Heat and moisture loads in farrowing rooms

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P. C. Clark and McQuitty, J. B. 1989. **Heat and moisture loads in farrowing rooms.** Can. Agric. Eng. **31**: 55–59. Accurate estimates of heat and moisture loads are essential in the design of efficient and economic environmental control systems in farrowing houses. Five farrowing rooms were studied using whole-house calorimetry techniques. Comparisons were made between batch and continuous farrowing regimes, and three flooring types. The total heat load was found on average to be 1850 kJ/h for each sow and litter with 61, 60 and 51% of the total heat exhausted as latent heat for raised crates, crates with partly perforated floors, and crates with fully perforated floors, respectively. The results of this study suggest that the recommended minimum ventilation rates should be increased. Some problems were observed in the design and management of the environmental control systems.

INTRODUCTION

A significant portion of the energy input required in modern swine production facilities is used in farrowing barns (Alberta Agriculture 1982). Minimizing heat loss in the exchange air by reducing the ventilation rates, thus reducing the supplemental heat requirements, offers the greatest potential for reducing energy consumption. Although improved technology in environmental control systems may contribute significantly to reduced energy use, there is a need for reliable animal heat and moisture output data under commercial conditions. Such data are fundamental to the design of efficient and economic environmental control systems that will provide optimal conditions for animal performance while protecting the health of both workers and animals.

The animal heat and moisture data normally used in Canada for engineering design purposes are obtained from information given in the Canadian Farm Building Code (1977) and/or the Standards of the American Society of Agricultural Engineers (1987). With respect to sows and litters, the only data given in both these publications for environmental control purposes in farrowing barns are based on a study carried out over 30 yr ago that involved only three sows and litters (Bond et al 1952). Present-day commercial farrowing facilities, however, are subject to different genetic, nutritional and management standards than existed at that time.

The objectives of this project were to establish the heat and moisture loads in swine farrowing facilities in Alberta under commercial conditions, to ascertain the variability of these loads, and to determine the influence, if any, of management practices on the thermal characteristics of farrowing facilities.

EXPERIMENTAL FACILITIES

This project was carried out over a 2-yr period, commencing in the spring of 1984. Five farrowing rooms of modern construction were studied. The parameters of each room are shown in Table I.

The first barn monitored was typical of a batch-farrowing facility, having a concrete floor with 0.6 m of perforations across the rear of each crate and covering a shallow manure pit. The perforated area was expanded-metal/plastic composite flooring, with regular, rectangular openings. One of the farrowing rooms (Room BS) within this barn was monitored.

Rooms BR and CR were located in the same farrowing barn which was of recent construction. The crates in this barn were raised, allowing air movement between the fully perforated, woven steel mesh floors and the shallow manure pits. Room BR was managed as a batch-farrowing facility while Room CR was managed as a continuous-farrowing operation. The use of these two rooms on the same farm provided an opportunity to examine the influence, if any, of farrowing-room management on the rates of heat and moisture production.

Rooms CP and BP both utilized fully perforated crate floors. Room CP was managed under a continuous-farrowing regime, with the floor an expanded metal/plastic composite, with rhombic apertures, covering a continuous-flow shallow pit. Room BP was managed with strict attention to batch scheduling, while the floor was cast-iron with staggered rectangular openings covering a deep pit.

Table I summarizes the supplemental heating systems used. Room BS was constructed with electric creep floor-heating, hot-water space heating and fixed air inlets leading directly from an unheated attic. Rooms BR and CR utilized a preheated hallway and hot-water heating while Room CP had a single ventilation fan at the end of the room and an air inlet constructed in three separately-adjustable sections down the center of the room. A hot-water heating pipe was placed inside the adjustable inlet sections. Room BP had a preheated crawlspace and hot-water creep heating. All five rooms utilized radiant heat lamps for all or part of the farrowing period.

Data collection and analysis procedures

Data were collected on a 4-min basis for 24-h periods throughout the farrow-to-wean cycle of the batch-farrowing facilities, or until a representative number of days of monitoring were obtained from barns utilizing a continuous-farrowing regime. The maximum number of days of monitoring in any farrowing room was nine. Monitoring equipment was housed in a mobile environmental laboratory, described by Feddes and McQuitty (1977, 1981). The mobile laboratory provided an air-conditioned work area isolated from the farrowing room environment.

