7 for the calf No. 1. This is considered to be because the temperature difference between inside and outside calf hutches is originally small (2.5°C) and does not change very much according to the change of outside temperature. Calves would not feel the difference in cold stress due to such a temperature difference itself.

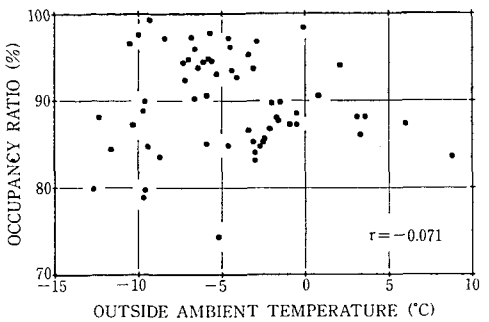


Fig. 7. Correlation between occupancy ratio and outside ambient temperature.

Although only one of three calves showed the significant negative correlation ($P<0.05$) between inside temperature and the occupancy ratio, the inside temperature does not seem a strong factor determining the occupancy ratio.

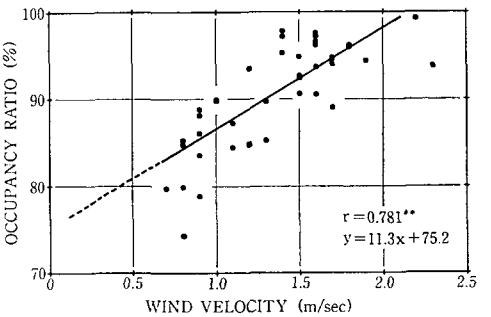


Fig. 8. Correlation between occupancy ratio and wind velocity.

Correlation between amount of insolation and the occupancy ratio was negatively significant ($P<0.05$) also for only one of three calves. No significant correlation between duration of sunshine and the occupancy ratio was observed.

However, correlation between wind velocity and the occupancy ratio was highly significant ($P<0.01$), as shown in Fig. 8 for the calf No. 1. Since the wind velocity ratio of inside versus outside in a calf hutch is constant regardless of the outside wind velocity as was stated previously, the wind velocity difference between inside and outside increases as the outside wind velocity increases. Therefore, the high correlation between wind velocity and the occupancy ratio indicates that calves move into calf hutches because of the protection from the strong wind, that is, the protection from the cold stress due to wind. It is not always satisfactory to estimate the occupancy ratio at calm condition from the value of the regression equation (Fig. 8) at the wind velocity (x)$=0$, since the reliable range of the anemometer used for this investigation was more than 0.7 m/sec. The minimum occupancy ratio of three calves, however, was 71%, and nearly equal to that estimated

from the regression equation (Fig. 8) at $x=0$. Therefore, it can be considered that calves tend to stay inside calf hutches about 70% of the day in winter regardless of the thermal environment. This reasons could not be clearly found. It might be caused by the bedding on the slatted boards. The remaining 30% occupancy is considered to be determined mainly by wind velocity, since the coefficients of determination calculated from the correlation coefficients are from 0.47 to 0.61.

The correlation between wind chill indexes and the occupancy ratios was a little more than that between temperature itself and the occupancy ratio, although it is an expected result because the wind chill indexes were obtained from both temperature and wind velocity.

The results stated above indicate that the calf hutch has an important role as a wind shelter which can decrease cold stress on calves housed in a cold climate.

In this investigation, the influences of snowfall and drifting snow on the occupancy ratio were not observed. But it can be estimated that the occupancy ratio increases because of the offered protection from cold stress due to those severe weather conditions. BATES *et al.* (1985) stated the tendency of the calf to occupy the back portion of the hutch during periods of extremely bad weather. Study on the location of the calf inside the hutch in the relation to the weather conditions also needs to be made.

C. AIR CHANGE RATE IN CALF HUTCHES

The sufficient fresh air supply is usually pointed out as one of the remarkable features of the calf hutch. However, it is always stated abstractly, never quantitatively. In winter, calves stay inside the hutches most of the time (85% to 90%) as was presented previously. Thus, the evaluation of the fresh air supply to the calf hutch should be made quantitatively. In addition, various covers to the front opening of the hutch can be seen in Hokkaido, especially on farms raising dairy beef calves. Effects of the covers on the air exchange should also be evaluated.

The objective of the study on this section is to obtain the air change rates of calf hutches under various conditions.

1. PROCEDURES

a. Construction of a Tested Calf Hutch

The dimensions of the calf hutch used for this experiment were basically the same as the plywood calf hutch used for measuring thermal environment. Although the roof incline of a hutch is normally 1/24, it was changed to flat (no incline) and 1/8 (Fig. 9), in order to investigate an effect of inclines on the

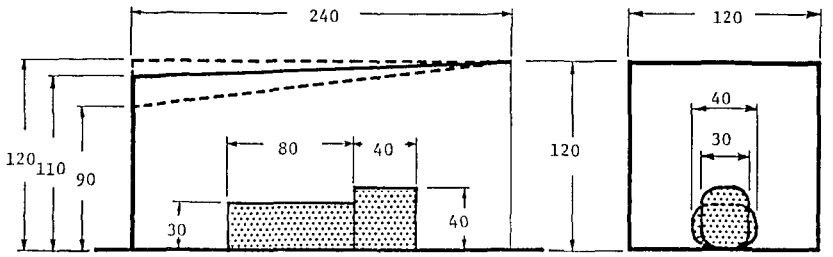


Fig. 9. Dimensions of a tested calf hutch and a calf model (units: cm). Roof incline of the calf hutch (normally 1/24) can be changed to no-incline and 1/8.

