FACILITIES AND EQUIPMENT FOR LIVESTOCK MANAGEMENT

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Summary

In this chapter, the evolution, fundamentals, need, challenges and future perspectives of livestock facility design are discussed. Livestock industry is one of the most value-added sectors in agriculture. It is changing rapidly and still has great potential to change all over the world. In developed countries, the traditional family livestock businesses quickly transform into corporations, and production scale has been increasing rapidly. In developing countries, demand on better nutrition provides a driving force for increasing the livestock production. Design and management of livestock facilities and equipment require more and more professional knowledge and new technologies. Compared with other biological structures such as residential buildings, livestock facilities present unique challenges in terms of heating, ventilation, air conditioning, air quality, physical environment for better animal welfare and production, waste handling and treatment, environmental and community relation issues. A successful design and management of a livestock facility has to address all the above issues.

1. The Evolution of Livestock Production

People have known for a long time that meat, eggs and milk are nutritious and a delicacy in the human food supply. Raising domestic food-animals for human nutrition can be traced back thousands of years. Livestock production is one of the most value-added agricultural sectors in the world. Sustainability of the livestock industry is critical to the continued prosperity of world economy and stability.

Traditionally, raising livestock was a family business and animals were often raised outdoors (Figure 1). Cattle strolling and grazing on open grassland, chickens running around and picking up feed and insects, and pigs rooting in the dirt and eating food scraps in a backyard or a shed were common sights. In such traditional systems, facilities and equipment for raising animals are minimal and the management activity is trivial. It is often a household business and only requires part-time labor. In many parts of the world today, such traditional production systems still exist and serve as the main means of meat, eggs and milk production. But in this book, facilities and equipment for livestock production are primarily devoted to large-scale intensive housing systems.

Figure1. Livestock have been traditionally raised outdoors as a family business. The equipment needed for such production is minimal: (a) dairy cows wandering on grassland with no equipment except for milk production; and (b) pigs are raised in a backyard shed, fed with leftovers using minimal equipment.

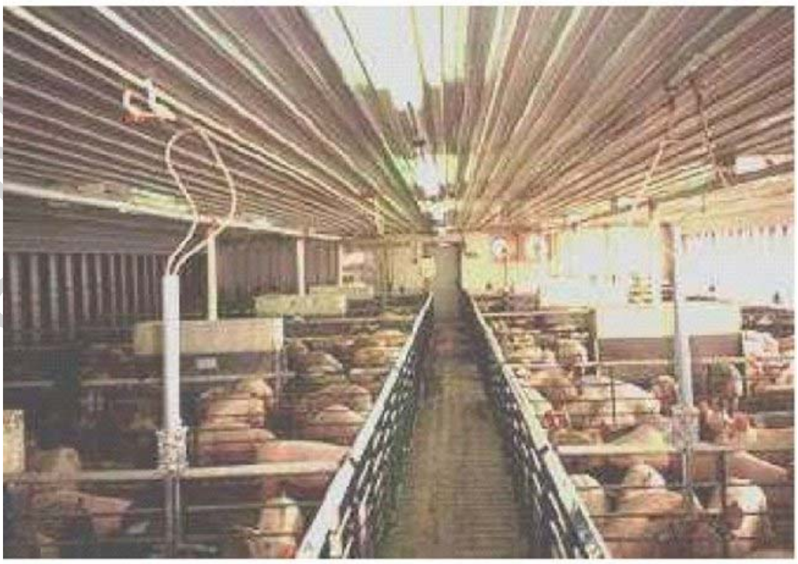

Figure 2. A typical swine production room in today's pork industry. Thousands of animals are housed in an environmentally-conditioned indoor space containing many rooms. A typical swine facility may include tens of thousands of pigs and cost millions of dollars to construct.

Raising livestock has changed rapidly since the late 1960s to meet the increasing need of high protein food for humans. A noticeable change is the intensity and the scale of livestock production facilities. Thousands of animals are housed in completely confined environmentally-conditioned indoor spaces (Figure 2).