Each room was divided into halves by length and a three-location temperature profile was monitored at the center of each half. The highest thermistors were placed 0.45 m from the ceiling, the mid-point thermistors at 1.2 m from the floor, and the low-level thermistors where fixed in place at 0.60 m from the floor to prevent interference by the piglets. To check the temperature laterally from the center of each half of the room, additional thermistors were placed approximately midpoint

Table I. Farrowing room parameters

	Room				
	BS	BR	CR	CP	BP
Farrowing regime	Batch	Batch	Continuous	Continuous	Batch
Floor type	Floor level partially perforated	Raised fully perforated	Raised fully perforated	Floor level fully perforated	Floor level fully perforated
Number of crates	5	5	10	36	6
Pen area (m^2)	3.1	4.0	4.0	3.0	4.0
Perforations (% of floor)	42	100	100	100	100
Void area (% of perforated area)	26	47	47	26	45
Pit type	Shallow	Shallow	Shallow	Continuous flow	Deep
Cleaning	Prior to batch	Prior to batch	Prior to monitoring	NA	Prior to batch
Fan size (mm)	461	305	2×305	457	400
Fan type	Variable	Variable	Variable	Variable	Variable
Inlet type	Fixed	Heated hallway	Heated hallway	Fixed	Counter balance
Location	Mundare	Smokey Lake	Smokey Lake	Meeting Creek	Neerlandia
Lighting	Continuous	---------------Normally off-------------			Reduced 8 h/day

Feeding time 06:00 to 08:00 and 17:00 to 19:00 for all barns.

between the profile and the wall on each side. Exhaust air temperature was recorded at three upstream locations in the vertical plane of the exhaust air at each fan except in Barn CR where the temperature was recorded in two locations at each of the two fans.

Air samples were taken at temperature-sensor locations within the rooms, including locations at air inlets and exhaust fans, and from outside air every four minutes during each 24-h run on a sequential basis. These samples were used in the determination of dewpoints and in a concurrent study of air quality in the five farrowing rooms, the results of which are reported elsewhere (Clark and McQuitty 1988). Heat flux was measured at a representative location on every wall or building component by a heat-flux plate described by DeShazer et al. (1982), each having its own calibration curve. The interior locations of the heat-flux plates were chosen on the basis of representative surface temperatures as measured by an infrared pyrometer (Omega Engineering, Stanford, Conn.).

To measure supplemental heat where hot-water heating was utilized, the water flow rate and temperature differential were measured if possible, allowing the supplemental heat to be calculated. Thermistors attached to the pipe surface and covered with insulation closely approximated the water temperature and had a very fast response to temperature changes. The flow rate was measured using a nondisruptive ultrasonic flow meter. In Room CP, flow meters were installed in the hot-water pipe. Where flow measurement was not possible, the pipe temperature was measured in several locations, and thermal transmission coefficients for pipe, as a function of pipe and ambient temperature differences, were utilized (Feddes et al. 1984; American Society of Heating, Refrigeration and Air-Conditioning Engineers (ASHRAE) 1981). The power ratings and hours of use of electric lighting and heating systems were recorded.

The ventilation rates were measured manually using 25-point velocity profiles in a calibration duct, located at each exchange fan, several times daily and correlated to 4-min fan speed readings. In addition, 4-min static pressure readings served as a check to ensure that fan speed-air flow relationships remained the same. The inlets were not adjusted during the entire monitoring period.

Stored data were transferred to the mainframe computer at the University of Alberta for data analysis. Hourly, daily, and total values were generated for each barn. Run dependent data are summarized in Table II. Differences within and between runs and barns were examined, including the differences in floor type and farrowing regime. Hourly data for each run are given elsewhere (Clark and McQuitty 1986).

The heat and moisture balance was based on standard psychrometric equations (ASHRAE 1981) and a standard heat balance as described in the Midwest Plan Service Structures and Environment Handbook (1980). Supplemental heat was subtracted from the sum of the heat lost through the building shell and to the exchange air. The resultant heat production of the building, including animal production and any experimental error, was partitioned into latent and sensible components. The latent component was assumed to be found only in the ventilation term of the room heat balance equation. The production term was composed primarily of heat and moisture production of the pigs. The sensible heat production from the room was less than that from the pigs due to a shift to latent because of evaporation from the floor or other wet surfaces, with the extent of this shift being dependent on ambient temperature, manure management system, and other management parameters.

