Chapter 1

HVAC Techniques for Modern Livestock and Poultry Production Systems

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Abstract

Thermal modification for housed livestock and poultry production (HLPP) systems has evolved from outside raised or uncontrolled naturally ventilated building systems into sophisticated computer-controlled cloud-analyzed complexes in the quest for producing a safe, reliable, sustainable, and efficient protein supply for our ever-growing population. This chapter discusses a few of the various HLPP systems used in the USA and details the design process in quantifying the needs for our housed livestock and poultry. Specific emphasis is placed on general building characteristics, general ventilation design features, heat stress control, and systems designed to address animal welfare.

Keywords: livestock, poultry, heat stress, animal welfare, ventilation

1. Introduction

Thermal modification for housed livestock and poultry production (HLPP) systems has evolved from outside raised or uncontrolled naturally ventilated building systems into sophisticated computer-controlled cloud-analyzed complexes in the quest for producing a safe, reliable, sustainable, and efficient protein supply for our ever growing population. This chapter discusses a few of the various HLPP systems used in the USA and details the design process in quantifying the needs for our housed livestock and poultry. Specific emphasis is placed on general building characteristics, general ventilation design features, heat stress control, and systems designed to address animal welfare.

2. General thermal modification systems for housed livestock and poultry

In the USA, the raising of food animals in controlled climate facilities has progressed rapidly since the 1980s. It was not uncommon for livestock and poultry producers to rear food animals in outdoor lots or partially contained facilities with minimal modification to the thermal environment. This small-scale production practice has now given way, for the most part, to intensive housing systems where thousands of food production livestock and poultry are raised in tightly controlled climates, with sophisticated thermal modification techniques. The following sections outline some of the systems in use today. For a more complete historical perspective on the development of HLPP systems, see [1].

2.1. Structural design basis for the USA HLPP building system

The majority of HLPP buildings in the USA are composed of wood-frame construction supplemented with concrete stub walls, polyethylene or equivalent curtain sidewall openings, and light-gauge steel roofing and siding (**Figure 1a**, **b**). Waste products are handled in repositories below a slotted flooring system (pigs, beef; **Figure 1b**), within the flooring material (e.g., sawdust) itself (broiler, turkey, hens; **Figure 1c**) or outside below- or above-grade earthen, concrete, or steel containment systems (pigs, beef, dairy, hens; **Figure 1d**). Insulation levels