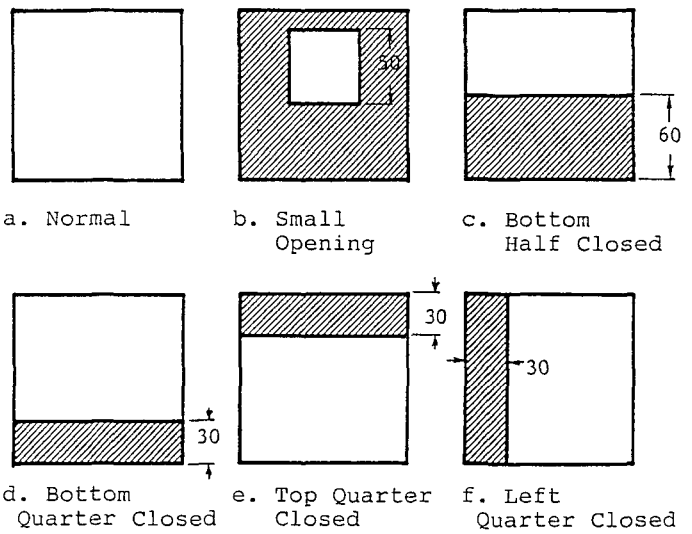


Fig. 10. Covers to a front opening of a calf.

air change rate. For the investigation of an influence of covers to a front opening on the air change rate, five types of covers were also prepared: small opening of 50×50 cm; bottom half closed; top quarter closed; bottom quarter closed; and left quarter closed, as shown in Fig. 10. These types of covers can be seen on farms in Hokkaido (SAHES, 1983).

b. Calf Model

A calf model which has similar size (Fig. 9) and amount of sensible heat production to a living calf was made, since it is difficult to measure ventilation rates with a real calf inside a calf hutch.

The amount of heat produced by the model calf was calculated (at 8.4

MJ/day) on the basis of both the estimated ratio of sensible heat to total heat production (70%) and the total heat production (530 KJ/kg$^{0.75}$·day) reported by MOROOKA *et al.* (1983) for calves of 63.3 kg in average body weight at 7 weeks of age in May. The heat producing surface area of the calf model was also nearly equal to that of a real calf. According to BRODY (1964), a body surface area (A m^2) is calculated from a body weight (W kg) with the following equation:

$$A = 0.15\, W^{0.56} \qquad (2)$$

The body surface area calculated for this case was about 1.5 m^2. The calf model was set at the center of the calf hutch in a lying posture as shown in Fig. 9.

c. Experiment Items

The following four experiments were made:

(a) Air change rate in a normal calf hutch (no front cover and roof incline of 1/24) in calm condition

(b) Influence of roof inclines on air change rate in calm condition

(c) Influence of covers to a front opening on air change rate in calm condition

(d) Influence of wind on air change rate

Experiments (a), (b) and (c) were made in calm condition, that is, in the case when the driving force of the air exchange was only natural convection due to temperature difference between inside and outside. Experiment (d) concerned the case when the driving force was both natural and forced convection. Experiment (c) and (d) were made by setting the roof incline as normal.

d. Method of Measuring Air Change Rate

The measurement of air change rate was made using gas tracer method with carbon dioxide gas. The change in concentration of carbon dioxide gas in the hutch was measured three times for each condition at point C in Fig. 11. The distribution of air change rates in the hutch was also obtained by measuring the changes in concentration at points A–F (thirteen times at C; three times at A; and twice at other points). Air temperatures inside and outside the calf hutch were measured using Cu–Co thermocouples.

The air change rate was calculated with the following equation (MIHARA, 1980):

$$N = -\frac{1}{t} \log \frac{C_t - C_{out}}{C_0 - C_{out}} \qquad (3)$$

where N=Air change rate (AC/hr)
t=Period of time after opening front cover (hr)
C_t=CO_2 gas concentration inside a calf hutch at time=t (ppm)
C_{out}=CO_2 gas concentration of outside environment (ppm)
C_0=CO_2 gas concentration inside a calf hutch at time=0 (ppm)

These experiments were made in a laboratory having 1,200 m² of floor area to obtain steady wind velocity and direction. Three 50 cm fans were used to produce the wind and the wind profile was almost logarithmic around the calf hutch.

2. RESULTS AND DISCUSSION

a. Air Exchange Rate in Normal Calf Hutch for Calm Condition

The ventilation in a calm condition is produced by natural convection due to heat production from the calf model. Air change rates at six points inside a calf hutch were shown in Fig. 11. The air change rates inside the calf hutch were 103 AC/hr in average and ranged from 78 to 163 AC/hr. These rates are far higher than the winter rates of well ventilated dairy barn with natural ventilation system (11 to 31 AC/hr; ISOBE *et al.*, 1984), and are even twice as many as the summer maximum rate for a stall dairy barn (40 AC/hr) recommended by BATES and ANDERSON (1984 a).

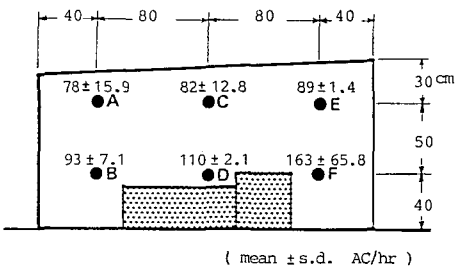


Fig. 11. Distribution of numbers of air changes per hour inside a calf hutch under calm condition with temperature difference of 1.6°C between inside and outside.

b. Influence of Roof Inclines on Air Change Rate in Calm Condition

The influence of rood incline on air change rate in calm condition is shown in Table 5. There was no significant difference in air change rates between normal incline (1/24) and others (no incline or 1/8). Therefore, the influence of the roof inclines on air change rate does not need to be considered in determining the incline, although an adequate roof incline is effective to drain off the rain from the roof.

c. Influence of Various Covers to Front opening on Air Change Rate in Calm Condition

The air change rate drastically decreased (14±1.2 AC/hr) when the front opening was covered leaving only the small opening of 50×50 cm as shown in Table 5. It also decreased to half the rate (42±3.8 AC/hr) when

TABLE 5. Numbers of air changes per hour (AC/hr) in calf hutches under various conditions

Conditions	No. of AC/hr (Mean±S.D.)
Calm	
Nomal[1]	82±12.8
Front covers	
Small opening	14± 1.2**[2]
Bottom half closed	42± 3.8**
Bottom quarter closed	97±12.5
Top quarter closed	66± 4.6
Left quarter closed	75± 4.5
Roof incline	
No-incline	73± 6.2
1/8	76± 0.6
Wind velocity=1 m/sec	
Toward open-front	
Normal	182±26.3**
Front covers	
Small opening	29± 1.2**
Bottom half closed	78± 8.9
Toward back-wall	
Normal	61± 3.8*[3]

1) "Normal" indicates no front cover and roof incline of 1/24.
2), 3) Test of significancy for difference from the number of AC/hr for the condition of calm-normal.
**P<0.01, *P<0.05.
4) Number of measurements for condition of calm-normal was 13, and that for the other conditions was 3.

the bottom half of the front opening was covered. When the quarter of the front opening was covered, however, the air change rates (66 to 97 AC/hr) were not significantly different from the normal calf hutch, regardless of the positions of the quarter cover.

