**Title:** Reducing the Environmental Footprint of Pig Finishing Barns **- NPB #09-055**

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**Institution:** University of Minnesota

**Date Submitted:** Dec 31, 2010 (revised Feb 28, 2011)

**Industry Summary**:

Increasing energy costs and regulatory push for lower emissions of air pollutants is a fact facing swine producers throughout the upper Midwest. The primary objective of this project was to develop a new housing design for the pig finishing production phase in Minnesota and other surrounding Midwestern states. A secondary objective was to provide guidance for reducing energy and air emissions for a majority of the existing pig finishing barns currently being used in the upper Midwest. This new building design is referred to in this report as the "Greener Pig Barn" or GPB. In addition to an extensive literature review, project leaders from the University of Minnesota worked with an advisory team of researchers, extension educators from surrounding states, consultants, and swine industry leaders to develop this new building design and barn retrofit ideas for existing facilities.

Design concepts for the GPB focused on providing optimum environmental conditions for maximum pig production efficiency. It was anticipated that the additional investment in building a barn to provide these optimum conditions must be significantly offset with production efficiencies. Two other principles guided the team in the GPB design development. First, reductions in emission must be integrated into the housing design rather than by add-on emission control technologies. This integration rewards the appropriate management and operation of the housing system because it is tied to production economics. Secondly, the design must result in improvements to worker and pig safety/health by providing better indoor air quality and reducing hazardous gas emissions from the barn. In addition, trends in animal welfare were considered and addressed in the final GPB design.

A 2400-head double wide, tunnel-ventilated, fully slatted, deep pit finishing barn was used as the reference facility to compare energy use and air emissions with the new GPB housing design. The tunnel ventilated (TV) barn was used as a baseline in this study because it has been the most commonly built pig finishing facility in the upper Midwest for the past 5 to 10 years. It is estimated that over 80% of all pig marketed in the upper Midwest are either grown in a tunnel ventilated (TV) or the deep pit, fully slatted, curtain sided (CS) barn.

This report includes four GPB design variations. Version A features pens with partially slatted floors and in-floor heating and cooling in the solid floor section, shallow gutters under the slats with mechanical scrapers for manure removal to an outside covered manure storage tank, and an evaporative cooling system. Version B is similar to Version A but integrates a mechanical (geothermal) cooling system (rather than evaporation pads). Version C is similar to Version A, but has fully slatted floors and is cooled only with evaporative cooling pads. Version D is similar to Version B (mechanical cooling) but has fully slatted floors. All GPB design versions use shallow gutters with mechanical scrapers and an in-ground, covered, concrete manure storage tank located adjacent to the barn.

All versions of the Green Pig Barns are expected to save energy in the winter due to better insulation and environmental control. Reduced emissions are also expected due to the lack of long term manure storage inside/under the barn and to the incorporation of barn cooling. Building construction costs per pig space, which includes an outside, covered, in-ground concrete manure storage tank, are expected to be 1.3 to 2 times higher than typical construction of the baseline TV barn. These costs are offset by a 3-7% increase in average daily gain and 5-10% decrease in feed consumption per pound of pork produced. Other benefits include better pig health and worker environment. Using these assumptions in a standard economic projection, annualized net present value per pig space is between $2.43 and $9.03 with 6.0 to 12.8 years to payback over the baseline (TV) facility. These economic projections would improve significantly with additional gains in animal performance. It is generally thought that these performance gains are anticipated but there is currently no research data to confidently predict the magnitude of these performance improvements on an annual basis in commercial scale operations.

Barn retrofit concepts reported in this document focus on structural upgrades such as insulation and mechanical items like improved environmental control, fan and heater maintenance and management, along with manure pit management. Recommendations are outlined in a factsheet that can be found in the Appendix D of this document and on-line at www.bbe.umn.ed/Animal_Housing_and_Livestock_Systems.html .

Moving the swine industry forward to a more sustainable production facility was the focus of this project. Results from the project indicate that current facilities in the upper Midwest can be modified or managed to reduce energy inputs. Results also indicate that there are alternatives to the current finishing facilities in the Midwest that could result in reduced energy and emissions per pound of meat produced while still being economically viable. Construction and monitoring of the design housing concepts laid out in this report is a critical next step in moving the industry forward in sustainable pig finishing production.

Further information concerning the findings from this study can be obtained by contacting Larry D. Jacobson at the University of Minnesota, jacob007@umn.edu or 612-625-8288.

**Keywords**:

Swine Housing, Energy, Emissions, Environmental Footprint, Economic Viability

**Scientific Abstract:**

Design, construction, and management of pig production buildings in Minnesota and the upper Midwest have changed little in the past 30 years. Inexpensive energy (fossil fuel and feed), plentiful water, and limited concern of air emissions has resulted in few incentives to critically evaluate, modify, or significantly change pig housing designs. However, recent global trends have forced the pork industry (both in Midwest and throughout the U.S.) to reduce the environmental impact of swine production systems. For pork production this could partially be accomplished through the development and use of smarter and/or "greener" housing designs and management that reduces both fossil and feed energy use as well as air emissions including hazardous (ammonia and hydrogen sulfide) and greenhouse (carbon dioxide, methane, and nitrous oxide) gases plus odor

and particulate matter (NPB, 2007). In this study, the new pig finishing housing design proposed is referred to as the "Greener Pig Barn" or GPB.

A 2400-head double wide, tunnel-ventilated, fully slatted, deep pit finishing barn was used as the reference facility to compare energy use and air emissions with the new GPB housing design. The tunnel ventilated (TV) barn was used as a baseline in this study because it has been the most commonly built pig finishing facility in the upper Midwest for the past 5 to 10 years. It is estimated that over 80% of all pig marketed in the upper Midwest are either grown in a tunnel ventilated (TV) or the deep pit, fully slatted, curtain sided (CS) barn.

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## Introduction:

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*Energy Accounting*

Energy use in an animal production system is often tied to a particular site and divided into gallons of fuel (L.P. or natural gas) and kilowatts of electricity per year or month per site. Energy use might also be reported on either a per pig space basis or a per pig produced basis. Rarely is energy use reported on the quantity of production (e.g. pounds of pork produced). This same "site based" accounting system is also used in air (odor, gas, or PM) emissions and can result in a misrepresentation of true reduction targets in energy use and gas emissions. Because of how energy is expressed or what the actual energy values are divided by, producers can misevaluate energy use patterns. Additionally, this "site based" accounting may also incorrectly bias sites or farms with poor production efficiencies. What may be seen as high energy use or high gas emissions on a site or farm basis may in fact result in more efficient energy use or reduced emissions on a pound of product produced. This is especially true when winter ventilation is managed (reduced) to save fuel (L.P. gas) and results in indoor air quality conditions that result in reduced animal performance, or when facilities have excessively high indoor temperatures in the summer resulting in heat stressed animals, also resulting in reduced pig performance. Hot and humid conditions or poor air quality result in both a reduced rate of gain and feed conversion efficiency. The result is a savings in energy costs but a likely increase in feed cost per pound of pork produced.

*Energy Use*

Current financial summaries from the University of Minnesota Center for Farm Financial Management indicates direct electrical and fuel usage account for from 2 to 5% of pig production costs averaging $1.40 invested per pig produced (www.finbin.umn.edu). Brodeur (2008) presented data indicating combined fossil fuel energy cost of production percentage of 6.6 and 2.2 respectively for swine farrowing and finishing production systems in Quebec, Canada with 43% of the energy consumption in the finishing phase attributed to electricity and 27% to LP gas. Barber (1989) reports 64% of energy use in the finishing phase is for ventilation (fan operation), 12% for heating, 17% for lighting, and 7% for feed, water, and manure management.

Table 1 provides energy use data from a survey of six farm sites in Minnesota and Iowa. Energy use data was estimated using producer supplied annual performance data and energy expenses. Data reported are in the range of farm survey data reported by OMAFRA (2006) with grow-finish barns averaging 5.45 kwh/cwt (18,600 BTU/cwt) and nursery facilities averaging 6.36 kwh/cwt (21,700 BTU/cwt).

**Table 1. Survey of energy use data for grow-finish barns in Iowa and Minnesota.**

| Farm ID | Farm/Barn Details | Electrical Kwh/cwt | Heat Gal LP/cwt |
|---|---|---|---|
| A | 1-120-hd power vent barn & 1-480-hd curtain sided barn | 4.69 | 0.58 |
| B | Triple long natural ventilation 3000 head, Iowa | 1.8 | 0.17 |
| C | 2400-head, curtain sided, Iowa | 3.2 | nd |
| D | 1200-head curtain sided, Iowa | 3.72 | nd |
| E | 2-1000-head curtain sided, Iowa | 4.51 | nd |
| F | 2-1400-head power ventilated, MN | 5.20 | 0.32 |
| G | 2-1200 hd power ventilated, Iowa | 5.16 | nd |
| H | 2-1200 hd power ventilated, Iowa | 4.46 | nd |

nd = no data

*Optimizing the Environment = Optimizing Performance*

One of the most important factors in energy consumption is not related to typical efficiencies in heating and ventilating but rather in optimizing the barn environment for pig performance. Curtis (1973), along with subsequent texts and articles on animal environment and production performance (Hahn et al. 1987; Huynh et al., 2004, Mount, 1975, Brown-Brandel et al., 2000), stress the need to provide an indoor climate conducive to animal performance. Providing this environment requires proper control of indoor temperature, humidity, airflow rates and velocities, and gas concentrations. Unfortunately, in an effort to reduce building costs, barns have been built with inadequate insulation and have heating, cooling, and ventilation systems that do not provide for optimum environmental conditions in the barn.