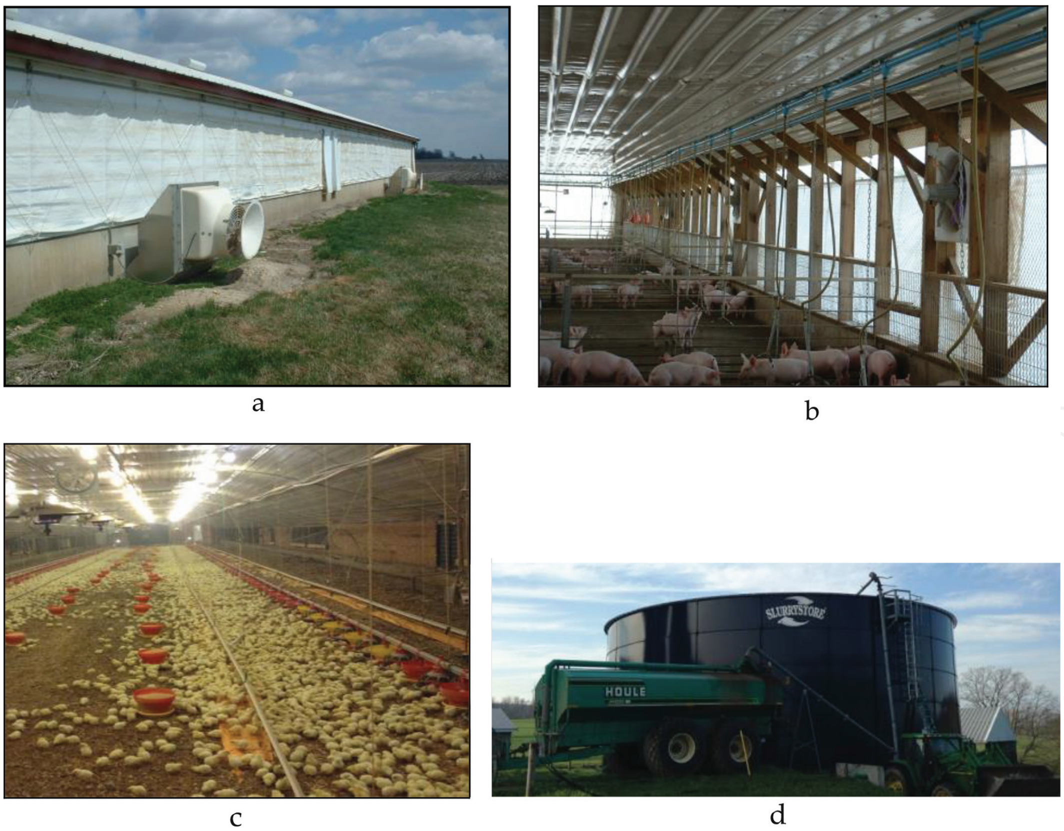

Figure 1. (a) A common Midwestern USA swine finisher with curtain sidewalls and (b) metal flat interior ceiling with concrete slatted flooring, (c) common broiler housing [2], and (d) common above-ground metal manure storage system [3].

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vary greatly by region of the country. For all intensive purposes, HLPP buildings are considered thermally light, responding quickly to outside weather influences.

2.2. Ventilation design basis for the USA HLPP building system

Ventilation designs for HLPP systems range from complete natural ventilation (NV) to a combined hybrid natural/mechanical ventilation (NMV), to full mechanical ventilation (MV).

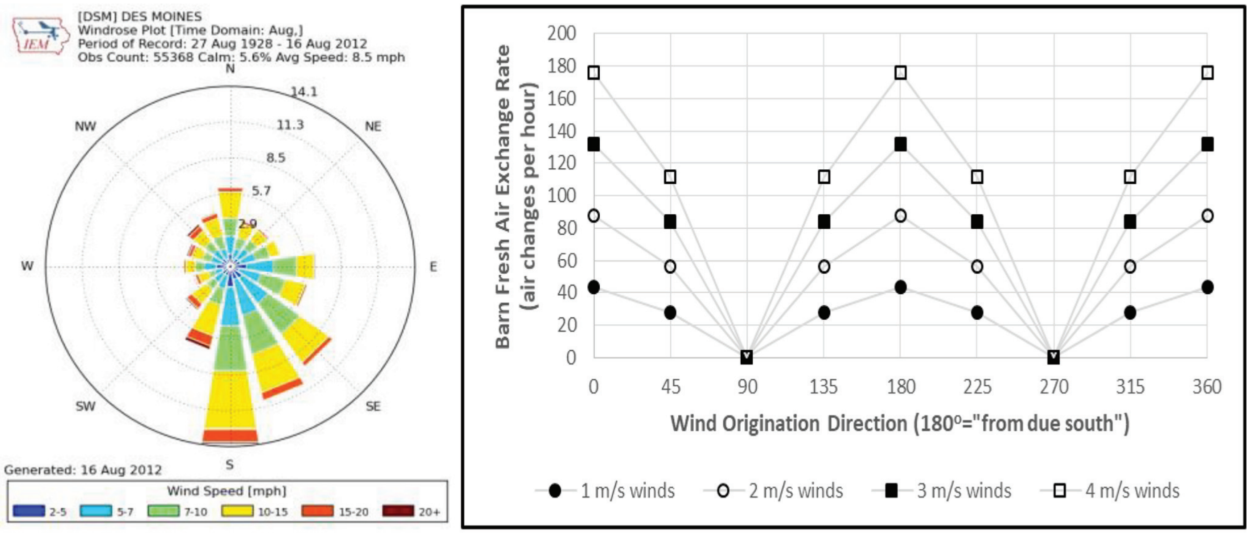
2.2.1. The naturally ventilated HLPP system

The NV building design (**Figure 2**) features controlled sidewall curtain and ridge vent openings. The sidewall and ridge vents are either manually or automatically controlled. The NV barn design has traditionally been used in broiler, turkey, beef, pig finishing, and dairy housing.