This large population of animals within the building produces large amounts of heat, moisture and contaminants such as airborne dust and gases. Buildings with rooms similar to that of Figure 2 are widely used worldwide. A prevailing trend in livestock production is toward more intensive animal housing and a larger scale in facilities. Since the large-scale confinement buildings require large capital investment, the livestock industry is quickly transforming from a family business to large corporations. In the United States and Canada for example, more than 80% of the poultry and more than 50% of the pork is produced by corporations.

The primary driving force for more intensive and large-scale animal facilities is to decrease cost and labor, thus increasing the profitability. Large-scale confinement livestock housing has brought a number of advantages to modern animal production. First, animal production efficiency is usually increased in large confinement buildings because the labor requirement is less in a more intense housing system than an extensive system. For example, one person can raise 5000 pigs to market weight per year in a fully automated building. In extensive facilities, one person may only be able to raise a few dozen pigs. Second, under cold or hot climatic conditions, an indoor environment prevents the animals from suffering temperature stress and thus improves the animal performance. The working conditions for human workers and welfare for animals are also improved in those environmentally controlled buildings. Third, the security of the animals is improved since the animals live indoors for their entire lives.

On the other hand, large-scale confinement livestock housing has caused much dispute with respect to environment, occupational safety and health of workers, the community development and relations, and the animal function and performance. Storage, treatment and land application of livestock manure and the impact on the environment have been increasing concerns of government agencies, scientific communities, the livestock industry, and the general public. Manure solids from livestock farms adds up to approximately 20 billion tons per year. If the waste was made into building blocks, it would be sufficient to construct a 5 m wide, 10 m high wall around the earth each year.

Environmental concerns and public reactions over the intensive livestock production facilities have led governments to pass new regulations regulating manure management, gaseous emissions and facility siting. Government regulations vary among nations, but the general trend is that the regulations become more stringent, making livestock production more expensive. Livestock producers now face public outcries over livestock waste and air pollution, which could drag producers into expensive legal disputes. The manure, traditionally regarded as a nutrient-rich fertilizer, is becoming an expensive burden to the large-scale confinement livestock industry in many countries. Many technologies to treat livestock waste are available, but economically and environmentally sound alternatives are hard to find.

Large-scale confinement animal housing intensifies the living environment within the buildings. A large amount of heat, moisture and contaminants such as airborne dust and gases are produced within the building airspace. Many studies have identified confinement livestock buildings as particularly hazardous workplaces. Aerosols (dust, endotoxins, live and dead microorganisms) and gases (ammonia, carbon dioxide and hydrogen sulfide) in swine buildings have been implicated as contributors to the increased incidence of respiratory disorders among livestock farmers compared to grain farmers and non-farm workers. In Europe, 33% of pork producers suffer chronic respiratory symptoms related to poor indoor air quality. In the Netherlands, 10% of swine farmers had to change jobs because of severe respiratory problems caused by poor air quality. In the United States and Canada, the problems appear to be more serious because of (1) the larger barn size and longer working hours in the building and (2) lower air exchange rates due to longer heating seasons, especially in the upper Midwest US and Canada. In very cold climate regions, a majority of confinement swine farmers suffer acute respiratory symptoms such as coughing, wheezing, nasal and throat irritation, and chest tightness, and many suffer chronic lung dysfunction, allegedly due to airspace contaminants. Improving the working environment for livestock producers becomes an increasingly important issue for health care officials, governments and especially producers and animal facility designers.