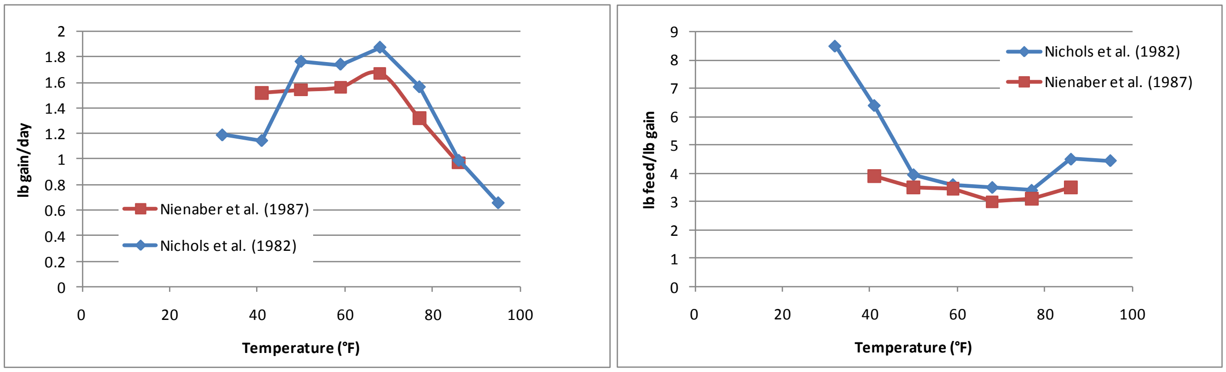


**Figure 1. Temperature vs pig performance modified from Hahn et al. 1987. (Daily gain and feed conversion for grow-finish pig.)**

Baker (2004) provides an overview of all of the parameters impacting the effective environmental temperature (EET) of the pig. In general, drafts (high air velocities at pig levels) and cold surfaces significantly reduce this EET resulting in the need to increase the setpoint temperature and subsequent heat energy (both fossil fuel and feed). Optimizing pig performance and quantifying these results is challenging due to the complexity and interactions of multiple factors responsible for performance. In general, ideal temperatures are mostly reported to be about 65-70° F with some work suggesting ideals extending outside this range (Figure 1). Factors such as beginning and ending pig weight, group size, pig space allocation, and genotype may be responsible for part of the variation in the reported ideal temperature.

Nienaber (1987), with pigs fed from 96 pounds to 195 pounds, reported pigs maintained at 77° F gained 82% as much as those housed at 68° F and required 103% as much feed per unit of gain. Pigs at 88° F gained 58% as much as the ideal situation (68° F) and required 118% as much feed per unit of gain. Lopez (1991), with data collected on pigs starting at 198 pounds and fed over a 21 day period, reported that pigs maintained at 77° F gained 90% as much as those housed at 68° F and required 101% as much feed per unit of gain. Pigs at 85° F gained 80% as much as the ideal situation (68° F) and required 103% as much feed per unit of gain.

Massabie, P. (1991) conducted two experiments, with 192 pigs each to determine the effects of air movement and ambient temperature on pig performance and behavior. Treatments included three ambient temperatures (28, 24 and 20°C or 82, 75, and 68° F) combined with two air velocities (still air or 0.56 m/s at day 1 increasing up to 1.3 m/s at day 43). It was concluded that for the hotter environmental temperatures air velocity improved ADFI and ADG but lowered FE and lean tissue percentage. However, at temperatures near the optimum, 68 to 75° F (20-24° C), air movement had a negative effect on pig performance. ADG was higher but feed efficiency declined and lean tissue percentage was lower. This suggests that achieving optimum temperature through methods (floor cooling) other than ventilation air movement has production advantages. Huynh, T. T. T. (2004) found that floor cooling significantly increased feed intake and growth rate under summer conditions. ADG was improved by 0.07 pounds or about 4.5%.

Brown-Brandl (2000) studied manual and thermal induced feed intake restriction on finishing barrows measuring effects on growth, carcass composition and feeding behavior. Results suggest that high-lean-growth pigs reared in hot environments deposit more fat and less protein than those raised in a "thermoneutral" environment and fed similar amounts. Backfat difference between manual and thermal induced feed intake restriction at the 26% level was about 0.138 inches greater at the $10^{th}$ rib for the hotter pigs.

Minert (1996) studied the impact of selected hog carcass traits on prices received. Regression model results indicated that increases in backfat led to lower carcass prices. A backfat increase of 0.1 inch was associated with an average carcass price decline of $0.88 per cwt. Carcass prices averaged $63.95 per cwt. during the study. Higher carcass prices would increase the effect.

This research suggests that some improved performance (ADG and FE) can be achieved through environmental control, primarily cooler barn temperatures in the summer.

**Options for Reducing Energy**
Several publications and reports address energy use in swine production. These publications can be found on-line and in many trade journals. The following are the most common practices and considerations found in this literature supplemented with additional information developed as part of this project. Note that most of the ideas presented below relate to the heating and ventilation systems as these systems represent an estimated 70% of fossil fuel energy use in a finishing building (Brodeur, 2008).

*Fan Maintenance:*
As has been the focus of many extension publications and producer workshops, proper fan maintenance can have an impact on energy use. Cleaning fans and especially shutters on a routine basis will allow the fans to operate at maximum efficiency. Belt driven fans should be closely monitored for belt slippage.

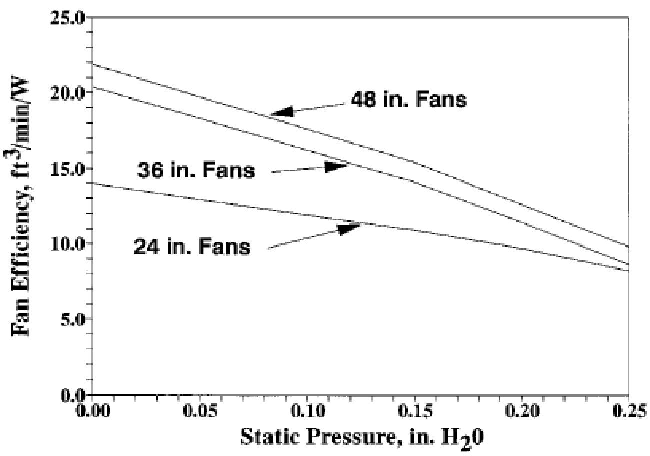

**Figure 2. Graph of typical fan efficiencies. (ASAE EP566.1)**

*Fan Efficiencies:*
In general, small fans are less energy efficient (cfm/watt) compared to larger capacity fans (Figure 2). Because of this, ventilation control systems should limit operation of minimum ventilation fans (smaller fans) during periods of higher ventilation requirements. Also, variable speed fans should be operated at full speed whenever possible as fan efficiencies are highest at full power (when operated at 100%). Frequency drive motors for fans are gaining popularity as they are much more efficient when run at less than 100% capacity.

*Minimum Ventilation:*
Make sure minimum ventilation fans are sized to provide the minimum or continuous air exchange rate. Over ventilation during cold weather will increase furnace run-times and fossil fuel use. However, remember that maintaining minimum ventilation is essential for providing a healthy environment for pigs and workers. Small nursery pigs (15 lbs) require a minimum ventilation or air exchange rate of two cubic feet of air per minute (cfm/pig) while large finishing pigs (200+ lbs) require approximately ten cfm/pig.

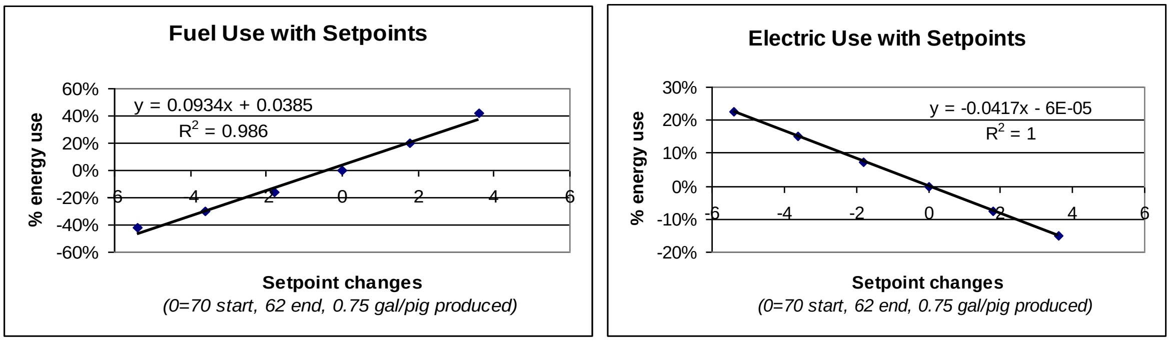


Figure 3. Staldvent Model predictions for fuel use based on changes in setpoint for a typical 2800 hd, mechanically ventilated swine finishing barn in West Central MN.

*Set points:*

Temperature setpoints or targets on controllers that regulate barn heaters and ventilation fans can have a dramatic affect on energy use. Optimum temperatures for pigs from 12-30 lbs are between 75-85 °F while pigs between 30-75 lbs require temperatures between 65 and 70 °F and temperatures between 50 and 65°F for pigs between 75-265 lbs. Often this setpoint temperature control is based on one or two sensory locations in the barn. A check should be made to determine if the environmental control system is indeed providing proper temperatures throughout the barn and at pig level. A degree or two different temperature setpoints can significantly impact heater run-time and fuel use. Figure 3 shows estimates of fuel use and electrical use with changes in temperature setpoints. Note that decreases in temperature setpoints results in decreased fuel consumption (winter) and increased electrical consumption (summer). Additionally, the controller's setpoints for heaters, inlets, and ventilation fans should be synchronized properly to produce acceptable static pressure ranges in the barn and prevent "heater overshooting" that causes unnecessary cycling of the heater and excessive fossil fuel use.

*Heaters:*

Heaters are often over sized to insure adequate heating capacity to maintain room temperatures during cold weather. However, this over-sizing often results in the overshooting of temperature setpoints and more frequency cycling of the second stage ventilation fans. The temperature when the heater comes on should be at least 2 degrees F below the ventilation setpoint. Radiant heaters offer an advantage over direct-fired combustion furnaces because they heat surfaces rather than the air. In general, radiant heaters will reduce total barn energy use by as much as 50% since it heats strategic "zones" such as the solid floor for weaned pigs rather that the whole barn.

*Insulation and draft reduction:*

Reductions in winter heating can also be achieved by reducing any drafts (undersized air inlets) in the barn from leaky curtains or fan openings. Insulating and sealing curtains and summer fan openings with bubble wrap, although requiring some initial investment and seasonal labor, will tighten up the barn substantially and result in heat and fossil fuel savings. Barns with poorly insulated sidewalls such as un-insulated concrete and curtains may only have an average R-value of 1. Increasing the R-value to 2, 5 and 10 (as estimated by the Danish StaldVent pig housing/growth model (Morsing, et al, 1997) for central Minnesota) results in fuel savings of 30% and 50%, and 65% respectively. Less savings would occur in warmer climates.