Orientation of building relative to historical summer winds is critical, as well as the percent calm periods during warm weather. For example, **Figure 3a** outlines the historical August wind rose pattern for Des Moines, Iowa, USA. For this region, the predominant summer winds are from the S-SE and a properly oriented NV building would have the ridge axis E-W or slightly tilted counter-clockwise to expose the sidewall curtains to the predominant summer winds. Deviation from predominant summer winds will significantly affect the potential fresh-air exchange rate in the building. **Figure 3b** outlines the predicted fresh air exchange rate (air changes per hour; ach) for a typical pig finishing facility designed to house 1000 pigs. The design maximum hot weather rate for this type of facility is 100–120 ach. For this example, both sidewall curtains are open 1.2 m. If the building is oriented completely E-W, with a perpendicular southern (180^{o}) or northern (0^{o}, 360^{o}) wind, a 3 m s^{-1} and above wind speed will sufficiently ventilate this building at and above design criteria. An orientation that deviates from the predominant wind direction significantly reduces ventilation potential. In theory, a lateral (along the ridge line) wind direction (90^{o}, 270^{o}) will not ventilate the building at all, although certainly some low-level exchange of fresh air will still take place. The NV building design is still a staple for many animal groups, especially dairy, beef, broilers, turkeys, and swine finishers.

a b

Figure 2. Naturally ventilated (a) pig finishing building with (b) close-up of modern controlled ridge vents.



a b

Figure 3. Typical (a) wind rose pattern evaluated when planning for a naturally ventilated building and (b) the influence of improper alignment relative to predominant summer winds.

2.2.2. The hybrid natural/mechanical HLPP system

The NV method of HLPP building ventilation, although once the predominant method of ventilating HLPP systems, has given way in many cases to NMV or MV approaches where tighter control of the thermal environment is desired. The NMV method uses exhaust fan ventilation in cold-to-mild conditions with sidewall curtains and wind potential handling warm weather ventilation (see **Figure 1a**). The NMV method was developed to replace the NV action during cold weather in an attempt to better control the thermal environment. Warm and hot weather ventilation is handled with sidewall curtain opening action and wind, requiring the same basic orientation requirements of an NV building. The NMV method does not require cold weather ridge vents and therefore in the NMV method a flat interior ceiling is often used (see **Figure 1b**) with a heavily insulated attic space.

2.2.3. The mechanically ventilated HLPP system

The vast majority of modern intensive HLPP systems use a negative pressure MV system with exhaust fans connected in parallel and fresh inlet air drawn in through ceiling diffusers (**Figure 4**) in cold-to-mild conditions and sidewall and/or endwall curtains (**Figure 1a**, **b**) in warm-to-hot conditions. In modern HLPP systems, the ceiling diffusers are cable controlled to stage inlet action with fan staging, using static pressure differential as feedback. Typical operating static pressures range from 10 to 30 Pascals ($P_{outside}$-P_{inside}). The MV system will typically incorporate at least one sidewall 'drop' curtain opening for emergency power loss events. The negative pressure MV arrangement has become a popular choice, preventing moisture and gas-laden air from exfiltrating through uncontrolled locations where condensation and building deterioration could be an issue. Specialty-designed positive pressure systems are becoming more popular, which are discussed in a later section.

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Figure 4. Example ceiling fresh-air diffuser commonly used in HLPP systems. The cable shown passing through the diffuser is used to automatically control baffle opening in response to ventilation rate changes with static pressure control as the ultimate diffuser opening control objective.