RESULTS AND DISCUSSION

This study found that the hourly values in heat and moisture production varied due to changes in the activity of the pigs, and the environmental system interaction. Diurnal fluctuations which have been noted in other types of confinement housing (for example, Clark et al. 1984) were not as evident in this study due to a uniform lighting regime (Table I) and interruptions common in farrowing facilities. Table III lists the mean heat and moisture production data for each room.

Table II. Mean parameter values for monitored rooms

	Room				
	BS	BR	CR	CP	BP
Total runs	7	8	8	6	7
Monitoring start	27 Nov. 1984	6 Feb. 1985	19 Mar. 1985	18 Nov. 1985	16 Jan. 1986
Mean sow number	5	5	8.37	26.7	6
(Range)	NA	NA	(6/10)	(26/27)	NA
Piglet numbers, range	28/39	12/43	40/70	191/212	0/57
Piglet age (days)	NA	NA	18.43	16.86	NA
Range	1/19.9	1.7/28	NA	NA	0/24.2
Litter age (days)	0.8/22	0.4/27.8	NA	NA	0/29
Outside temperature (°C)					
Average	−8.3	−13.7	1.7	−12.1	−9.8
Range	−11/−3.9	−18/−9.5	−1.8/6.4	−17/−5	−14/−4.4
Ambient temperature (°C)					
Average	20.6	21.1	20.8	22.9	22.0
Range	19.3/21.8	20.4/21.9	19.8/21.8	22.0/23.6	21.7/22.5
Temperature differential, high-low (°C)	0.5	1.6	1.7	−0.6	−0.5
Static pressure differential (Pa)	−32	−50	−40	−15	−31
Ambient relative humidity (%)					
Average	35	59	54	50	37
Range	31/43	51/73	49/63	40/60	33/43
Total room ventilation rate (L/s)					
Average	148	78	244	474	152
Range	125/171	74/82	208/300	374/623	129/179

Table III. Production values for each monitored room (24-hour means)

	Room				
	BS	BR	CR	CP	BP
Ventilation rate (L/(s.sow))					
Average	29	16	29	18	25
Latent heat production (kJ/(h.sow))					
Average	1097	1192	1069	1072	829
Sensible heat production, kJ/(h.sow)					
Average	739	696	765	765	1045
Total heat produced, kJ/(h.sow)					
Range of daily values	959-2698	1491-2445	1348-2645	1332-2410	1567-2286
Latent heat as a percent of total	60	63	58	58	44

The overall mean of total heat production from five rooms was 1850 kJ/h for each sow and litter with latent heat making up 56% of the total heat production at an average ambient temperature of 21.5°C. Daily values ranged from 1740 to 2000 kJ/(h.sow) with measured hourly values having a far greater variation. The average weight of the sows was estimated to be between 170 and 180 kg while the average litter size was 5.7–9.3 pigs per litter in the five rooms monitored. No significant difference could be shown to exist between the total mean heat production in barns using continuous or batch-farrowing regimes.

Bond et al. (1952) in their study found the total heat and moisture output of three 170-kg sows with six pigs per litter to average 2150 kJ/h for the first 4 wk after farrowing at an ambient temperature of about 21°C. Strom and Feenstra (1980) reviewed the existing literature and determined, with some estimates based on the energetics of milk production, that a 175-kg sow with litter would produce in excess of 2200 kJ/h at 3 wk after farrowing. Robbins and Spillman (1982) measured the heat and moisture production in a commercial-scale, 22-crate slotted-floor farrowing house with zoned ventilation and maintained at an ambient temperature of 26–27°C. The total heat was found to be less than 60% of the previously reported values, and below that found in this study. Lower feed consumption at higher temperature probably would account for some of this discrepancy. In a farrowing barn with partially-perforated floors, Mangold et al. (1982) reported values that were only 70% of those reported by Bond et al. (1952), and suggested that slatted floors could have caused differences in latent heat production.

This study determined that the overall average ratio of latent to total heat was 56%. This ratio was highest in the units with raised crates, declining marginally in rooms with mostly solid floors and lowest in units where the crates had fully-perforated floors (Table III). In the study by Bond et al. (1952), in which solid floor crates were used, the latent to total heat ratio averaged 50%. The percentage of latent to total heat in Room BS was 60%. This crate type was closest to the floor type utilized by Bond et al. (1952). However, in that study, the average relative humidity was 50%, while Room BS had an average of 35% relative humidity as a result of higher ventilation rates. The lower vapor pressure could account for the increased evaporation in the current study. Latent heat production in Room CP was only 44 % of the total heat production. The low RH and use of a deep pit suggest that evaporation rates or conversion of sensible to latent heat were lowered in this Room.