Another noticeable change in animal production is the genetic changes of animals. Animal production cycles have been substantially shortened in the past few decades. A production cycle refers to the period of time required to raise an animal from birth to market weight. For example, it took 20 or more weeks to raise a broiler chicken to market weight (typically 2 kg per chicken) before 1960; it only took 6 weeks to reach the same weight since 1980. The production cycle of larger animals such as pigs and beef cattle have also been significantly reduced. The reduction of the production time, or the increase of the growth rate, is primarily attributed to the genetic modification of animals and better nutritional management. The change in production cycles has an effect on livestock equipment design. For example, a shorter production cycle allows a quicker turnaround rate of facilities, thus all-in-all-out production systems are gaining popularity. An all-in-all-out facility houses animals at the same age, i.e., a room in a facility is filled with animals of the same age, and all are shipped out together when they reach market weight. In an all-in-all-out facility, animals can be fed with diets formulated for the animals in specific growth stages. In contrast to the all-in-all-out facility is the continuous facility, where animals at different ages (or weight) are housed together.

The large-scale confinement livestock housing would not be possible had new technologies in animal health care and disease prevention not been available. When animals are intensively housed, the risk of disease spread is increased. With vaccines and antibiotics, it became feasible to control a variety of contagious diseases of animals in a modern animal facility. The best strategy to avoid a disease outbreak is prevention. The consideration of animal health care and disease control have been integrated into the modern animal facility design. Biosecurity measures have become part of the facility design and daily operation routines for intensive livestock production. For example, many intensive animal facilities require their employees to shower and change clothing before entering the facility. All equipment exposed to outside environments must be sanitized before use within the animal facility.

Animal welfare has a profound effect on livestock equipment design. Confinement housing improves the thermal environment and production efficiency, but may reduce the opportunities for animals to choose, alter and use the environment to their advantage. The restrictions may not be beneficial to production efficiency in the long run. For instance, consider sows that farrow and lactate in closed houses equipped with slotted concrete floors. First, the sows are deprived of the opportunity to build a nest (as they instinctively do in nature) to protect their cold susceptible piglets. Second, the suckling piglets in such an artificial environment are prone to develop iron-deficiency anemia because they have no opportunity to obtain iron by rooting about in soil as they would outdoors. High ammonia levels in the air may cause aggression of animals and reduce their performance. The balance between the confinement intensity and allowing animals to choose is a major challenge for animal equipment designers. A good design should seek the optimum balance between the production efficiency and the welfare of the animals.

2. Fundamentals for Equipment Design

A governing principle of livestock equipment design has been to create an overall environment that maximizes production efficiency. The overall environment includes thermal, physical and social environment. Thermal environment includes the temperature, humidity, air velocity and radiation surrounding the animals. Physical environment includes the building shelter, pens, floors, bedding, feeders, stalls, cages and waste handling systems that physically constrain the movement of the animals. Social environment includes animal density in a pen or in a building, difference of ages in the same group, and ability to choose companionship and interaction with other animals. It is important to understand the environmental needs of animals when designing facilities and equipment.

Large-scale confinement livestock production facilities vary largely with the climatic conditions. In a cold climate, animals are commonly housed in well-insulated buildings. The insulation of the building keeps the animals warm and thus improves animal performance. In mild climates, less fully enclosed building structures are often used. The heating and cooling loads can be managed by closing or opening a side wall or other part of the shelter. In hot climates, the buildings are usually less enclosed and natural ventilation is widely used. The roof of the building shelter should be insulated to prevent excessive solar heat transfer. With development of cooling technology such as evaporative cooling pads, animal buildings in hot climates become more enclosed and insulated to preserve the energy used for cooling. In general, cooling the ventilating air requires more energy than does heating the air.

It is easier to understand the importance of thermal and physical environments to the animals than the importance of the social environment. A better social environment can reduce the stress and aggression of animals and hence improve animal performance. For example, grower pigs from the same litter have less hierarchy and thus less aggression than the piglets from different litters.

2.1. Heating/Cooling and Ventilation Systems

Large-scale confinement livestock production requires heating, ventilation and cooling for the animal buildings. The ultimate purpose of ventilation is to supply fresh air to, and meet the heating/cooling requirements of, animals and humans in the building. It fulfills this purpose by bringing fresh air into the building airspace to replace and dilute the heat, moisture, toxic gases, and contaminants that eventually build up indoors. The ventilation fans (Figure 3) deliver thousands of cubic meters of air per hour according to the climatic conditions. The fans are automatically controlled, some are computer remote controlled.