3. Space and zone heating for housed livestock and poultry

Space and/or zone heating are integral components of modern HLPP systems. Space heating has been traditionally accomplished with unvented forced air furnaces. Heated air distribution is handled primarily with a single diffuser attached to the heater outlet, providing minimal distribution and thus uniformity. Ducting of heated air to targeted locations is traditionally not employed in the HLPP systems. Zone heating has traditionally been handled with radiant spot (**Figure 5a**), radiant tube, or heat lamps (**Figure 5b**). In some of the colder regions of the USA (e.g., Minnesota), additional microclimate enclosures with heat lamps are provided for immature animals in the coldest weather (**Figure 5b**). Cold climate ventilation rates are designed to control moisture, gases, and temperature, with moisture control almost always governing the cold weather ventilation rates. Many HLPP ventilation control platforms available today allow the producer to control for building temperature, with relative humidity sensing as a backup for assessing moisture control. Gases such as ammonia, carbon dioxide, hydrogen sulfide, and methane can be an issue in many HLPP systems. In most cold weather situations, and during

a b

Figure 5. (a) Radiant spot heater with shielded radiant sensor for feedback control and (b) microclimate with heat lamps.

normal operating conditions, ventilating for moisture control will also control targeted gases below occupational standards such as those provided by ACGIH or OSHA [4, 5].

4. Space and zone cooling for housed livestock and poultry

Space and/or zone cooling methods have been traditionally limited to evaporative pad cooling systems, high pressure foggers, or direct low pressure water spray systems accompanied most often with elevated airspeed control. Compression-based cooling is not traditionally used, except in specialty cases not covered in this chapter. Heat stress control for housed livestock and poultry is becoming an ever growing concern, fueled mainly by our changing climate, global expansion of HLPP systems in hot and humid climates, and the increased productivity levels of modern food animals where increased internal heat generation must be released to the environment.

4.1. Heat production of modern food animals

Modern genetics has increased the productivity levels of our food animals. This in turn has increased the internal heat produced that must be dissipated to the surrounding thermal environment. For example, one study found that comparing pre-1988 to post-1988 heat production data, the total heat produced by modern pigs increased by 12–35% for 90 kg pigs at 15°C and 5 kg pigs at 35°C, respectively [6]. Similar increases are known in other animal and poultry groups as a natural outcome of increased productivity. Dissipating this heat to prevent heat stress has become challenging.

4.2. Methods to increase animal heat dissipation

The typical HLLP system for heat stress control is a tunnel ventilated (TV) arrangement of fresh air inlets and fans along the long axis of the building (**Figure 6a**) or arranged in cross-flow perpendicular to the long axis (**Figure 6b**). TV systems were first developed in the southeastern quadrant of the USA where the percent calm periods in the summer months can be high. For example, in North Carolina, the hot weather months are associated with up to 18% calm periods, far in excess of desired for proper hot weather NV ventilation performance. The TV HLLP system guarantees a specific average airspeed in the barn when required. The typical design airspeed is 2 m s^{-1}, but some broiler systems are being designed as high as 3 m s^{-1} [7].

Designing the hot weather ventilation rate for airspeed control will in most cases significantly increase the overall building ventilation rate. For example, take the cases depicted in **Figure 6**. If the barn in question houses 1000–600 kg lactating dairy cows, the ventilation rate typically used, designed to keep internal temperature rise less than about 2°C, is roughly 1.90 m^3 $hr.^{-1}$ kg^{-1}. This equates to a maximum building ventilation rate of about 1.14×10^6 m^3 $hr.^{-1}$. A typical dairy barn housing 1000 lactating cows would be about 75 m