*Prevent wind pressure on the fans:*

Wind pressures against the exhaust fans result in reduced fan efficiency and over or under ventilation of the building (Table 2). With a typical barn operating static pressure of 0.1 inches of water, wind speeds of 15 mph would reduce fan output to nearly 0 cfm. These wind pressures result in under-ventilation and more fans running to meet the temperature setpoint requirements. Wind pressures can be reduced with the use of fan barriers (Figure 4), inverted cones or by having fans exhaust vertically through the ceiling and roof. Also, for tunnel ventilated barns, an east/west vs north/south layout is more desirable since the east/west orientation has the large tunnel fans typically facing east rather than south which is the common summer wind direction in the Midwest.

Figure 4. Fan baffle.

Table 2. Static pressure caused by wind (with no wind shielding).

| Wind speed (mph) | Pressure on fan (inches $H_2O$) |
|---|---|
| 5 | 0.02 |
| 10 | 0.05 |
| 15 | 0.10 |
| 20 | 0.20 |
| 25 | 0.28 |

**Emissions**

Pollutant emissions from swine finishing facilities are also a concern for producers. Like energy use, air emissions can be reported on a per site basis, a per animal space basis or on a production basis (per pound of pork produced). Estimates of pollutant emissions found in literature and presented in Table 3 suggest building emissions are the sum of emissions from animals, feeding, manure on the floor, heater combustion, and manure stored below the floor (slats). Each of sources can be evaluated separately but may also be interrelated. Of these sources, the two manure sources (flooring and pit or gutter storage) were shown to be the largest emitters of ammonia emissions (Kai et al., 2006, Aarnick et al., 1997). These sources were also the ones targeted by the project advisory team.

Table 3. Gas and Odor Emissions from Swine Finishing Facilities.

| Parameter | Value | Units | Description | Reference |
|---|---|---|---|---|
| Ammonia | 151 | µg/s/$m^2$ | Finish, full slats, deep pit | Gay et al (2001) |
| | 105 | µg/s/$m^2$ | Finish, full slats, deep pit | Verdoes et al. (1997)[1] |
| | 73.5 | µg/s/$m^2$ | Finish, partial slats, drain | Verdoes et al. (1997)[1] |
| Hydrogen Sulfide | 14 | µg/s/$m^2$ | Finish, full slats, deep pit | Gay et al (2001) |
| Methane | 63 | µg/s/$m^2$ | Finish, full slats, deep pit | Ni et al (2008) |
| | 106 | µg/s/$m^2$ | Finish, full slats, flush | Sharpe et al. (2001) |
| | 450 | µg/s/$m^2$ | Finish, full slats, flush | Sharpe et al. (2001) |
| Carbon Dioxide | 28.9 | mg/s/ $m^2$ | Finish, Full slats, deep pit | Ni et al (2008) |
| Odor | 6.7 | ou/s/$m^2$ | Finish, Full slats, deep pit | Gay et al (2001) |
| | 2.5 | ou/s/$m^2$ | Finish, Full slats, scraper | Parker (2011) |
| | 11.7 | ou/s/$m^2$ | Finish, Full slats, flush | Parker (2011) |
| | 22 | ou/s/$m^2$ | Finish, Full slats, deep pit | Jacobson (2009) |

| | | | |
|---|---|---|---|
| | 35-54 | ou/s/m$^2$ | Guo et al (2006) |
| | 19-34 | ou/s/m$^2$ | Mol and Ogink (2003) |

*original units in g $NH^3$-N/d/pig and converted using x 0.3 m$^2$/weaner and 0.75 m$^2$/finisher.

*Flooring:*

Aarnink et al (1997) compared emissions from five different flooring types: concrete slats with 15% opening, concrete slats with 18% opening, cast iron flooring with 32% opening, metal slats with 50% opening and metal floor with 50% opening plus metal studs to prevent the pigs from lying on the floor. The metal floor with 50% opening showed reductions in ammonia emissions of 27% compared to the other flooring types. However, metal flooring is typically not recommended for pig comfort (slippery floor surfaces). Plastic flooring may be an option because of the reduced surface area (increased % open). In general, the less urine and feces remaining on the floor resulted in lower ammonia emissions (Aarnink et al., 1997).
Pens with partial slats have been shown to have lower emissions provided there is little or no dunging on the solid floor. Kai et. al. (2006) studied a partially slatted barn and found that 40-50% of ammonia emissions were from the slatted-floor with the remainder of the emissions coming from the manure stored in shallow gutters below the slats. Only a small fraction was emitted from the solid floor area-provided there was limited dunging on the solid floor. Aarnink and Wagemans (1997) demonstrated the impact of dunging pattern on ammonia emissions noting that pigs properly maintained dunging patterns during winter months when the slats were colder than the solid floor but reversed this dunging pattern during summer conditions resulting in a subsequent increase in ammonia emissions from the pen. It was also noted in this study that installing studs in the slatted area will reduce lying on the slats and aid in maintaining proper dunging patterns.

*Manure Storage and Handling:*

Surface area, stored manure temperature, air velocity, and manure chemistry all impact gas emissions from the manure surface. Several papers (Kai et al. 2006; Zhang et al., 2007; Aarnink et al., 2007; Wang et al., 2006) measured direct correlations between gas emissions and manure temperature. Figure 5 shows this relationship between ammonia and temperature based on standard chemical equilibrium for ammonia in lagoon effluent (Liang et al., 2002). With this situation, increasing manure temperature from 68 to 77 °F results in approximately 60% increase (10-16 µg/s/m$^2$) in ammonia emissions. In addition, cooler temperatures reduce microbial activity which may further reduce ammonia emissions by slowing the conversion of organic nitrogen to ammonia nitrogen.

Reduced barn gas emissions have also been accomplished through more frequent manure removal. Lim et al (2001) compared daily flush with recycled lagoon effluent, 2 week pull plug, and long term storage. In this controlled study all rooms had a 3.6 ft deep manure pit under a fully slatted floor. At all start times pits were recharged with recycled lagoon effluent. Average emissions were less for the daily flush and 2-week pull plug except during manure removal when spikes of ammonia and hydrogen sulfide were noted.

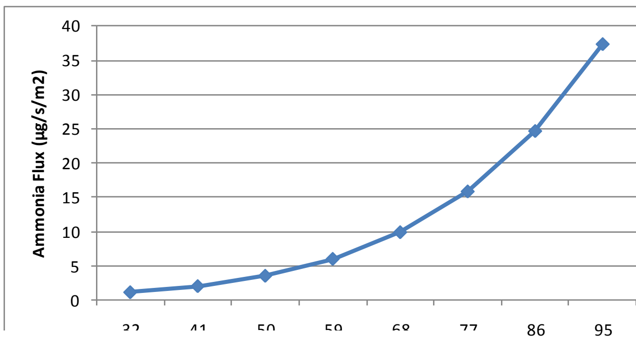

Figure 5. Temperature influence on ammonia flux.

In two separate studies, Predicala et al. (2005, 2007) compared hydrogen sulfide emissions between a manure scraper vs. a pull plug system of manure removal from the swine barn only and found reductions of 90% with the scraper system.

Other researchers have evaluated manure belt systems to continuously remove manure from barns (Predicala et al 2007; Pedersen and Kai, 2008; Elmer et al., 2001). Most studies indicate reductions in odor and ammonia emissions using these systems as the immediate separation of feces and urine reduces ammonia production and emissions from these barns with either a belt or scraper. Parker et al (2010) found manure scrapers reduced barn odor emissions by 75% and hydrogen sulfide emissions by nearly 90% as compared to lagoon water flush pig finishing barns for a Missouri integrator. Mol and Ogink (2003) conducted field measurements to compare standard partial slat systems, deep pit systems, partial slats with shallow gutter flushing, and partial slats with manure surface cooling. They reported a wide variation in odor measurements which resulted in no statistical difference between the barns for odor though the average odor emissions tended lower in both the partial slats barns and the partial slat barns with manure cooling. The study also showed emissions increased during flushing of shallow gutter barns by a factor of 3 to 3.5. Dutch researchers, Huynh et al. (2004), tested a V-shaped bottom pull plug system, noting that manure surface area is directly related to ammonia emissions.

In comparing odor emissions from deep pit and shallow gutter mechanically ventilated systems, Miller et al. (2004) found that deep pits had higher odor emissions than shallow gutter systems unless the manure in the pit was less than 2 feet deep.

*Pit ventilation:*

Results from a recent National Pork Board funded project (Jacobson et al., 2009) showed that operation of pit fans, when the pits are at or near capacity, increased hydrogen sulfide emissions by 75% and ammonia emissions by 25% compared to no pit ventilation (minimum ventilation supplied by wall fans). Not ventilating the pit did not decrease air quality inside the barn. The research suggests lower barn emissions can be achieved simply by removing pit ventilation and/or by pumping the manure more frequently, providing more than 2 feet of headspace in the pit.

*Safety:*

There are also growing safety and health concerns with deep-pitted barns. Hazards include barn explosions related to manure foaming, and hydrogen sulfide hazards for both animals and humans during pit agitation and pumping. High hydrogen sulfide concentrations (above 100 ppm) have also been documented in pull plug systems when the plug is pulled (Chenard et al., 2003).

*Diet:*

Dietary manipulation is another effective means of reducing gas and odor emissions but not the primary focus of this study. A literature summary quantifying these emission reductions is included in the Appendix.

## Objectives

This project used a systematic approach to create a new design for pig finishing facilities in Minnesota and the upper Midwest, which reduces energy and environmental impacts and maintains, or hopefully increases, animal production efficiency. Most swine production facilities are built without optimum integration of individual components (ventilation and heating/cooling, manure handling, flooring, insulation, feeding, watering, etc). A systematic design integrates all these components with the goal of providing the optimum conditions for animal production and minimizing energy and air emissions. Many of the lessons learned in the development of such a facility may be transferred to existing facilities resulting in similar energy and emission reductions and production benefits.