In Hokkaido, Japan, calf hutches are sometimes used with the front opening partially covered by battens on dairy farms or farms raising dairy beef calves (SAHES, 1983), although BATES *et al.* (1985) recommended an entirely open front. This is because the farmers try to reduce cold stress or to save the cost of building a front fence. Calf hutches are still effective compared to typical calf raising facilities because the separation prevents each calf from direct contact with other calves or older cattle. However,

since air purity is considered to be the most important characteristic of a calf hutch, any covers more than a quarter of the front opening should not be used although quarter covers are acceptable.

d. Influence of Wind on Air Change Rate

When calf hutches are used on farms, the calm conditions is seldom experienced. The bottom half of the Table 5 shows the results of the measurements for various conditions at the wind velocity of about 1.0 m/sec at a height of 60 cm. The air change rate in a normal calf hutch for a wind blowing toward the front opening was more than twice as many as that in a calm condition.

The air change rate markedly decreased (29 ± 12 AC/hr) for wind direction toward the front opening in the calf hutch having only a small opening of 50×50 cm at the front. Although the bottom half cover to the front opening also decreased the air change rate, the difference from that of a normal calf hutch was not significant, probably because of the small number of measurements taken.

Although sufficient fresh air was supplied in a normal calf hutch with the wind direction toward a front opening, the orientation of a calf hutch in cold winter should be carefully determined, since the wind velocity inside a hutch (at point F) is still about 20% of that outside hutch. For the strong wind, calves would feel cold stress due to the wind. Therefore, in winter calf hutches should be located so that the prevailing wind hits the back.

D. CONCENTRATION OF BACTERIAL AEROSOLS

It is not unusual that the mortality rate of calves reaches 20% on dairy farms in the U. S. A. (JENNY *et al.*, 1983) and on farms raising dairy beef calves in Japan (NAKANE, 1979). Mainly pneumonia is considered to be the cause of the high mortality rate. This evidence would suggest the possibility of air-borne infection of the disease. Although high air change rate in calf hutches showed the sufficient amount of fresh air in the calf hutch, it should be proved by the parameter more closely relating to the infection of the disease. The bacterial aerosol concentration was chosen as the parameter in this study.

The objective of the study on this section is to evaluate the air purity in calf hutches by measuring bacterial aerosol concentrations.

Samplings of bacterial aerosols were also made in the other facilities as well as calf hutches at both the SAHES and a farm in Sapporo (I Farm) in order to compare the levels of the concentrations. The ditribution of the bacterial aerosol concentrations around calf hutches will also be discussed.

1. PROCEDURES

a. Method of Samling Bacterial Aerosols and Calculation of Concentration

Although there are various methods of sampling bacterial aerosols, the filtration method was chosen for this study as it is so simple that researchers not having much expert knowledge on microoganisms can treat with it.

A schematic diagram of the filtration method used in this study is shown in Fig. 12. A certain amount of the air (about 7 litters) is sucked through a membrane filter (0.47 μm in pore size) for 30 seconds and thus bacterial aerosols are sampled on the filter. A liquid medium for total count (M-TGE broth) is poured from the bottom of the filter holder. After the incubation at 25°C for 48 hours, bacteria colony forming particles (BCFP) on the filter are counted.

Since bacterial aerosol concentrations have been seldom measured in livestock buildings and also the concentrations are extremely high, the sampling method has not been well established. Thus the sumpling air volume and incubation temperature mentioned above were determined by another experiment previously made (HOSHIBA *et al.*, 1984).

An average BCFP is obtained by calculating a geometric mean of counted BCFP's. The following equations are used so that a logarithm of BCFP could be calculated even when no BCFP is counted:

$$\bar{X}g = 10^p - 1 \tag{4}$$

$$p = \frac{1}{n} \sum_{i=1}^{n} \log (Xi+1) \tag{5}$$

where $\bar{X}g$=logarithmic mean of BCFP's
p=common logarithm of average number of BCFP
n=number of sampling times
Xi=BCFP at each sampling

In this study, the concentration of bacterial aerosols is expressed as the number of BCFP per 10 liters of the air (BCFP/10 l).

b. Sampling in Calf Hutches

1) At the SAHES

Investigations were made at the SAHES four times in total: twice in summer (August and September) of 1980; and twice in winter (February and March) of 1981. Three types of calf hutches were used in summer: plywood calf hutch (Fig. 1 b), FRP calf hutch (Fig. 1 a), and plywood calf hutch without a back wall. Three hutches for each type, i. e. 9 hutches

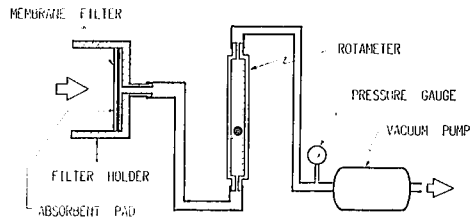


Fig. 12. Schematic diagram showing instrument for measuring concentration of bacterial aerosols (filtration method).

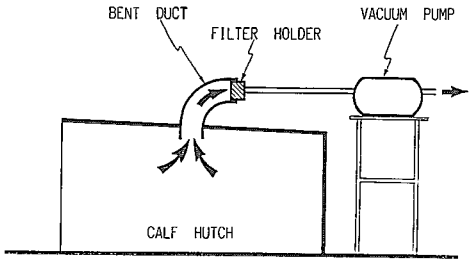


Fig. 13. Schematic diagram showing method for measuring concentration of bacterial aerosols inside a calf hutch without disturbing the calf.

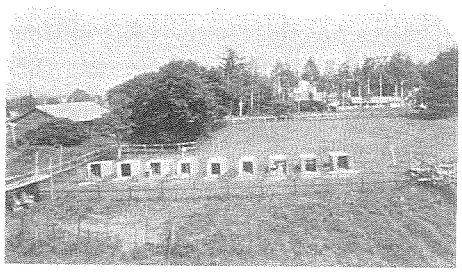


Photo 1. Calf hutches and experiment site in Shintoku Animal Husbandry Experiment Station.