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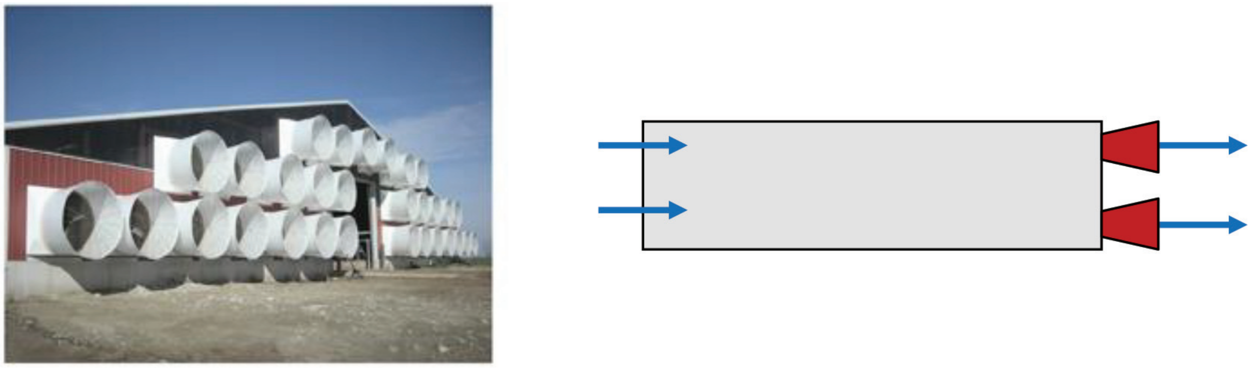

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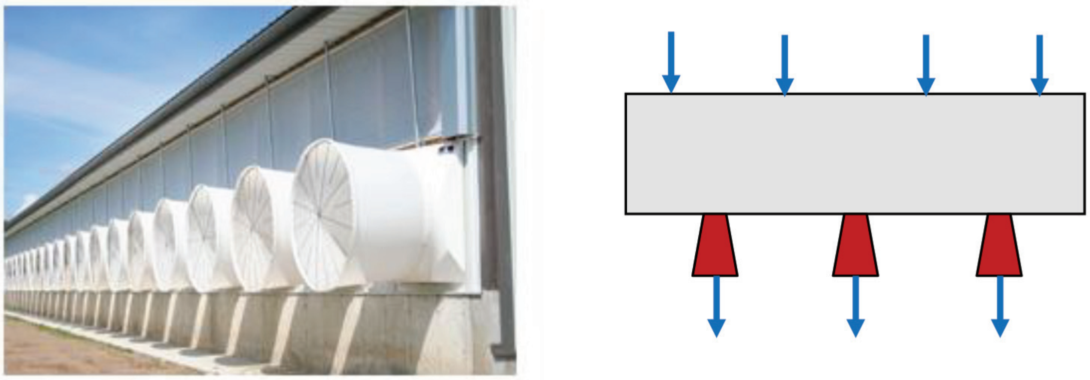

b

Figure 6. (a) True tunnel ventilated fan/inlet and (b) cross-flow tunnel ventilated fan/inlet arrangements for airspeed control.

wide, 140 m long, with 4.25 m high sidewalls. If this building was ventilated for a 2 m s^{-1} airspeed in true tunnel ventilation mode (**Figure 6a**), the maximum ventilation rate would be 2.30×10^6 m^3 $hr.^{-1}$; a 200% increase from typical. If designed in cross-flow tunnel, a more common dairy housing arrangement, the maximum ventilation rate would be 4.28×106 m^3 h^{-1}; a 375% increase from typical and a 186% increase from true tunnel. In some cases, dairy buildings would be fitted with drop panels over the cow resting area, to accelerate cross-flow ventilation over the cows, allowing the overall maximum cross-flow tunnel ventilation rate to be reduced (see **Figure 7b**).

In many cases, the elevated airspeed with TV systems is supplemented with evaporative pad cooling at the fresh-air intake and/or low pressure water sprinkling, especially in pig and dairy systems. Strategies are being developed to actively select the most effective cooling strategy in a suite of options based on the climate's ability to dissipate the sensible and latent heat generated by the animals [8, 9]. For example, in some situations, evaporative pad cooling might raise the humidity ratio to a point detrimental for latent heat release from the animals, instead, warranting the use of low pressure water sprinkling. Heat production and heat/mass transfer models continue to be developed to assist heat stress mitigation decisions [8, 9].