## Materials and Methods

The advisory team (members listed below) met three times on this project to debate, brainstorm, and prioritize design factors for the GPB. On April 27 and 28 (2010) the advisory committee met to discuss the working draft of the GPB. The meeting included presentations on building designs to reduce energy use and emissions in Europe. Researchers Nico Ogink (Wageningen, Netherlands) and Merete Lyngbye, (Pig Research Center, Denmark) provided a summary of pig production in their respective countries and provided input on the GPB

design. In the fall of 2009, members of the advisory team toured a partially slatted grow-finish barn in Northern Iowa and a geothermal farrow to nursery barn in western Minnesota.
*Advisory Members:*

Larry Jacobson, PhD, University of Minnesota
David Schmidt, MS, University of Minnesota
Robert Koehler, MS, University of Minnesota
Bill Lazarus, PhD, University of Minnesota
Tom Stuthman, Automated Production Systems
Mark Whitney, PhD, University of Minnesota
Steve Pohl, PhD, South Dakota State University
Richard Nicolai, South Dakota State University
Jay Harmon, PhD, Iowa State University
Steven Hoff, PhD, Iowa State University
Rick Stowell, PhD, University of Nebraska
Crystal Powers, University of Nebraska
Mike Brumm, PhD, Brumm Consulting

Energy use in the various GPB designs or versions was estimated by the Danish StaldVent pig housing/growth model (Morsing, et al, 1997) using weather data from St. Cloud, MN and Des Moines, IA. Also, an EXCEL spreadsheet model developed by advisory members Bob Koehler and Bill Lazarus was used to assess the economics of the GPB designs and the sensitivity of the input parameters.

Capital investment in the buildings was estimated by a consulting engineer and general bids from commercial vendors. These cost estimates can be found in the appendix. Note that all of the GPB versions include a covered round concrete tank for manure storage. These costs are included in the analysis. The baseline pig finishing building costs are for the commonly built tunnel ventilated (TV) barn which is fully-slatted, mechanically-ventilated, with an eight foot deep pit manure storage under the footprint of the barn.

Final recommendations by the advisory team are summarized below and many of the ideas are incorporated into the final GPB design. One of the key design criteria from the earliest advisory team discussions was the impact of manure on both the barn's interior environment and emissions. Secondly, it was understood that the cost of the GPB would likely be greater than standard construction and would have to be significantly offset by improved pig performance.

**Results**

The basic GPB barn is a 2400 head facility (all in/all out) with shallow pits (18-24") and full width gutter scrapers. Version A and B have partially slatted floors with the solid floor incorporating in-floor heating and cooling provided by "cross-linked polyethylene" or PEX tubing in the floor. Version A uses a geothermal heat pump capable of providing 40 tons of heating and cooling to the floor. Theoretically, this cooling capacity will remove 25% of the sensible heat production from pigs at the final growth stage. This cooling is anticipated to reduce maximum ventilation requirements by 25%. Additional cooling of the incoming ventilation air will be provided with evaporative cooling pads located at both ends of the barn.
Version B incorporates the use of mechanical cooling (geothermal) of the solid floor and the incoming ventilation air. A boiler system would be required to provide floor and traditional convective heating. This system insures that thermal-neutral conditions for the pigs in the barn can be met during the entire season at all growth phases.

Version C is a fully slatted barn with shallow pits or gutters and manure scrapers. Cooling in this design is provided solely through evaporative cooling. Heating is accomplished through direct-fired heaters in the inlet hallways and radiant heat tubes or lamps in conjunction with solid pads for weaned pigs if used as a “wean to finish” facility.

Version D is also a fully slatted barn with shallow pits or gutters and manure scrapers. However, mechanical cooling (geothermal) is used to cool the barn in the summer and temper the incoming ventilation air in the winter. Supplemental heating in winter is provided by direct fire heaters in the inlet hallways along with radiant heat tubes or lamps in conjunction with solid pads for weaned pigs if used as a “wean to finish” facility.

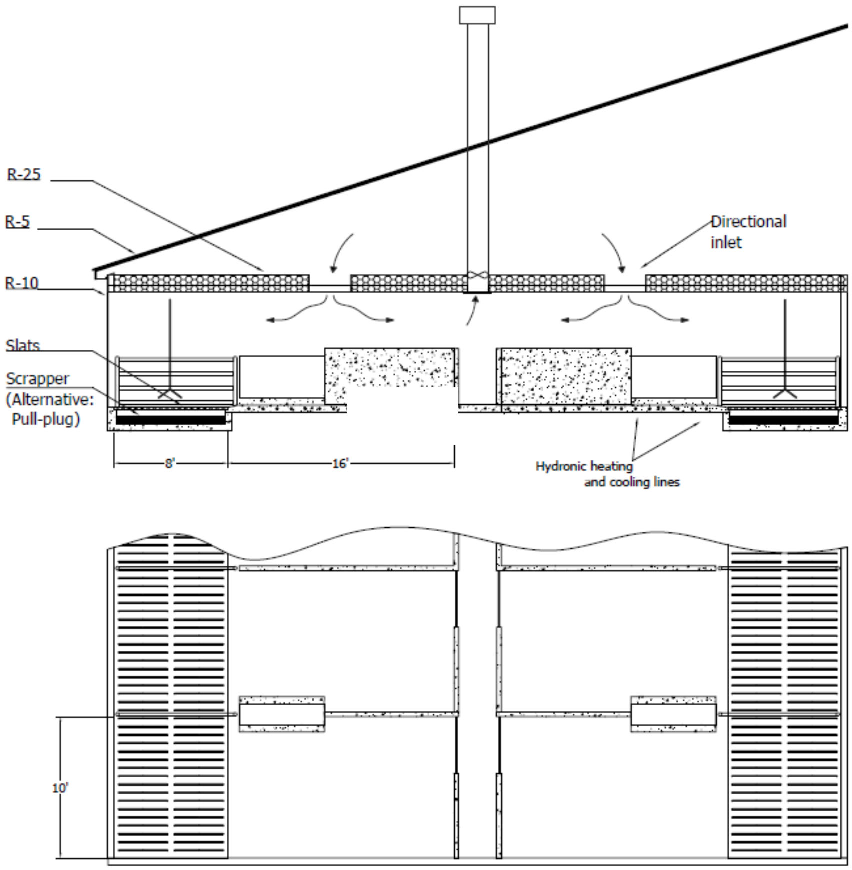


Figure 6. Half section and plan view of GPB A and B, partial slat barns.

*GPB Version A Features:*

- 2400 head wean to finish (2 rooms, 40 pens per room, 30 pigs per pen)
- 102’wide by 212’ long building
- Pen size 10’ x 24’ with 16’ solid flooring and 8’ slats
- Partial slats with scrapers (alternative pull plug)
- Cooling of floor provided by geothermal system
- Heating of floor and air using geothermal assisted heat pump
- Ceiling inlets for all ventilation air
- Evaporative cooling pads for temperature control in summer
- Maximum ventilation 80 cfm/pig with 40 cfm/pig ceiling fan capacity

*GPB Version B Features (Same as Version A except):*

- Thermoneutral barn temperature with mechanical (geothermal) tempering of inlet air
- Maximum ventilation of 40 cfm per pig with all ceiling fan capacity through the ceiling
- Boiler is used to provide additional floor and air heating (fin tubes) in winter

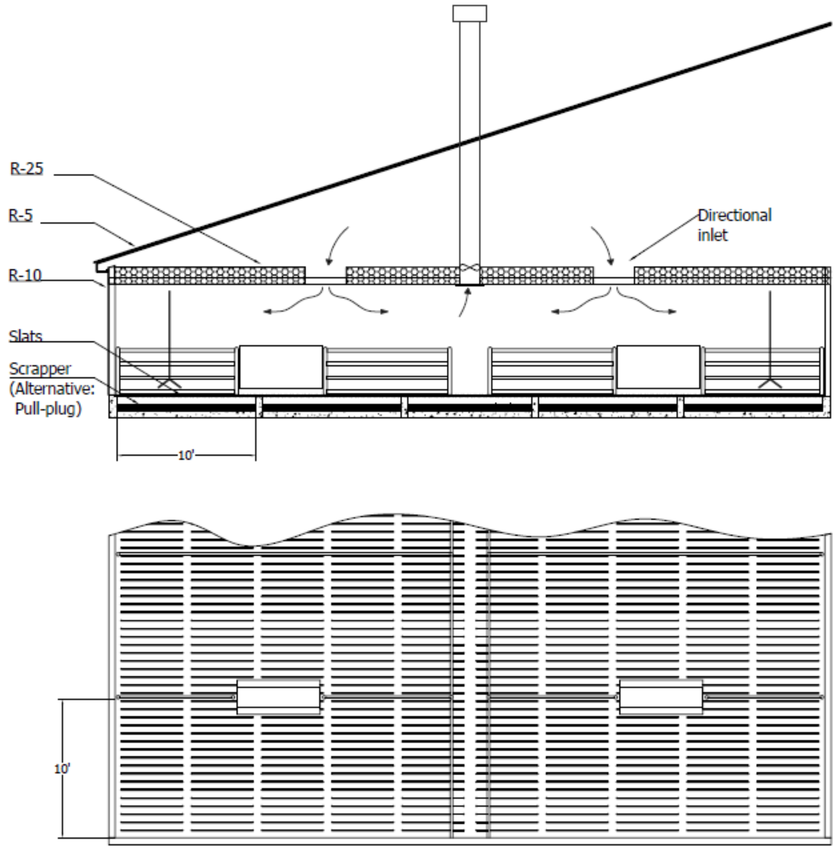


Figure 7. Half section and plan view of GPB C and D, full-slat barns.