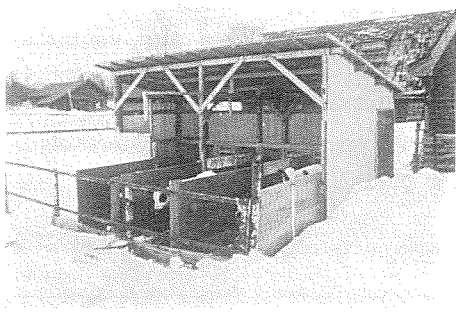


Photo 2. A "chained hutch" in Shintoku Animal Husbandry Experiment Station.

In total were set as shown in Photo 1. The center hutches of the three for each type were used for measuring thermal environmental factors, and calves were housed in other 6 hutches. In winter, only three plywood calf hutches were used with calves housed. Although bacterial aerosols were sampled only inside calf hutches in August, 1980, those inside fences and between or around hutches were sampled at the other measurements (September, 1980; February and March, 1981) as well as inside calf hutches to investigate distribution of bacterial aerosol concentrations around calf hutches. The sampling height was about 60 cm from the ground. During the sampling inside a calf hutch the calf was sometimes surprised by the procedure and moved wildly. This movement rapidly increased the concentration of bacterial aerosols. Therefore, the sampling inside the hutch was made a short time after the calf moved outside to the fence area at the SAHES.

2) At I Farm

investigations were also made at I Farm twice (August and December) in 1984, using three normal plywood calf hutches.

Bacterial aerosols inside the calf hutch were sampled without disturbing the calf by setting a bent duct on the roof of the hutch as shown in Fig. 13. The sampling loss in the bent duct was theoretically estimated at under 1% for particles less than 15 μm (SATO, 1985).

c. Sampling in the Other Facilities

1) At the SAHES

Sampling were also made in other facilities at the SAHES for comparison. A conventional barn housing cattle of all ages was used in both summer (August, 1980) and winter (March, 1981). Numbers of stalls, pens and cattle housed are shown in Table 6. Ventilation of the barn in summer was made by natural draft, opening all doors and windows. In winter, all doors and windows were closed and ventilation was not positively made. No serious health problems have arisen for raising calves in this barn. A "chained hutch" (Photo 2) was also used in winter as the facility for comparison. The concentration of bacterial aerosols in the outside environment was measured for each investigation.

TABLE 6. Number of stalls or pens, and number of cattle housed at the measurement in the conventional barn, Shintoku Animal Husbandry Experiment Station

Stage	Number of stalls & pens	No. of cattle housed	
		Summer	Winter
Adult cow	35	17	23
Calf (4-10 days)	8	27	19
Calf (11days-3 months)	10*		
Maternity cow	4	0	2

* Two calves are housed in a pen conventionally.

2) At I Farm

A dairy barn, a heifer barn, and a maternity barn in I Farm were used for comparison. The dairy barn was free stall type (60 stalls) and was built in 1983. This barn can be called "an insulated and naturally ventilated barn", having open ridge (DOHKOSHI *et al*, 1984). The heifer barn was built in 1977. It has a width of 10.8 m and a length of 25.2 m, and can

house about 35 heifers. It has a barrel shaped roof with open ridge and was made of corrugated metal sheets. All doors and windows are open in summer. The maternity barn was built in 1972. It has a width of 9 m and a length of 25.2 m, and a mansard roof. Although six fans 30 cm in diameter were operating continuously in winter, ventilation in summer depended on natural draft through doors and windows. About 30 calves after being raised in calf hutches were also housed in the maternity barn in winter.

2. RESULTS AND DISCUSSION

a. Concentration in Calf Hutches

1) At the SAHES

Fig. 14 shows concentrations of bacterial aerosols in the facilities in summer (August, 1980). The oncentration inside plywood and FRP calf hutches was 15 BCFP/10 l and 44 BCFP/10 l respectively, and was a little higher than that in the outside environment (1 BCFP/10 l). However, that inside a plywood calf hutch without a back wall was 4 BCFP/10 l and close to that in the outside environment, because of the high ventilation rate due to removing a back wall.

In winter, on the other hand, the concentration inside plywood calf hutches (3 BCFP/10 l in Fig. 15) was almost equal to that in the outside environment (1 BCFP/10 l). Cold environment might affect on the concentration.

Although no data are available in the literature with respect to the

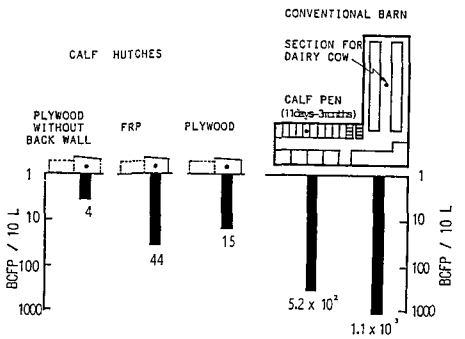


Fig. 14. Concentration of bacterial aerosols in summer in calf hutch and conventional barn, Shintoku Animal Husbandry Experiment Station.

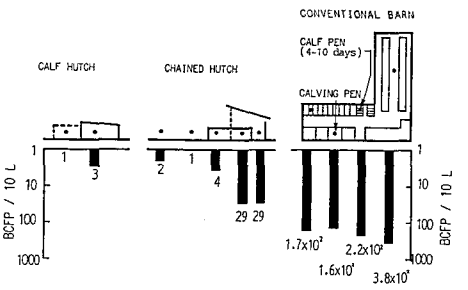


Fig. 15. Concentration of bacterial aerosols in winter in calf hutch, chained hutch and conventional barn, Shintoku Animal Husbandry Experiment Station.

bacterial aerosol concentration in calf hutches, there are only a few reports available on the concentration in calf barns. PRICHARD *et al.* (1981) presented relatively high concentration of 9.9 BCFP/l (99 BCFP/10 l) in a barn for veal calves despite of having a filtering facility to remove bacterial aerosols. WATHES *et al.* (1984) reported the concentration of about 6 and 22 BCFP/l (60 and 220 BCFP/10 l) at 3 and 16 weeks of age respectively in a naturally ventilated room. These data in the literatures clearly showed how clean the environment in calf hutches is.