Figure 3. An example of ventilation fans in a swine facility. Fans for each building have a ventilation capacity of approximately 50 m^3h^{-1}.

Heat, moisture, toxic gases, and contaminants are produced by various sources. Heat is produced by animals, lights and equipment in the building. Moisture is produced by animals through the respiration process and also comes from other sources, including manure, water spills and feed. Toxic gases, such as ammonia and hydrogen sulfide, are continuously emitted from animal waste. Other types of contaminants such as airborne dusts are generated from fecal material, feed, dander (tiny particles from skin, hair or feathers), and dead microorganisms. Unless removed, these components will accumulate to levels detrimental to humans and animals.

Heating and ventilation equipment must be selected to balance temperature, humidity and contaminants as presented in a ventilation graph. On a ventilation graph the minimum ventilation rates required to maintain a desirable temperature, humidity and contaminant level are plotted against outside temperatures (Figure 4). The graph is determined by the building heat transfer rate, production rates of heat, moisture and contaminants within the building, set-point (desirable) room temperature and relative humidity, and outside air temperature and relative humidity. A ventilation system should always provide fresh air at a rate at or above the uppermost curve in the graph. A heating and ventilation system needs to be designed to provide variable ventilation rates for seasonal change. When outside temperature is below the heat deficit temperature, the building needs to be heated to maintain the desirable temperature. A heat deficit temperature is an outside temperature below which supplemental heat is needed. The example in Figure 4 shows that the ventilation rate should be at or above the contaminant and moisture balance requirements when outside temperatures are below –21 ^{o}C and 9 ^{o}C, respectively. During cold weather, under-ventilation (shaded area in Figure 4) will cause either high humidity or air quality problems, or both. Over-ventilation will increase supplemental heat consumption. In an extreme situation, over-ventilation in cold weather may lead to temperature control failure if heater capacity is inadequate.