Figure 7. (a) Dairy housing sidewall inlet with or without evaporative cooling pads and in some cases (b) drop curtains/walls to force cross-flow ventilation over rows of cows, enhancing airspeed maintenance.

5. HVAC design for virus control

Disease transmission from herd-to-herd via aerosol transport is a concern, driving significant HLLP system changes to accommodate new and innovative ventilation designs. Many HLLP systems are being designed today to capture viruses before entry into a building. This movement has been especially prevalent in pig housing systems where the porcine reproductive and respiratory syndrome virus (PRRSv) has caused significant economic hardship. Building ventilation systems have been retrofitted to incorporate high efficiency filters at fresh-air intakes as a physical capture of the virus.

Two basic ventilation retrofit strategies have been implemented, one that maintains traditional negative pressure MV and a second option that utilizes a positive pressure MV system in a 'push-only' or 'push-pull' fan configuration. In a negative pressure filtration arrangement, primary (MERV 8) and secondary (MERV 16) filters are attached in the attic space to the existing fresh-air ceiling intakes as depicted in **Figure 8a** for an inlet depicted in **Figure 4**. This method suffers tremendously from the high infiltration rates common in many HLLP systems [10]. In negative pressure filtration systems, significant sealing of the building is required to limit unfiltered air from entering the animal zone through air leakage points, and this can be an annual challenge after each seasonal freeze/thaw cycle.

In a positive pressure filtered barn, industrial blowers (**Figure 8b**), or equivalent are used to push air through primary and secondary filter banks (**Figure 8c**), maintaining the building operating pressure slightly above ambient, bypassing the infiltration issues common with negative pressure systems. The major drawback with positive pressure filtered systems is the tendency for moisture laden air to exfiltrate, potentially condensing in the building cavity. In positive pressure systems, care must be taken as well to control exfiltration for this reason.

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c

Figure 8. Virus filtration with (a) filters attached directly to ceiling fresh-air intakes in a negative pressure system, or (b) using blowers and (c) filtration banks in a positive pressure filtration system.

6. HLLP design for livestock and poultry welfare

Producers of food animals place animal welfare at the forefront of their operation. Several building design changes have evolved as a result of public pressure stemming from concerns related to animal welfare. The most prominent changes have been made in pig gestation and egg-laying facilities. Traditional gestation housing uses individual stalls (**Figure 9a**) from which precise nutritional needs can be maintained and monitored. Due to public pressure, the traditional stall gestation has given way, in some cases, to group housing gestation facilities, with, in many cases, electronic feed dispensing and pig monitoring (**Figure 9b**).

a b

Figure 9. (a) Sow gestation housing using stalls [10], and (b) the alternative group housing with electronic feeding and monitoring systems [11].

Unquestionably, the biggest change in HLPP systems has occurred in the egg-laying sector. Many large fast-food chains have demanded bird space allocation changes and overall free-roaming requirements that have significantly changed the hen housing system. The conventional caged-layer system is rapidly being replaced by enriched colony or aviary systems where birds are allowed extensive movement and ample opportunity for perching and nesting behavior. An excellent overview of the various hen housing systems can be found in [12].

7. Conclusions

Thermal modification for housed livestock and poultry production (HLPP) systems has evolved from outside raised or uncontrolled naturally ventilated building systems into sophisticated computer-controlled cloud-analyzed complexes in the quest for producing a safe, reliable, sustainable, and efficient protein supply for our ever growing population. This chapter summarized a few of the various HLPP systems used in the USA. Specific emphasis was placed on general building characteristics, general ventilation design features, heat stress control, and systems designed to address animal welfare. Significant advances have been made in HLPP systems in response to global food demand and as a matter of efficiency. Advances will continue as we strive to ensure a safe, environmentally sustainable, and efficient food supply.

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