2) At I Farm

Sampling of bacterial aerosols inside a calf hutch was made without disturbing the calf in I Farm (Table 7). The concentration of bacterial aerosols inside calf hutches was a little higher than that at the SAHES for both summer (59 BCFP/10 l) and winter (22 BCFP/10 l). It may be because of calves' staying inside as well as a higher concentration in the outside environment (16 BCFP/10 l in summer and 3 BCFP/10 l in winter) at I Farm than that at the SAHES. However, these concentrations are still quite low compared with those in calf barns.

TABLE 7. Concentration of bacterial aerosols in I Farm

Facilities		Summer	Winter
Calf hutch	(inside)	59	22
	(fence)	16	12
Dairy barn		268	144
Heifer barn		173	330
Maternity barn		84	223
Outside		16	3

(Units: BCFF/10 1)

b. Comparison with the Other Facilities

1) At the SAHES

The concentrations of bacterial aerosols in the conventional barn in winter were 5.2×10^2 BCFP/10 l at a pen for a heifer, and 1.1×10^3 BCFP/10 l at the center alley for dairy cows as shown in Fig. 14. These values were extremly higher than those in calf hutches. In the literatures, the concentration of 5×10^4 BCFP/m^3 (5×10^2 BCFP/10 l) was reported with respect to a heifer barn having a stocking rate of 6 m/head and at a relative humidity of 80% (JONES *et al*, 1982). HOSHIBA (1980 b) also reported the concentration

of 1×10^2 to 5×10^2 BCFP/10 l in a well ventilated warm type stall dairy barn. These values are similar to that at the pen for a heifer in the conventional barn.

In winter, the concentration at a pen for a calf, a heifer and a maternity cow was 2.2×10^2, 1.7×10^2 and 1.6×10^2 BCFP/10 l respectively as shown in Fig. 15. It is obvious that all values are lower than those in summer. However, the markedly large difference in the concentration between calf hutches (3 BCFP/10 l) and the conventional barn (3.8×10^2 BCFP/10 l at the center alley for dairy cows) was observed in the same manner as that in summer.

The concentration of bacterial aerosols inside the "chained hutch" was low (29 BCFP/10 l) and still decreased toward outside since this facility has a construction which permits sufficient ventilation.

2) At I Farm

The concentrations in the facilities at I Farm were shown in Table 15. The cocentration in the dairy barn were 2.7×10^2 and 1.4×10^2 BCFP/10 l in summer and winter respectively, and were a little lower than that in the conventional dairy barn at the SAHES. It may because the dairy barn at I Farm has higher ventilation rate obtained by natural ventilation system. The relatively lower concentration of bacterial aerosols inside a maternity barn in summer may be caused by very low stocking rate (only 3 maternity cows in the barn). Although the difference is not so large as that in the SAHES, levels of the concentrations were obviously different between calf hutches and other barns such as 22 BCFP/10 l versus 1.4×10^2 BCFP/10 l (in the dairy barn) in winter. The difference was a little more obvious in winter than in summer, probably because the windows and doors in the barns could not be open in winter unlike in summer.

c. Distribution of Concentration Around Calf Hutches

Fig. 16 and Fig. 17 show the distribution of concentrations of bacterial aerosols between and around calf hutches in summer (September, 1980) and winter (February, 1981) respectively. The concentrations were almost the same level as those in the outside environment in both summer and winter. Relatively high concentrations (29 and 58 BCFP/10 l) at points around plywood calf hutches was observed in summer. It was because a calf in the plywood calf hutch located top in Fig. 16 moved wildly in the fence at the sampling.

Since pathogenic microorganisms other than bacteria were not measured in this study, it is not possible to evaluate the likelyhood of air-borne infection resulting only from the concentration of bacterial aerosols. However,

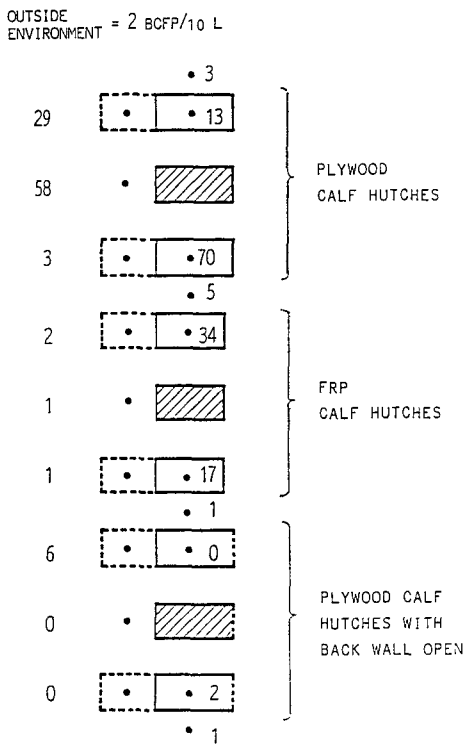


Fig. 16. Distribution of concentration of bacterial aerosols inside and around calf hutches in summer. Calf hutcs with oblique lines were used for measuring meteorological environment.

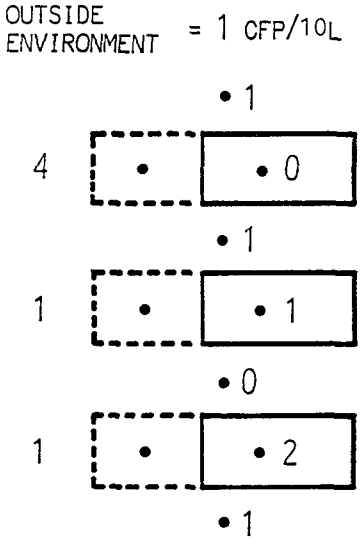


Fig. 17. Distribution of concentration of bacterial aerosols inside and around calf hutches in winter.

it can be considered that the low concentration of bacterial aerosols inside and around calf hutches suggests the low possibility of the air-borne infection at least due to pathogenic bacteria, in other words, semi-isolation (as expressed by ANDERSON and BATES, 1983) with respect to the air-borne bacterial infection.

ANDERSON and BATES (1983) stated that mature cows are sometimes inapparent carriers of disease, and continue to serve as reservoirs disseminating disease organisms to non-immune animals. From their point of view, calves should be separated from older cattle. This can also explain the effectiveness of calf hutches.