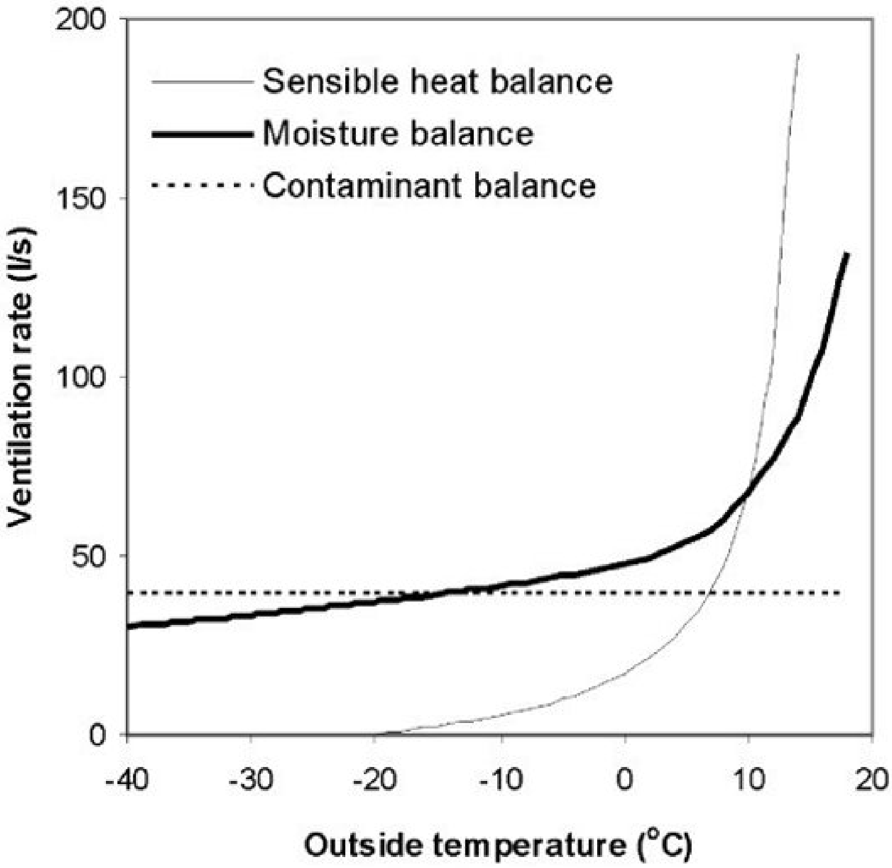

Figure 4. An example of a ventilation graph and heat deficit temperature, T_d. The minimum ventilation should follow the uppermost curves.

In cold climates, the minimum ventilation rate in most livestock buildings is determined by the need to remove moisture or gases. Ventilation at this minimum rate requires the addition of supplemental heat. The supplemental heat can be provided by a heating system, a heat recovery system (e.g., heat pump or heat exchanger) or a combination of the two. In hot climates, excessive heat must be removed through ventilation or by means of cooling. Due to the large ventilation rate for livestock buildings, inexpensive cooling methods such as evaporative cooling are widely used.

Heating and cooling loads have a major impact on heating and ventilation equipment selection. Three modes of heat transfer occur around a building: conduction through the building envelope, convection through ventilation and radiation from solar energy. Heat sources include animals, management activity, solar radiation and equipment. Heat transfer through a building envelope occurs in two ways: heat loss in cold weather and heat gain in warm weather. Ventilation removes undesirable heat and moisture generated by animals and other sources by expelling warm room air and bringing in fresh air. Heat loss or gain through walls, ceiling, floor, and foundation vary with the insulation value of the building materials. Solar radiation (heating) is a potentially useful and significant alternative energy source. For animal buildings, solar radiation is desirable during heating seasons and undesirable during cooling seasons. Ideally, animal buildings should be designed to collect solar energy in the winter and insulate from solar radiation in the summer.

Heat and moisture production of animals is an important factor in heating/cooling and ventilation equipment design. Heat and moisture production data can be found in various sources such as the American Society of Agricultural Engineers (ASAE) Standards (1999). Data for heat and moisture production rates of animals vary from source to source in the literature. Factors affecting the data include room temperature, floor type, feed, and management activities such as power washing.

Only recently has concern for air quality begun to match concern for food and water quality. People are now beginning to realize how important high quality air is for the health and well being of humans and animals. Air is a critical factor to living things. People, on average, consume 15 kg of air per day (compared to 1 kg of food and 1.5 kg of water); a market size pig breathes about 40 kg of air per day (compared to 2.5 kg of feed and 4 kg of water). Therefore, animal building air needs to be of the best quality possible.

Airborne contaminants in livestock buildings are gases and dusts. Equipment design and selection for animal housing should strive for minimizing the gas production and release rates. Gaseous contaminants are primarily ammonia, hydrogen sulfide, methane, carbon dioxide, and odorous gases. Ammonia is produced by the decomposition of the nitrogenous compounds in feces, urine, and other organic wastes deposited on solid surfaces. Relatively little ammonia is produced from liquid waste. Ammonia has a pungent smell and can be detected easily when it is above the 5 parts-per-million (ppm) level. Ammonia becomes irritating when it exceeds 25 ppm. Hydrogen sulfide is generated from anaerobic decomposition in manure storage pits. It smells of rotten eggs and can be detected at a very low concentration. Hydrogen sulfide is not normally released to the room air in a significant amount, but agitating liquid manure in a below-floor storage can greatly increase the amount of hydrogen sulfide released into a room. Methane is rarely produced in significant quantities within an animal building, so it is not an air quality concern. Carbon dioxide is produced primarily from animal respiration. It is odorless and does not generally pose a danger because it is adequately removed by the ventilation system. It is a good indicator of ventilation rate. Odor is a very complicated term because precise definition for livestock odor is yet to be defined and accurate objective measurements of the odor are yet to be developed.