*GPB Version C Features (Same as Version A except):*

- Fully slatted barn with manure scrapers
- Cooling provided by evaporative cooling pads
- Direct fire heaters to supply heat in inlet hallway with additional heat for weaned pigs supplied by infrared heating
- Maximum ventilation 100 cfm per pig with 40 cfm exhausted through ceiling

*GPB Version D Features (Same as Version A except):*

- Fully slatted barn with manure scraper
- Thermoneutral barn temperature with mechanical (geothermal) tempering of inlet air
- Direct fire heaters to supply heat in inlet hallway in winter and radiant heat for young pigs supplied by infrared heaters if wean to finish facility
- Maximum ventilation 40 cfm per pig exhausted through the ceiling

## IX. Discussion

### *GPB Features and Assessment*

*Cooling:*

As discussed above, animal performance is critical to making large reductions in energy inputs per pound of pork produced. Pig finishing barns in the upper Midwest are either power ventilated year around, such as the TV barns described earlier or naturally ventilated year around or just during warm conditions, such as the CS barns mentioned previously. For any of these barns, reducing heat stress in growing pigs during hot ambient conditions is limited to the use of periodically sprinkling water directly on the pigs.

Two cooling options are considered in the proposed GPB partial-slat system (Versions A and B); floor cooling with either evaporative cooling pads or with mechanical air cooling. Floor cooling is required in both cases to insure proper dunging habits for the pigs in the partial-slat versions. During hot conditions, the solid floor must be maintained at temperatures lower than the slatted floor to prevent dunging on the solid floor. Floor cooling would be accomplished through PEX tubes installed in the solid portion of the floor. Maintaining the floor at this lower temperature also will remove some heat (estimated at 40-60 BTU/hr/ft$^2$) from the pig through conduction (Kelly et al 1964). This approximate rate of heat removal was confirmed by Stillman and Hinkle (1971) with similar rates reported. This latter study reported no affect of floor or air temperature on the rate of heat transfer (floor temperatures between 70 and 85°F and air temperatures between 72 and 92°F). Kelly et al 1964 took this data one step further using an estimated 15 ft$^2$ of surface area per pig and 20% of the lying pig surface area in contact with the floor (3 sq ft) to calculate an approximate removal rate of 140 BTU/hr/pig or about 25% of the sensible heat production of the pig. Although significant, it is likely that this amount of cooling will not have a significant impact on pig performance but only dunging habits.

For the purposes of this study, the maximum floor cooling (slab to air) to avoid condensation is limited to about 4.8 BTU/hr/ft$^2$ (Olesen, 2008). Using this value and an estimate design of 5 ft$^2$ per pig of solid flooring, the total heat removal through the floor is estimated to be 24 BTU/hr/pig. This removal rate would increase significantly with animals lying on the floor as noted above (140 BTU/hr/pig).


Figure 8. Slatted area of pen with waterer

GPB Version A uses a ground source heat pump system for heating and cooling the solid floor. System sizing was estimated by Enertech Manufacturing LLC. The system would include 24 deep wells and a heat pump to supply approximately 585,000 BTU/hr of cooling. An evaporative pad system with a capacity of 724 gph (would be required to further reduce ambient air temperatures. As a result of this cooling, maximum ventilation in the barn is reduced to 80 cfm per pig. Heat for the building would also be supplied by the heat pump through the floor tubes in addition to some heat provided to the room air through fin tubes.

GPB Version B uses a complete geothermal exchange system to heat and cool the inlet air and solid floors in the barn. Additional floor heating and air heating would be provided by a boiler with the use of PEX tubing in the floor and fin tubes respectively. Preliminary system design for central Minnesota and costs were provided by ITB of Canada. This system requires 96 deep wells (250' deep) to supply 1.6 M BTU cooling. This same system is used to provide the cooling and heating for Version D.

Both barns A and C include evaporative cooling to help reduce heat stress while Versions B and D use geothermal cooling of the incoming ventilation air. Other options and bids for cooling should be considered prior to construction. In general, a ground to air heat pump system has a COP of 3 (Coefficient of Performance) and the geothermal only system has a COP of 15. The geothermal only system is not capable of providing sufficient floor heat and must be coupled with a boiler or heat pump to provide the floor heating required in the Version B (partially slatted).

*Manure Handling (Scraper):*
From early on the advisory team felt that to maintain air quality in the animal environment some separation between the animal production area / environment and the manure storage was important. Both scraper and pull plug systems were discussed by the advisory group and both have strengths and weaknesses but in the end, it was decided that scraper systems will likely have a larger impact on barn emissions and barn air quality. As such, scrapers are recommended in all GPB versions. It is recognized that producers are wary of scrapers (moving parts mean more repairs) but experience with scrapers in several pig finishing (grow-finish) barns in northern Iowa has been positive. Also, an integrator in Missouri is replacing their manure collection system from a lagoon water flush to scrapers in many of their grow-finish barns to reduce gas and odor emissions.

Scraper systems offer several advantages. With a scraper system, manure is moved out of the barn twice or more each day, resulting in fewer anaerobically created gas emissions. Scraping removes all hazards related to intermittent high gas concentrations and subsequent hazards during agitation and pumping of deep pits or when the plugs are pulled in shallow gutter barns.

In addition, it is anticipated that future housing designs will incorporate energy recovery systems such as anaerobic digesters. In such cases, daily feeding of fresh manure from scraper systems will result in better digester performance and energy balance. (Note that a 150 lb pig can potentially produce about 2400 BTU/day from a well managed digester which could be used for cooling and heating the swine building.)

*Ventilation:*
Ventilation systems should be designed to insure uniform air quality throughout the barn at parameters specified by the producer. These parameters typically include temperature but can also consider humidity, air speed, and carbon dioxide concentrations. Several manufacturers design, sell, and install these systems. Advisory team members recommend ceiling exhaust fans with variable frequency drive electric motors for all minimum (cold and cool weather) ventilation fans. These fans are likely to resist wind pressures better than wall fans. Additional wall fans are installed in GPB version A to provide the required air exchange rates for warm weather brought through the evaporative cool pads. Because of the geothermal cooling system in Versions B and D, the ventilation requirements are lower (40 cfm/pig) and enough airflow (cold and cool weather rates) capacity can be provided with ceiling fans only.

The design calls for two rows of ceiling inlets per room with the capacity for all the ventilation air. Inlets are directional to allow for air distribution over the slats or on the solid portion of the floor to aid in controlling dunging habits in the partial slatted barns (Versions A and B). Ceiling inlets throughout the barn will provide more uniform and better air quality in the barn for the same ventilation rate. Fans and inlet controls will be synchronized and controlled by at least two temperature sensors per room to insure uniform conditions.

***Estimated Energy and Emissions with GPD***

The project's goal was to design a building for finishing pigs that would reduce its energy consumption and air emissions by 50% compared to the commonly used double-wide, tunnel ventilated (TV) pig finishing barn. The Danish building model StaldVent™ was used and estimated up to 50% reduction in LP Gas use by increasing insulation in the walls and ceilings. Additional LP Gas savings of 20% was determined through reduced barn temperatures for larger pigs. These same savings will likely be realized in the GPB barns but it is difficult to precisely predict these efficiencies due to the additional features of the barns such as cooling systems, shallow gutters, and solid floors. Rather, in the table 4 below, we have made some relative estimates for energy (divided into electrical and LP) use and the air emission compared to our reference TV barn.

Table 4. Energy usage and air emission estimates for the four GPB versions

| Version of barn | Electrical energy | LP use | Air Emissions |
|---|---|---|---|
| Version A (partial slat – 80 cfm/pig max) | + | - | -- |
| Version B (partial slat -40 cfm/pig max) | - | - | --- |
| Version C (full slat – 100 cfm/pig max) | 0 | 0 | - |
| Version D (full slat – 40 cfm/pig max) | - | - | -- |

Electrical energy use will likely increase in only version A because of the use of an electrical heat pump. Version C will have similar electrical energy requirements compared to the reference TV barn but Versions B and D should use less electricity than a TV barn since there will be less exhaust fans operating and the small power usage of the geothermal and broiler water pumps. Fossil fuel (primarily L.P. Gas) use will be less in versions A, B, and D since more efficient heating systems (geothermal, boilers and fin tubes) will be utilized. Thus, total energy (electrical and fossil fuel) should be less for all version B and D, about the same for version C and maybe slightly more for version A. However, when expressed on a production (lb of pork) basis even versions A and possibly C will have lower energy use than the reference barn because of improved pig performance. Air emissions should be reduced in all versions, since none of the versions have deep pits (all versions have an adjacent covered concrete manure pits) which would result in less gas and odor emitted from the combined barn and manure storages, plus summer airflow rates are all less than the standard TV barn (120 cfm/pig) which may also help reduce the emission rate of gases and odor. Additionally, these barns will operate with cooler room temperatures than typical barns further reducing emission rates due to less generation of odorous gases.

***Economics of GPD***

Technologies that can reduce emissions and provide cleaner air and greater barn environmental control (like covered outside manure storage, floor cooling, and geothermal cooling) add to facility cost when compared to current swine finishing designs. One possible method of cost recovery is improved pig performance. Increased ADG, improved feed conversion, lower death loss, and reduced pig health costs can cover all or some of the added costs. Research data on the effects of lower and uniformity of temperature and ventilation air speed can be used to estimate improved pig performance for the technologies included in the “green” alternatives suggested in this report. However, confidently estimating this improvement is challenging since most available research was collected under constant conditions (such as temperature). Obviously conventional facilities currently in use have environments (temperature, ventilation air speed, humidity, etc.) that vary during the day and season. Effect of short term stress from less than ideal conditions and potential compensatory gain complicate estimation of performance differences in comparisons to more constant ideal or thermoneutral conditions in the GPB alternatives.

If reduced emissions and improved environment for pigs and workers increases pork production costs more than improved performance can recover when compared to conventional systems, consumers must be willing to spend more for pork produced in environmentally friendly designs. Also, that premium must be returned to producers who have made the necessary investment to achieve these environmental standards.

An EXCEL spreadsheet model developed by advisory members Bob Koehler and Bill Lazarus was used to assess the economics of the GPB and the sensitivity of the input parameters.

Baseline input parameters for pig performance, shown in Table 5, are based on advisory team data and best professional judgment. Four versions of the GPB are compared. Version A has partial slats, a scraper, geothermal floor cooling, and evaporative air cooling. Version B has partial slats and a geothermal system to cool floor and incoming air. Version C is fully slatted with a full scraper and evaporative cooling. Version D has full slats, a scraper, and mechanical (geothermal) cooling.