From the results stated above the advantages of calf hutches with respect to the air quality are: (1) remarkably low concentration of bacterial

aerosols, sometimes less than one fiftieth of that in the conventional dairy barn ; and (2) nearly isolated conditions with respect to air-borne infection at least due to pathogenic bacteria.

In addition, the protection from contact infectious disease caused by the separate raising system must be noted as one of the important characteristics of calf hutches, although it is not related to the air quality.

IV. GENERAL DISCUSSION

A. ENVIRONMENTAL CHARACTERISTICS OF CALF HUTCHES

Environmental characteristics of calf hutches will be first discussed based on the data obtained by investigating environment of calf hutches from various viewpoints.

It was verified from investigating thermal environmental factors that the calf hutch can improve thermal environment in winter. The calf hutch can produce reduction of cold stress due to strong wind by its wind protection effects. It was also presented that calves still exposed severe cold environment in winter depending on low temperature itself. The temperature inside calf hutches in winter was close to the outside temperature (difference of only 2.5°C in average), and is expected to be much lower than the lower critical temperature of calves.

The behavior study showed that calves used calf hutches to protect themselves from cold stress due to strong wind in winter. They did not stay inside hutches longer than usual when temperature dropped down, but did stay longer when strong wind blew.

On the other hand, the air quality in calf hutches was also evaluated by measuring air change rates and bacterial aerosol concentrations.

The air change rates in calf hutches were extremely high regardless of conditions such as roof inclines and wind directions except when most of the front opening is covered. This shows fully plentiful fresh air can be supplied in calf hutches unless most of the front opening is covered.

The concentrations of bacterial aerosols in calf hutches were remarkably low regardless of seasons and were sometimes less than one fiftieth of that in the conventional dairy barns. The distribution of the concentrations around calf hutches suggested that nearly isolated conditions with respect to air-borne infection at least due to pathogenic bacteria can be obtained in calf hutches.

Based on the data described above, it must be first considered in which season the remarkable features of the environment in calf hutches can be seen. It is clear that the difference in thermal environment between the

calf hutch and the conventional indoor housing system is much more obvious in winter than in summer, and that the difference in the air quality between the facilities, however, does not differ very much regardless of the seasons. Therefore, the remarkable environmental characteristics in the calf hutch can be seen during winter in cold areas.

In winter, although effective temperature is improved by a wind protection effect of the calf hutch, it is not unusual that the temperature drops down below −20°C in severe cold areas such as Tokachi district in Hokkaido. Thus, calves raised in calf hutches are exposed to severe cold environment or severe thermal environment in winter.

Whereas, from the investigation of bacterial aerosol concentrations, the air quality in calf hutches can be expected to be almost the same as that in the outside environment in winter.

Therefore, it is concluded that the essential environmental characteristics of calf hutches can be seen during winter in cold areas and are the simultaneous existence of severe thermal environment and high air quality. These environmental characteristics are thought to be opposite to those in conventional indoor facilities for calves, which are often observed acceptable in thermal environment but poor in air quality.

B. PERFORMANCE OF CALVES RAISED IN CALF HUTCHES

In order to discuss the significance of the environment in calf hutches, the performance of calves raised in hutches must be known.

Six experiments in total were made using 45 Holstein calves to investigate the performance of calves raised in calf hutches from 1978 to 1982 at the SAHES as a part of the research project on the calf hutch (OKAMOTO *et al.*, 1983). Four experiment out of six were conducted in winter, and three of the four (Experiment 1, 2 and 3) were made in comparison between calf hutches and two temperature controlled (at about 10°C) rooms (warm type rooms): poorly ventilated room and well ventilated room. There was no significant difference in daily gains or monthly growths of withers height and chest girth between calf hutches and warm type rooms during the periods of 1 to 4, 1 to 8 and 1 to 12 weeks except the growth of chest girth in Experiment 2 which was recovered at 12 weeks of age. However, calves in calf hutches tended to consume more calf starter than those in warm type rooms, although statistically significant difference between the facilities were observed only in Experiment 3, because of relatively high individual differences. Average calf starter consumption of hutch calves from 1 to 7 weeks of age for three experiments was 36 kg and was 40% more than that of calves in warm type rooms (25 kg). Calves in hutches had

less health problems than those in warm type rooms where coughing was often observed especially in the poorly ventilated room.

Similar results can be seen in a paper presented by McKNIGHT (1978). He stated that hutch calves grew as well as, consumed more starter and required less medical treatment than did calves housed indoor.

Most papers showed comparable growth of calves in calf hutches to those housed indoor (JORGENSON *et al.*, 1970 ; WARNIC *et al.*, 1977). Although several reports indicated no significant differences in feed consumption at about 14 weeks of age, MURLEY and CULVAHOUSE (1958) showed slightly more hay consumption in calf hutches than indoor pens. Since lower critical temperature of new born and one month old calves were evaluated as 9°C and 0°C respectively by WEBSTER (1974), hutch calves less than about 2 months age is thought to have lower feed efficiencies than calves raised in indoor pens during winter in cold areas.

Many cases of improvement in health problems by using calf hutches were reported. DOHKOSHI (1985) showed a remarkable decrease of mortality from 40% to less than 10% of dairy beef calves during first 8 months by using calf hutches at a farm in the Shakotan Peninsula, Hokkaido. A magazine (Hoard's Dairyman) presented many cases, for example reduction of calf loses from 15 to 20% down to 5 to 10% according to Owen, Univ. of NEBRASKA (1978 a) ; only 17 losses out of 333 calves (1978 b) ; from 10% loss to less than 2% (2 losses out of 140 calves) at a WISCONSIN farm (1973). In most of the cases, pneumonia had been the most troublesome disease before calf hutches were used.

The questionnaire made by HOMES *et al.* (1983) showed the reasons of using calf hutches : 38% responded calf health ; 2% responded housing cost ; and 27% responded both cost and herd health. Another questionnaire made by the SAHES (1983) indicated more than 80% of farmers using hutches recognized the effectiveness on scours and coughing.

According to the studies at the SAHES and many reports, the performance of calves raised in calf hutches in comparison with conventional calf housing system, can be summarized as (1) comparable growth, (2) lower feed efficiency, (3) much less disease problems, especially with regard to respiratory disease, and finally (4) excellent overall performance.