Dust in livestock buildings is biologically active and different from ordinary dust such as field dust. Livestock building dust is primarily generated from feed grains, fecal materials, animal skin and hair, insects, and dead micro-organisms. Dust contains components of volatile organic compounds, fungi, endotoxins (the polysaccharide that is combined with a lipid and released from the cell walls of gram-negative bacteria), toxic gases, and other hazardous agents. Although the pathology of aerosols in animal facilities remains unclear, there is little argument about their adverse effects on animal and human health.

While ventilation is effective in the control of temperature, relative humidity and gas concentration, it may be less effective in dust control. Dust control strategies for livestock buildings involve scrubbing, electrostatic precipitation, ionization, ventilation, filtration and source control technology.

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Bibliography

ACGIH. (1992). ACGIH.: Threshold limit values for chemical substances in work air. *American Conference of Governmental Industrial Hygienists*, Cincinnati, Ohio.

ASAE Standards (1997). *Engineering Practices (EP391.1) Control of Manure Odors.* ASAE 2950 Niles Road, St. Joseph, MI 49085, pp. 546–547.

ASHRAE (1996). *ASHRAE Handbook—HAVC Systems and Equipment*. Atlanta: American Society of Heating, Refrigerating, and Air-conditioning Engineers, Inc. pp. 24.5–24.11

Carpenter G. A. (1986). Dust in livestock buildings – Review of some aspects. *Journal of Agricultural Engineering Research* **33**, 227–241.

Donham J. K., Haglind P., Peterson Y., Rylander R., and Belin L. (1989). Environmental and health studies of workers in Swedish swine confinement buildings. *British Journal of Industrial Medicine* **40**, 31–37.

Dosman J. A., Graham B. L., Hall D., Pahwa P., McDuffie H. H., and Lucewicz M. (1988). Respiratory symptoms and alterations in pulmonary function tests in swine producers in Saskatchewan: Results of a survey of farmers. *Journal of Occupational Medicine* **30**, 715–720.

ISO (1983). Air quality—particle size fraction definitions for health related sampling. *Technical Report ISO/TR/7708–1983.* International Standard Organization, Geneva, Switzerland.

Miner R. J. (1995). *Nature and Control of Odors from Pork Production Facilities.* National Port Producers Council. P.O. Box 10383, Des Moines, IA, 50306 USA.

MWPS (1983). *Swine Housing and Equipment Handbook*, MWPS-3. MidWest Plan Service. 122 Davidson Hall, Iowa State University, Ames, IA 50011-3080, USA.

MWPS (1986). *Beef Housing and Equipment Handbook*, MWPS-6. MidWest Plan Service. 122 Davidson Hall, Iowa State University, Ames, IA 50011-3080, USA.

Van't Klooster C. E. and Voermans J. A. M. (1993). European perspectives: how are they solving their problems? *Symposium "Meeting the Environmental Challenge"*. National Pork Producers Council, November 17–18, 1993, Minneapolis, MN.

Zejda J. E., Barber E. M., Dosman J. A., Olenchock S. A., McDuffie H. H., Rhodes C. S., and Hurst T. S. (1994). Respiratory health status in swine producers relates to endotoxin exposure in the presence of low dust levels. *Journal of Occupational Medicine* **36**(1), 49–56.

Zhang Y. (1994). *Swine Building Ventilation.* Printing Services, University of Saskatchewan, Saskatoon, SK, Canada.

Zhang Y., Tanaka A., Barber E. M., and Feddes J. J. R. (1996). Effect of frequency and quantity of sprinkling canola oil on dust reduction in swine buildings. *Transactions of the American Society of Agricultural Engineering* **39**(3), 1077–1081.

Zhang Y., Tanaka A., Dosman J. A., Senthilselvan A., Barber E. M., Kirychuk S., and Hurst T. (1998b). Acute respiratory responses of human subjects to air quality in a swine building. *Journal of Agricultural Engineering Research* **70**, 367–373.

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