**Information and data that influenced these estimates include:**

Cold conditions (below the thermoneutral zone) increase feed intake with minor or no change in average daily gain and increase the amount of feed required per unit of gain. GPB and conventional facilities will likely not often be colder than desired temperatures for finishing pigs and little potential performance improvement would be expected from the more closely controlled GPB. However, when temperature exceeds the thermoneutral zone feed intake in finishing pigs is significantly reduced. This results in lower ADG. Feed efficiency response is reported in a range from little or no change to moderate increases in the amount of feed required per unit of gain at the warmer temperatures.

Logically, barn cooling has the largest economic benefit in regions where conditions causing heat stress are more prevalent. Hourly barn temperatures, with no cooling, were calculated using the Danish model StaldVent for St. Cloud, MN and Des Moines, Iowa. This data indicates that in Central Minnesota hourly barn temperatures exceed 72 °F approximately 25% of the time and are above 79 °F 10% of the time. Near Des Moines, Iowa, hourly barn temperatures exceed 72 °F approximately 37% of the time and are above 79 °F 10% of the time. From the data cited above we estimate a 15% decrease in ADG with temperatures exceeding 72 °F and 3% increase in feed efficiency (lbs feed/lb gain). This estimate, coupled with the frequency of temperatures above, suggest a 0.07 lb/day increase in ADG and a 0.02 decrease in FE by maintaining temperatures at or below 72 °F from baseline data. For the purposes of our economic analysis we used the 0.11 lb/day increase in ADG and a 0.3 decrease in FE for our Version B barn and modified this value for the other GPB Versions based on best professional judgment considering reduced humidity, lower air velocities and better barn air quality. These performance values are critical to a positive economic return on these buildings.

Capital investment in the buildings was estimated by a consulting engineer and general bids from commercial vendors. These cost estimates are available on request and will be posted at our website (www.bbe.umn.ed/Animal_Housing_and_Livestock_Systems.html). Note that all of the GPB versions include a covered round concrete tank for manure storage located adjacent to the buildings. These costs are included in the analysis. The baseline pig finishing building costs are for the typical TV facility being built today in the upper Midwest.

**Table 5. Input parameters and results for the economic analysis.**

| | Units | Baseline Full Slats, Deep Pit | Green pig barn scenarios: Version A | Version B | Version C | Version D |
|---|---|---|---|---|---|---|
| ***Input parameters*** | | | | | | |
| Facility Investment [1] | $ / pig space | 261 | 400 | 511 | 350 | 525 |
| ADG [2] | lb/day | 1.55 | 1.62 | 1.66 | 1.60 | 1.66 |
| Start Wt. | lb | 16 | 16 | 16 | 16 | 16 |
| End Wt. | lb | 280 | 280 | 280 | 280 | 280 |
| Weaned Pig Cost | $/pig | 38 | 38 | 38 | 38 | 38 |
| Additional days to end group [3] | days | 15 | 15 | 15 | 15 | 15 |
| Down time between groups [4] | days | 7 | 7 | 7 | 7 | 7 |
| Feed cost [5] | $/ton | 220 | 220 | 220 | 220 | 220 |
| Feed efficiency [6] | lb feed/ lb gain | 2.75 | 2.55 | 2.45 | 2.6 | 2.45 |
| Death loss [7] | % | 3.0 | 2.5 | 2.5 | 2.5 | 2.5 |
| Pig health costs [8] | $/pig | 2.50 | 2.00 | 2.00 | 2.00 | 2.00 |
| Other costs (labor, transportation, marketing, etc.) [9] | $/pig | 8.00 | 9.00 | 9.00 | 8.00 | 8.00 |
| Facility life | years | 15 | 15 | 15 | 15 | 15 |
| Electricity use [10] | kWh/pig produced | 10 | 13 | 8 | 10 | 8 |
| LP use [11] | Gal. / pig produced | 0.7 | 0.3 | 0.5 | 0.7 | 0.5 |
| Mkt. hog price [12] | $/cwt. | 55.00 | 56.00 | 56.00 | 56.00 | 56.00 |
| ***Results*** | | | | | | |
| Estimated profit per pig [13] | $/pig | 3.73 | 6.65 | 4.95 | 8.18 | 5.30 |
| Annualized NPV/pig space compared to baseline facility | $/pig space | ____ | $5.95 | $2.43 | [illegible] | [illegible] |
| Years to payback additional facility depreciation over baseline facility [14] | Years | ____ | 9.1 | 12.8 | 6.0 | 12.5 |

(1) Based estimates by field engineers to build barn and install features
(2) Based on 2009 Finbin records of 36 farms and other industry observations with upward adjustments for cooled facilities
(3) Days on feed for a group is calculated on ADG. Then this number of days is added to account for time for below average pigs to reach market weight to close out the group.
(4) Days between last pig out and new arrivals for clean up, etc.
(5) Based on Fall 2010 prices with $5/bu corn prices
(6) Based on 2009 Finbin records of 36 farms and other industry observations with downward adjustment for cooled facilities
7) Based on estimates from well managed operations with healthy pigs with downward adjustment for cooled facilities
(8) Based on 2009 Finbin records of 36 farms with downward adjustment for cooled facilities
(9) Based on 2009 Finbin records of 36 farms with upward adjustment for partial slat facilities
(10) Estimated based on survey of actual barn usages in Midwest U. S.
(11) Estimated based on survey of actual barn usages in Midwest U. S.
(12) Long term estimate with futures prices that have been influenced by projected high feed costs
(13) (Change in pig value over all costs/ year/facility) / (annual number of pigs produced for facility)
(14) (Change in investment) / (Return over non-fac cost & interest on average facility investment/ year/facility)

***Summary*:**

A 2400-head double wide, tunnel-ventilated, fully slatted, deep pit finishing barn was used as the reference facility to compare energy use and air emissions with the new GPB housing design. The tunnel ventilated (TV) barn was used as a baseline in this study because it has been the most commonly built pig finishing facility in the upper Midwest for the past 5 to 10 years. It is estimated that over 80% of all pig marketed in the upper Midwest are either grown in a tunnel ventilated (TV) or the deep pit, fully slatted, curtain sided (CS) barn.

This report includes four GPB design variations. Version A features pens with partially slatted floors and in-floor heating and cooling in the solid floor section, shallow gutters under the slats with mechanical scrapers for manure removal to an outside covered manure storage tank, and an evaporative cooling system. Version B is similar to Version A but integrates a mechanical (geothermal) cooling system (rather than evaporation pads). Version C is similar to Version A, but has fully slatted floors and is cooled only with evaporative cooling pads. Version D is similar to Version B (mechanical cooling) but has fully slatted floors. All GPB design versions use shallow gutters with mechanical scrapers and an in-ground, covered, concrete manure storage tank located adjacent to the barn.

All versions of the Green Pig Barns are expected to save energy in the winter due to better insulation and environmental control. Reduced emissions are also expected due to the incorporation of cooling systems. Building construction costs per pig space are expected to be 1.3 to 2 times higher than typical construction. These costs are offset by a 3-7% increase in average daily gain and 5-10% decrease in feed consumption per pound of meat produced. Other benefits include better pig health and worker environment. Using these assumptions a standard economic projection, annualized net present value per pig space is between $2.43 and $9.03 with 6.0 to 12.8 years to payback over the baseline building. These economic projections would improve significantly with additional gains in animal performance. It is generally thought that these performance gains are anticipated but there is currently no supporting research data to confidently predict the magnitude of these performance improvements on an annual basis in commercial scale operations.

Barn retrofit concepts reported in this document focus on structural upgrades such as insulation and mechanical items like improved environmental control, fan and heater maintenance and management, along with manure pit management. Recommendations are outlined in a factsheet that can be found in the Appendix D of this document and on-line at www.bbe.umn.ed/Animal_Housing_and_Livestock_Systems.html .

Moving the swine industry forward to a more sustainable production facility was the focus of this project. Results from the project indicate that current facilities in the upper Midwest can be modified or managed to reduce energy inputs. Results also indicate that there are alternatives to the current finishing facilities in the Midwest that could result in reduced energy and emissions per pound of meat produced while still being economically viable. Construction and monitoring of the design housing concepts laid out in this report is a critical next step in moving the industry forward in sustainable pig finishing production.

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**Appendix A**

***Advisory Group Summary of Recommendations (04/28/2010)***

| Factor | Available Options Discussed | Advisory Member Choice and Justification |
|---|---|---|
| **Flooring** | Fully slats<br>Partial slats<br>Narrow slats<br>Other Flooring | Partial slats have the advantage of less emissions (if managed properly) because of less emission area. Partial slats are also viewed as more animal friendly.<br>Full slats will likely be more accepted in the industry and will be considered in the 2nd design option. Option 2 (Full slats) will still be a pull plug system with European V-Gutters |
| | Finishing<br>Wean to Finish | The proposal was open ended on whether the barn should be a finish only barn or a wean-finish. Wean-finish was chosen as this is the most common barn being constructed now and in the near future. |
| **Stock Rate** | Stocking rates per pen could range from 16 to 100 | Stocking rate (pen size) is not critical for energy management or emission control and is more of a labor issue or matter of preference. It was generally thought that pens having groups of 30 pigs are most common and are easiest to manage. |
| **Pen Size** | More rectangular or more square and stocking density | Once again, more of a personal preference but required to complete the building design. Stocking density is commonly 8 sq ft per pig and pen dimensions for groups of 30 pigs is 10' x 24.' |
| **Building Size and shape** | | Building size and shape is also somewhat of a personal preference but typical barns are 1200 head or 2400 head with two rows of pens separated by a walk alley. Since these buildings will be mechanically ventilated, width is not critical for ventilation. Energy efficiency principles lean toward more square buildings (rather than long and narrow). Barn width is also dictated by construction principles. Building design is for two rooms of 40 pens per room with a center walkway in each room. Dimensions are 100' wide by 200 ft long. |
| **Partial Slat Dimensions** | | Option 1, Partial slat barn requires a decision on the amount and location of the slats and solid flooring. With a pen length of 24 feet the typical ratio of solid to slat is 2:1 meaning a slat area of 8 feet and a solid area of 16 feet or a solid floor area of 5.3 sq ft per pig.<br>NOTE: New information from sub advisory group meeting on July 8th decided 50% solid with – 8'slats, 12' solid, then 4'slats. |
| **Manure Storage** | Inside the barn in deep pits or in outdoor manure storages | Literature suggests manure storage under the barn contributes significantly to barn emissions, barn air quality, and more recently, explosion hazards. In both the fully slatted barn and the partially slatted barn it was decided that the manure storage should be outside of the building. |
| **Manure Collection and** | Deep Pits<br>Flush gutters<br>Pull plug | Because of the need to have manure storage out of the barn, the option of deep pit manure storage has been dismissed. Gutter cleaners and belt systems were thought to require too |