C. ENVIRONMENTAL REQUIREMENTS FOR CALVES

The significance of the environment of calf hutches will be discussed considering characteristics of both the environment and the performance. Calves raised in calf hutches grow comparable to those in conventional calf

housing system, but consume more feed because of severe cold environment. Despite the disadvantage caused by the severe thermal environment, overall performance of calves in hutches is excellent. This is because calves in hutches have less disease problems and less mortality, that is, both airborne and contact infection of disease can be restricted in calf hutches. It was revealed from investigation of bacterial aerosol concentration that nearly isolated conditions are obtained in calf hutches with respect to air-borne infection at least due to pathogenic bacteria. Thus it is reasonable to relate the excellent performance to high air quality. Of course, the low mortality of calves can not be explained only from the air quality. The protection from contact infection of disease would be another important factor affecting on minimizing disease problems. However, it has been reported that calves raised in a dairy barn individually without being allowed to contact with each other still had remarkable higher mortality than those raised in calf hutches (DAVIS, 1952). In addition, BATES and ANDERSON (1979) reported the effect of air change rate on calf health. The medical treatment for calves in the room having 4 air changes per hour costs only about 60% of that having one air change per hour. These results also support the relationship between the low mortality and the excellent air quality. Therefore, high air quality is considered to be one of the most important factors minimizing mortality of calves or producing the excellent performance in calf hutches.

From the discussion above, it can be concluded that thermal environment is not always the most affecting environment on the performance of calves, and air quality can be comparable or may often be preferential environment to thermal environment for calves.

This conclusion is the most significant for environment in calf hutches since the comparison in importance between thermal environment and air quality has little been intended, and can hardly be made in the other facilities, although it is still insufficient and not quantitatively made.

One might think there is no need of the box (calf hutch) if the air quality is as important as was stated. However, the studies on thermal environment in the calf hutch and behavior of calves clearly showed the necessity of the box as the facility for preventing calves from being exposed to severe cold environment. This suggests that there must be certain balance between thermal environment and air quality for practical environmental managements.

D. REARRANGEMENT OF ENVIRONMENTAL FACTORS

Based on the conclusion obtained above, the concept of air quality

should be properly arranged in livestock environment. Thus the rearrangement of livestock environmental factors will be attempted considering with practical environmental managements.

The environment which describes the air quality is called here as the aerial environment. The term aerial environment has not been commonly used. CURTIS (1972) used the term "air" environment, and defined its factors as dusts, liquid droplets, microbes, gases, odors and ions (1982). WATHES *et al.* (1984) used the term "aerial" environment paired with the physical environment. Since the air quality is discussed in relation to thermal environment in this study, the "aerial" environment would be suitable.

Numbers of classifications of livestock environment have been presented. Each classification is made depending on different purposes, that is, what the author chooses. For example, ROLLER and STOMBAUGH (1974) took the photoperiodic factor as one of three main environmental factors, because they could explain the relationship between reproduction and environmental factors.

In this study the following classification (Fig. 18) is made to explain the importance of aerial environment for controlling livestock environment practically. First, the environment in livestock buildings is divided into two factors, i. e. social and physical environmental. The social factors involve size and composition of groups, inter animal behavior, and stockmen's management, as defined by other authors (ROLLER and STOMBAUGH 1974; HENRIKSSON, 1982). The physical environmental factors involve factors other

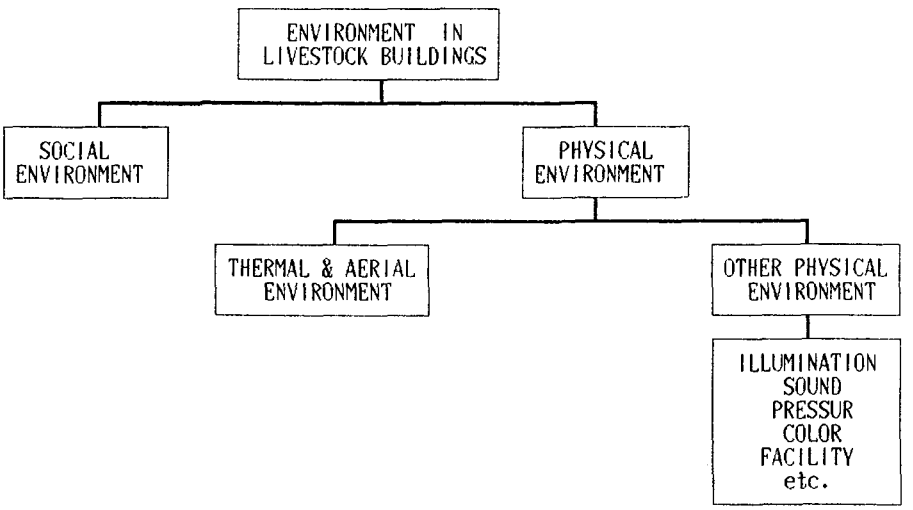


Fig. 18. Classification of environment in livestock buildings.

than the social environmental factors. As a second classification the physical factors are divided into two groups : thermal and aerial environmental factors, and other physical factors. The thermal and aerial environmental factors are those related to ventilation and insulation or heating. These are generally controllable factors in livestock buildings. The other physical environmental factors are those other than the thermal and aerial factors and include illumination, sound, pressure, color, equipment, etc.. These first and second classifications are similar to those by ROLLER and STOMBAUGH (1974). The difference depends only on the purpose of the classification : relationship between livestock reproduction and environmental factors for ROLLER and STOMBAUGH ; and the explanation of the importance of aerial environment for this study.

Further classification of the thermal and aerial environment is made as shown in Table 8. The environmental factors have often been divided from the standpoint of scientific categories, which is, however, of little use for practical environmental management. The classification into thermal and aerial environmental factors is more closely related to practical environmental management. Ventilation, insulation and heating are primary considerations. Although other considerations, such as air filtration and dehumidification can be applied to environmental management, they are usually impractical because of economy, difficulties in maintenance and poor performance. It should be noted that the thermal environmental factors have

TABLE 8. Thermal & Aerial Environment and Environmental Management

Classification from Environmental Management	Environmental Factors	Environmental Management	Scientfic Classification
Thermal Environment	Radiation	Insulation or Supp. Heat	Physical Environment
	Temperature		
	Humidity		
	Air Flow	Ventilation System	
Aerial Environment	Dust		
	Microbesl		Biolog. Env.
	CO_2 Gas		Chemical Environment
	NH_3 Gas		
	Other Odors		

influences on the aerial environmental factors. For example, it is well known that humidity affects the death rate of aerial microbes (JONES, *et al.*, 1982). However, the reverse is not true.