In Barns BR and CR, utilizing raised crates, latent heat production was 63 and 58% of the total heat production, respectively. These results suggest that raised crates with fully-perforated floors have as high, or higher, rates of evaporation as crates with partially perforated or solid floors. Sows and litters in crates having fully-perforated floors, under which air movement was restricted, produced latent heat as only 51% of the total heat load.

Indirect calorimetry (Feddes and DeShazer 1985; Close 1978; Whittemore 1983) and estimates of animal weight, feed consumption and energy content were used to indicate possible errors in the heat balance. The measured heat loss from the sows was on average somewhat higher than the calculated values. Since latent heat and carbon dioxide production are parameters in which high confidence is held, experimental error may have caused a slight underestimation of supplemental heat or building heat losses.

Ventilation rate and air distribution

Current recommendations for winter conditions in Alberta are for a minimum ventilation rate of 7 L/s for each sow and litter and can range to 14 L/s, while the Midwest Plan Service (1980) recommends 9.5 L/s to control odors and moisture. In this study, Rooms BR and BP had the lower ventilation rates of 16 and 18 L/(s.sow), corresponding to the lowest mean outdoor temperatures (−13.7 and −12.1°C, respectively).

In general, based on carbon dioxide concentrations and relative humidities, Rooms BR and CP were ventilated closest to recommendations. In Room BR, the propeller of the single variable speed fan had been replaced with one of a diameter, while in Room CP, the fan was more optimally sized, considering the number of pigs in the barn. In both Rooms BR and CP, a ventilation rate in the order of 12 L/s per sow and litter during cold outside temperatures allowed the relative humidity to approach approximately 60%. This is well below the 75% suggested in most extension literature as a maximum for an acceptable environment and maintaining a dry structure. The results of the air quality study (Clark and McQuitty 1988) indicated, however, that 12 L/s per sow and litter may be required as a winter minimum ventilation rate for the rooms monitored to maintain both ammonia and carbon dioxide at acceptable concentrations. In Room CP, for example, carbon dioxide concentrations reached a daily average exceeding 3000 ppm. This suggests that the existing criterion based on relative humidity alone may not be appropriate for use in determining the minimum ventilation rate in farrowing rooms.

Farrow-to-finish operations with a single owner/operator frequently failed in this study to have the heating and ventilating systems adjusted during climatic changes, because of operator time constraints. In one instance, in Room CP, the outside temperature approached 0°C, yet the daily supplemental heat was the highest measured. Daily adjustment of thermostats, water flow, inlets, or glass fiber batts over inlets, and a poor understanding in some cases of the capabilities of a heating and ventilating system, resulted in an apparent inability to achieve consistent control of the barn environment. Heating of attics, backdraft from slow fans through other farrowing rooms, and poor air mixing were observed frequently. During identical periods of warm outside conditions, supplemental heat and ventilation rates were found to vary widely, suggesting poor interlock between the two and excess energy use.

SUMMARY AND CONCLUSIONS

A summary of measured parameters and conclusions drawn from the results of this study are as follows:

(1) Total heat production was 1850 kJ/(h.sow) for all five rooms and could be used as a design figure for either batch or farrowing regimes, operated under conditions similar to those found in this study. The range of values was 1834-1888 kJ/(h.sow) between the five rooms, with hourly values ranging from 959 to 2698 kJ/(h.sow).

(2) Latent heat production was found to be 56% of the total heat production at an average temperature of 21°C, varying from 44% in a batch-farrowing room with floor-level crates and fully perforated floors to 63% in a batch-farrowing room with raised crates and fully perforated floors.

(3) The difference in total heat production between batch and continuous farrowing units was not found to be sufficiently substantial to justify a different design procedure.

(4) The minimum ventilation rates observed were higher than recommended values, but allowed close to 3000 ppm of carbon dioxide to exist under some conditions. This observation suggests that the minimum recommended value be increased.

(5) Problems were observed in the management or design of the environmental control systems studied in this project suggesting that improvements are required.

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