| | | |
|---|---|---|
| **removal** | Gutter scrapers<br>Belt Conveyors (Faeces and urine separation)<br>Liquid solid separation<br>Manure Treatment | much maintenance and would be rejected by farmers. Flush systems typically produce more emissions and require manure treatment for flush water. A modified pull plug with a V gutters was shown to produce the least amount of emissions from Danish and Dutch research. As such, pull plug manure removal and V-gutters will be used in both the full slat and the partial slat designs.<br>Option 1 a) Pull Plug with V-gutters based on European design to reduce surface area<br>Option 1 b) Scraper – moving manure out of the barn more frequently is likely to improve barn air quality.<br>Option 2) European V-gutters under all slat area. |
| **Heating** | LP Tube Heating, Direct Heater Electric, Solar Air to air heat exchanger on fans, Ground Source heat pump (geothermal), Geothermal heat exchanger, Manure storage heat exchanger, Radiant Floor Heating | An evaluation of heat requirements and cost of the available options is required prior to making a decision on the type of heating system.<br>Working with GeoComfort to determine most cost effective option. |
| **Cooling** | Ground Source heat pump (geothermal)<br>Geothermal heat exchanger<br>Manure storage heat exchanger<br>Radiant Floor Cooling<br>Fogging<br>Evaporation pads<br>Building Orientation | Cooling is considered a critical requirement of this design because of the improved economics of swine production with cooler temperatures. Fogging and evaporative pads are often used in the industry but cannot provide enough cooling to maintain optimal conditions. Cooling options must be evaluated more thoroughly. One option being discussed is convective floor cooling. Convection is typically a very efficient means of energy transfer.<br>Working with GeoComfort to determine most cost effective option. |
| **Ventilation** | Natural Ventilation<br>Mechanical Ventilation<br>Control Sensors<br>Nocturnal Rates<br>Frequency drive fan motors<br>Air Treatment and Recirculation<br>Fan Placement<br>Inlet Placement | Mechanical ventilation was chosen over natural ventilation due to the desire to maintain cool summer conditions in the barn. Control systems will be based on the type of heating and cooling system but should provide for micro climate control. Ventilation will be done with a minimum of one frequency drive controller so ventilation set points can be more precisely managed. Heating, cooling and ventilation will be controlled using temperature, humidity and CO2. 1$^{st}$ and 2$^{nd}$ stage exhaust fans will be through the ceiling with the option of the larger fans going through the ceiling or through the wall. Inlets air will enter from the gable end of the barn and into the attic space. Inlets will be manufactured inlets and controlled with the ventilation controller so as to maintain proper building pressure. |
| **Insulation** | | Walls and ceilings will be insulated with R25. Roof will be insulated with R5. StaldVent will be used to estimate the cost benefit of the additional insulation.<br>Discussion post meeting suggests walls should have R5-R10. StaldVent should be run to determine cost differential |

| | | |
|---|---|---|
| **Feed and Water Systems** | Liquid feeding<br>Dry with swinging nipples<br>Wet bowl<br>Dry with drinking cup | Wet bowl and dry feeders with a drinking cup were chosen for both barn options. Neither has a clear advantage with producers, feed wastage, or feed efficiency. Nipple waterers added over slats to aid in training pigs in the partial slat floor option. |

## Appendix B

*Cost Estimates for GPB*

**Wenck and Associates (Baseline and all GPD Versions)**

**GeoComfort (Geothermal equipment for version A)**

**ITB Canada (Geothermal and ventilation system for version B and C)**

**Publications for more information on Energy Efficiency**

- Effective Environmental Temperature. Baker, J.E. J. Swine Health Production 2004;12(3):140-143 http://www.aasv.org/shap/issues/v12n3/v12n3ptip.html
- Energy Efficient Mechanical Ventilation Fan Systems. 2006. Ontario Ministry of Agriculture, Food and Rural Affairs #717. S. Clark. http://www.omafra.gov.on.ca/english/engineer/facts/06-057.htm
- Energy Efficient Swine Lighting. 2006. Ontario Ministry of Agriculture, Food and Rural Affairs. S. Clark. http://www.omafra.gov.on.ca/english/engineer/facts/06-011.htm
- Mechanical Ventilation Design Worksheet for Swine Housing. 1999. Iowa State University Livestock Industry Facilities and Environment Series. J. Harmon. http://www.extension.iastate.edu/Publications/PM1780.pdf
- Troubleshooting Swine Ventilation Systems. Pork Industry Handbook, Michigan State University, E-2574. L. Jacobson et al. http://web1.msue.msu.edu/msue/iac/disasterresp/Animals/e2574.pdf

*Internet Links for Energy and Emissions from Swine Buildings*

- Manure Management and Air Quality, University of Minnesota www.manure.umn.edu

- Energy Reduction in Swine Finishing Barns (Fact Sheet from this project), University of Minnesota http://www.bbe.umn.edu/ExtensionandOutreach/EnvironmentandEcology/resources/AnimalHousing/index.htm. Mechanical Ventilation Design Worksheet for Swine Housing http://www.extension.iastate.edu/publications/pm1780.pdf Iowa State University Extension

- Energy Efficient fans for Swine Production http://www.extension.iastate.edu/Publications/PM2089E.pdf Iowa State University Extension

- Energy Efficiency, Conservation and Management (a set of publications for energy efficiency in animal and crop production) http://www.omafra.gov.on.ca/english/engineer/con_energy.htm Ontario Ministry of Agriculture

- USDA Energy Estimator for Animal Housing http://ahat.sc.egov.usda.gov/

- Livestock Buildings' Energy Efficiency Checklist and Tips http://www.extension.org/pages/Livestock_Buildings_Energy_Efficiency_Checklist_and_Tips USDA eXtension

- ThePigSite http://www.thepigsite.com/ Articles on a variety of swine housing and energy topics.

## Appendix C

***Economic Analysis Methodology***

A spreadsheet model developed by advisory members Bill Lazarus and Bob Koehler was used to assess the economics of the GPB versions. Input parameters are listed in Table 3 in the report. This spreadsheet, along with instructions for its use is available at: http://www.apec.umn.edu/faculty/wlazarus/tools.html. Producers are urged to do their own analysis when considering GPB options that reflect bids specific to their operation and production estimates that may more closely fit their individual production situations.

***Summary of Dietary Influence on Pig Performance and Emissions***

***Reduced N from lowering CP and replacement with synthetic amino acids reduces NH3 emissions:***

- Reductions in nitrogen (N) fed has been shown to reduce ammonia ($NH_3$) emissions by 10 to 40% in poultry and swine without impacting performance. (Applegate, Richert, and Alan Sutton - Purdue University, Powers, Michigan State University, & Angel – University of Maryland.)
- NH3 concentrations were reduced 24% (2.93 ppm) and 36% in a 5-AA and 3-AA diet, respectively, compared to the 1 AA control diet containing only 1 AA. No diet effects were observed for H2S. NH3 and H2S emissions were increased as a result of DDGs inclusion in the diet. (W J Powers, S B Zamzow, B J Kerr)
- A series of studies have reported that reducing the CP from 3.5 to 4.5% of a corn-soy diet with supplemental Lys, Met, tryptophan (Trp) and Thr fed to grow-finish pigs compared to a commercial diets reduced slurry pH (0.4 units), total N (30 – 40%), ammonium N (20 – 31%), as well as reduced aerial $NH_3$ 40 – 60%, hydrogen sulfide 30 – 40%, and total odors 30 – 40% (Sutton, et al., 1999; Prince, et al., 2000; Richert and Sutton, 2006).
- Iowa State University: Direct emissions of ammonia are reduced by 19 percent for every percentage unit of dietary crude protein that is reduced in swine diets
- Diet calculations by Dean Koehler-Crude Protein levels of a GF Swine diet formulated to 0.80% SID Lysine (SID = Standardized Ileal Digestibility) or approximately 0.90% Total Lysine:
  - All SBM (no crystalline Lysine) = 18.30% CP
  - 3 lb/ton crystalline Lysine = 16.70% CP
  - 6 lb/ton crystalline Lysine + DL-Met + L-Thr = 15.06% CP
- L-Lysine, DL-Methionine and L-Threonine are routinely added to swine diets. L-Tryptophan is very expensive and is only used in a small proportion of nursery diets (if at all). Thus, I assume a lot of this potential reduction in NH3 emissions is already being experienced in the field because for economic reasons many swine finisher diets already contain AA additions.

***Influencing H2S emissions***

- Minimizing sulfur amino acid concentrations in the diet (methionine and cysteine) can reduce H2S emissions. (Applegate, Richert, and Alan Sutton - Purdue University, Powers, Michigan State University, & Angel – University of Maryland.)