E. BALANCE OF THERMAL AND AERIAL ENVIRONMENT

This classification involves an important concept which relates to the environmental characteristics of calf hutches. Although the practical means of obtaining adequate aerial environment is with ventilation, this also affects the thermal environment. In cold weather the ventilation can produce an adequate aerial environment yet simultaneously lower temperatures below the lower critical temperature for production. This phenomenon clearly can be seen in calf hutches. It would be ideal if both aerial and thermal environment are optimal for the livestock animal. However, it is not always easy to obtain such an environment not only because of an economical problem but also a technical one, especially during winter in cold areas. Filtration may be considered as an alternative method, but it is not economically or mechanically feasible. This relationship leads to the problem of the selection of preferential environment between aerial and thermal, in other words, the balance of the two environments, when an economical and practical environmental management is considered.

It is well known that the lower critical temperature decreases as the age of an animal increases. According to WEBSTER (1981) the lower critical temperature of a new born calf, a calf of one month old and a dairy cow producing 22 kg milk per day is +9°C, 0°C and −26°C, respectively. This change of the critical temperature indicates that optimal thermal environment largely differs depending on the stage of growth.

JENNY *et al*, (1981) investigated the mortality of calves and found a mortality of 9.4% within a month of age which is three quarters of the mortality within 6 months of age. DOHKOSHI (1985) also reported the exponential decrease of mortality of dairy beef calves according to age. These reports indicate that the immunity of calves to infectious diseases increases with age. In other words, the critical aerial environment or the quality level at which health of calves begins to be affected on deteriorates as they grow older. Therefore, it can be concluded that the sensitivity to thermal and aerial environment differs depending on the stage of growth. There must be the best combination of levels of thermal and aerial environment or the best level of ventilation rate for the practical performance in raising calves.

Since required environment together with management (waste handling, feeding) is different depending on the stage of animals, the housing system

also needs to be separated from stage to stage. In Japan, DOHKOSHI (1983) recommended separate housing systems for dairy cattle. Baby calves just after birth have almost no immunity, so they should be raised individually in good aerial environment preventing both direct and air-borne infection. A calf hutch is an adequate facility practically possible in which aerial environment intended to be preferential to thermal.

After weaning, calves have some immunity, but need to be housed in a small groups to develop further immunity. This accustoms the animals to group rearing and may reduce management time. They still must be separated from adult cows, however. BATES and ANDERSON (1982, 1984 b) developed the super calf hutch as a facility for calves after weaning. They recommended moving calves at four or five months of age to a more labor efficient building for housing older animals. Calves still need to be separated from their older counterparts by a wooden barrier wall to prevent direct contact which increase the spread of infectious disease. These animals would survive at lower temperatures and in a little higher concentration of pathogenic bacterial aerosols than they could at an earlier age. As they grow older they can survive in a still more severe thermal and aerial environment. Environmental management in a building housing these older animals might be determined by other management factors such as manure handling, the feeding system and animal movement, as well as the effect on the animals.

As was stated previously, environmental control has been accomplished mainly by using thermal environmental factors as parameters, especially air temperature and humidity, probably because of the relatively well known relation between those factors and the response of animals, the easiness of the sensing of the factors, and well developed controlling systems. It is evident that most agricultural engineers have relied only on the engineering skill of controlling thermal environmental factors and have disregarded other factors which bear on maintaining a healthy livestock environment.

Thus the need to determine the critical levels of aerial environmental factors should be emphasized, especially with respect to bacterial aerosol concentration which is considered more critical to animal health than other factors. If the effects of aerial environment on the performance of calves are evaluated, the way to the mathematical determination of the practically appropriate facility will be opened since the other factors such as the effects of thermal environment and costs of facilities and labor have been evaluated more accurately. For this purpose interdisciplinary studies must be carried out among agricultural engineering, animal science and veterinary medicine.

The most important thing is to allow animals the opportunity to reach their genetic potential for surviving exposure and to adapt to severe thermal and aerial environment. For instance, cattle's ability for surviving exposure and adaptation to severe cold weather should be utilized. The calf hutch is the best example showing it. Engineers should strive to create and environment where animals can reasonably obtain their genetic potential and where management time can be kept at a minimum.

V. SUMMARY AND CONCLUSION

Environmental characteristics of the calf hutch were investigated from four standpoints. Thermal environment in calf hutches was investigated to show actual conditions during severe cold winter and effects of modifying thermal environmental factors by the calf hutches during winter. Behavior of calves in calf hutches was observed to understand the role of the hutches as the facilities for modifying thermal environment. Air change rates were measured to verify how much fresh air is supplied to the hutches in various conditions. Concentrations of bacterial aerosols were also investigated to show the degree of the air quality of the calf hutches in comparison with that of the other facilities including conventional dairy barns.

The discussion was made with respect to the environmental factors bearing on the effectiveness of the calf hutches, and to the significance of the environmental characteristics of the calf hutches in livestock environment.

The following conclusions can be drawn from these investigations:

1. The calf hutch can improve thermal environment for calves, that is, the reduction of cold stress due to strong wind in winter. Calves were, however, still exposed to severe cold environment due to temperature itself during winter in cold areas.

2. The investigation of calf behavior showed that calves used calf hutches to protect themselves from cold stress not due to low temperature but due to strong wind in winter.

3. The air change rates in calf hutches were extremely high regardless of conditions such as roof inclines and wind directions except when most of the front opening was covered.

4. The concentrations of bacterial aerosols in calf hutches were remarkably low compared with those in conventional dairy barns in both winter and summer. Nearly isolated conditions with respect to air borne infection at least due to pathogenic bacteria can be obtained in calf hutches.

5. Essential characteristics of environment in calf hutches could be seen during winter in cold areas and was the simultaneous existence of the ex-

tremely high quality of the aerial environment and the severe thermal environment.

6. It is considered that the high quality of aerial environment is one of the most important factors which bear the excellent performance of calves in calf hutches. The aerial environment was certified comparably or often preferentially important to the thermal environment.

7. Environmental factors were rearranged considering the importance of aerial environment and the practical environmental managements, and need of consideration with respect to the balance between thermal and aerial environment was proposed.

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