- By replacing mineral sulfate sources (Zn, Fe, Mn, and Cu) in diets for grow-finish pigs with carbonate, oxide, and chloride sources, $H_2S$ concentrations in room and exhaust air from confinement buildings were numerically reduced by 39 and 30 %, respectively. Kendall et al. (2000).
- H2S emissions in exhaust and airflow air was not affected by replacing part of the commercial protein sources with amino acids (Powers). However, Sutton and others report H2S emission reductions with that approach.
- Shurson, Whitney, and Nicolai, U of MN, report studies have shown that by carefully selecting low sulfur feed ingredients and using them to formulate nutritionally adequate, low sulfur starter diets, total sulfur and sulfate excretion can be reduced by approximately 30%, without compromising energy and nitrogen digestibility or pig performance. Furthermore, our studies show that reduction in total sulfur consumption and excretion will lead to a reduction in hydrogen sulfide gas and odor, but not affect ammonia levels in nursery facilities

***Other Diet Inclusions***

- The use of sub-therapeutic levels of feed grade antibiotics and copper sulfate can improve feed efficiency.
- Growth promotors also have the potential to reduce air emissions. For example, diets for finisher (185 lb) pigs containing 20 ppm of a β- agonist (Paylean®) decreased total N excretion by 10.7%, total manure output by 3.9%, reduced $NH_3$ emissions by 20% decreased ammonium-N in stored manure (8 to 21%) and reduced odor emissions (DeCamp, et al. 2001; Hankins, et al. 2001).
- It was also reported that ammonia emission from pig manure could be reduced by 5.4% with each 100-g increase of fiber intake (Yingxin Gao).
- Addition of fiber to low protein, amino acid supplemented diets has the potential to further decrease urinary urea nitrogen excretion and, thus, ammonia emissions (Carter).
- Soybean Hulls have shown a 17 to 36 percent reduction in ammonia (NH3) emissions. Inclusion of 10 percent with 3.4 percent fat to a standard commercial diet reduced aerial NH3 by 20 percent and reduced hydrogen sulfide (H2S) by 32 percent. A five percent inclusion with reduced crude protein and supplemental amino acids in corn-soy diets reduced aerial NH3 by 50 percent and reduced aerial H2S by 48 percent (Sutton)
- Binding agents, such as clinoptilolite and clay minerals sometimes can reduce ammonia emission from the intestine by absorbing the hazardous gases (Yingxin Gao).
- Adipic acid, at the inclusion level of 1% in grower diets, can reduce ammonia emission from swine excretion by 25% through lowering the manure pH value, as reported recently (Yingxin Gao).

***DDGS***

- Powers found that corn co-products (including DDGs) increased NH3 and H2S emissions.
- Initial studies have indicated that including distiller's dried grains with solubles (DDGS) can greatly affect nutrient content of manure but has a minimal effect on odor and gasses emitted. In one study, adding 20% distiller's dried grains with solubles to swine diets had no effect on reducing odor, hydrogen sulfide, or ammonia emissions (Whitney).
- DDGS, however, also contains a high crude protein level and poor amino acid balance, similar to corn. This means a large amount of nonessential amino acids are subsequently excreted, increasing the nitrogen content of pig slurry. Inclusion of 20% DDGS in two studies (Spiehs et al., 1999; Spiehs et al.,

2000) resulted in a 25% increase in nitrogen excreted. However, use of synthetic amino acids (L-lysine) and formulation on a digestible amino acid basis can decrease the total amount of nitrogen excreted (Spiehs).

***Other Management Influences:***

- Other methods to improve dietary nutrient digestibilities and efficiencies in pigs are phase-feeding, split-sex feeding, fineness of grind, and pelleting. Diets should be formulated on a nutrient availability basis and adjusted to meet the specific requirements if the genetic lines of the pigs for efficient, profitable performance.

**Appendix D**

# Retrofit of Existing Midwest Pig Finishing Barns to Reduce Energy and Emissions

**Larry Jacobson and David Schmidt, U of MN, St. Paul, MN, Mike Brumm, Brumm Consultants LLC., Jay Harmon and Steve Hoff, Iowa State University, Steve Pohl, South Dakota State University, Rick Stowell, University of Nebraska**

One objective of the MPB/NPB funded project entitled: Reducing the Environmental Footprint of Swine Buildings or Greener Pig Barn (GPB), is to provide retrofit or remodeling guidelines to reduce energy use and the amount of gas, odor, and dust emissions for the existing wean to finish and/or grow to finishing pig buildings presently being used in the Midwestern part of the U.S. This is in lieu of the fact that the new barn designs proposed in this project would take time to be adopted and even if they were immediately utilized for new construction, it would take 10 or more years to replace the thousands of pig finishing barns presently being used in the Midwest.

The two types of finishing buildings that cover a large majority (> 80%) of the facilities presently being used in Midwestern U.S. to grow pigs are the curtain sided (CS) and the tunnel ventilated (TV) barns. The CS barn (figure 1), as the name implies, typically has vinyl curtains on both long sidewalls which are adjusted with a temperature controller to provide ventilation or air exchange in the barn during warm and some cool weather conditions. During cold weather, the sidewall curtains are closed up completely and the barn is mechanically ventilated by pit and possibly one or two end wall fans plus designed ceiling inlets. The typical mechanical ventilation fan capacity for a CS barn is from 20 to 25 cubic feet of air per minute per pig (cfm/pig).


Figure 1. Typical Curtain Sided (CS) pig finishing barn.

The TV barn (figure 2) is mechanically ventilated year around with total fan capacities generally at 120 cfm/pig that is divided between pit fans (~20 cfm/pig) and tunnel or wall fans (~100 cfm/pig). These barns have solid insulated sidewalls and one end that contain the large diameter "tunnel" exhaust fans while the other end has an adjustable vinyl curtain. During the winter the curtain end wall is completely closed and all the air is brought in through designed ceiling inlets that draw air from the barn's attic (similar to the CS barn). In the summer, the curtain opens as needed by the number of tunnel fans at the opposite end of the ban that are operating. During warm temperatures most of the incoming air is brought in through the end wall curtain although some may enter through the ceiling inlets.

Figure 2. Common Tunnel Ventilation (TV) pig finishing barn

**Retrofit suggestions to reduce energy and emissions for either the CS and TV barns:**

- The use of “bubble wrap” insulation, as shown in figure 3, can be very helpful to insulate and seal curtain side or endwalls during cold weather operation. This will save conductive heat loss and L.P. Gas usage, plus it will prevent frosting and excessive condensation on the inside curtain surface and tighten up the barn so inlet air will enter the barn through the design inlets rather than undersigned openings around the curtains.

Figure 3. Bubble wrap placed on inside of curtain with aluminum side on the inside (photo courtesy of Mike Brumm)

- Insulate any concrete knee side or end walls that are not presently insulated. This is best done on the outside with at least 2” rigid board insulation. This will prevent conductive heat loss and thus L.P. Gas usage plus prevent frosting and most condensation on the inside knee wall surface.

- Insulate the warm weather exhaust fans with an insulated cover placed over the inside louvers. This will reduce conductive heat loss plus more importantly prevent backdrafting of cold air through the warm weather fan louvers. Also, place a fan “sock” on the outside of any non-continuous running fans that will operate during cold weather to prevent backdrafting of air when these fans are not operating.

- Relocate pit exhaust fans to side or end walls (eliminate pit exhaust fans). This will reduce gas and odor emissions while still maintaining indoor air quality as long as similar air exchange or ventilation rates are maintained.

Figure 4. Pit fan has been move to sidewall.

- Pump manure from the deep pit twice a year instead of once. This management practice will prevent the manure level in the deep pit from becoming too high (goal is to keep three feet of freeboard below slats) which will reduces air emissions especially if pit fans are used.

- Change L.P. Gas heater setting on controller to prevent heater overshoot (temperature in room continues to rise in barn after heater shuts off and triggers first stage ventilation fans to come on). The shut off temperatures for heater should be at least 2 $^{o}$F under the controller “setpoint” temperature. Also, make sure the controller’s temperature sensors are placed well away from heated furnace jet airstream and are sensing a true room temperature. Preventing heater overshoot will save large amounts of L.P. Gas.

- Change L.P. Gas heaters setting to low (most direct fired heaters will have a low and high setting) which will also save L.P. Gas usage since often heaters are oversized in pig finishing barns. Ventilation performance will be improved (less temperature variations) since heaters will run longer but use less L.P. Gas and allow building to respond and prevent “heater overshoot”. Heaters only need to be switched to the high setting if the low setting heaters never shut off during cold conditions and with young pigs in barn.

- When selecting fans for the minimum or continuous ventilation rates in the winter, select the fewest number of exhaust fans possible and if possible only use single speed fans that can be manually operating (hot-wired or not part of controller). However, if variable speed fans are used for providing this rate, they should never run under 50% rpm, since they do not provide a reliable airflow rate and are energy inefficient at or below that speed. Energy and ventilation efficiencies will be improved when single speed fans are used to provide the minimum ventilation rate rather than using variable fans.

Retrofit suggestion for (CS) barn only:

If the mechanical ventilation capacity for a CS barn is only 20 or 25 cfm/pig considering increasing it to 40 or 45 cfm/pig. This will mean the installation of an additional exhaust wall fan or two plus corresponding additional ceiling and attic inlets. Such an increase in the ventilation rate, will allow the mechanical ventilation season for the barn to be extended to the fall and spring so the sidewall curtains will not need to operate when there are cold outside temperatures. Although there will be increased use of electrical energy for the additional fans, there will be less L.P. Gas usage due to the over ventilation of barn that almost always occurs when curtains are operating during cold outside temperatures.

The sidewall curtains in a CS barn should have over-lap of at least 3 inches to prevent leakage of air. An annual check of the curtain cables is required for CS barns to account for possible cable stretching.

**Retrofit suggestions to provide cooling for either CS or TV barns:**

Nearly all CS and TV finishing barns in the Midwest have sprinklers installed with timers (common to run them 1 or 2 minutes out of ten) and ceiling mounted circulation fans above pens to increase evaporation from the pigs, whenever inside room temperatures reach a threshold. To maximize pig cooling and prevent feed intake reduction and growth, the room temperature when these direct "on the pig" evaporative cooling is initiated should begin at roughly 80 F when pigs are small (50 lbs) and decreased proportionally to approximately 70 F when pigs are > 230 lbs.

Although common in sow gestation and farrowing buildings, consider adding evaporative cooling pads in TV pig finishing barns. The tunnel exhaust fans selected for an evaporative cooling pad TV barn must include the added pressure drop that the cooling pad will add to the ventilation system.

Another room cooling practice that can be used in either CS or TV barns is directly evaporative "misting" of the air as it enters either of these buildings through the sidewall or endwall curtains respectively. Direct misting is being down with high pressure lines and nozzles that create a mist or fog that evaporates in and cools down the incoming ventilation air. This might be best used in the TV barns but could also have application in CS barns, especially on the prevailing summer wind direction side (typically south in the Midwest). The activation time for these misting systems would be similar to those given above for standing in pen sprinklers systems, namely 80 F when pigs are small (50 lbs) and decreased proportionally to approximately 70 F when pigs are > 230 lbs.