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An ASABE Meeting Presentation

Paper Number: 1110589

Reducing the Environmental Footprint of Pig Finishing Barns

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Written for presentation at the
2011 ASABE Annual International Meeting
Sponsored by ASABE
Gault House

Louisville, Kentucky
August 7 – 10, 2011

Abstract. *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. 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. A new pig finishing housing design is proposed in this paper which is referred to as the "Greener Pig Barn" or GPB. This report includes four GPB design variations. All GPB design versions use shallow gutters with mechanical scrapers and an in-ground, covered, concrete manure storage tank so a reduction in air emissions are expected due to the lack of long term manure storage inside/under the barn and to 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 double wide, fully slatted, tunnel ventilated (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. 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 TV facility.*

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

Introduction

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). These reductions may result from obvious sources such as the selection of more efficient equipment such as high quality fans and energy efficient lights, but will also need to come from the design of innovative building and ventilation systems (NPB, 2007) that might include modified sensors and controls, new manure management systems, and smart pig management systems that reduces energy usage while still maintaining indoor air quality and pig performance.

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 for 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.

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 et al (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.

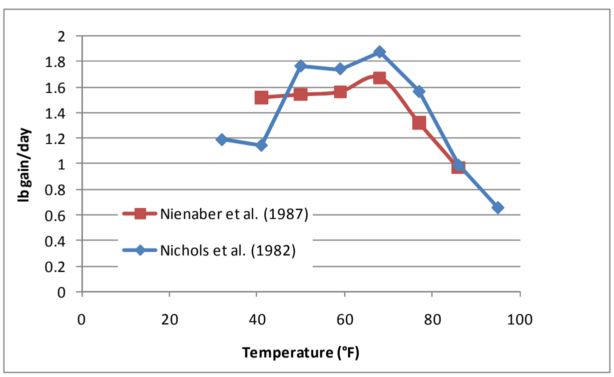
Table 1 provides energy use data from a survey of six farm sites in Minnesota and Iowa. Energy use data was estimated using producer supplied annual performance data and energy expenses. Data reported are in the range of farm survey data reported by OMAFRA (2006) with grow-finish barns averaging 5.45 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

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 (1983), along with subsequent texts and articles on animal environment and production performance (Hahn et al, 1987; Huynh et al, 2004a, 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.



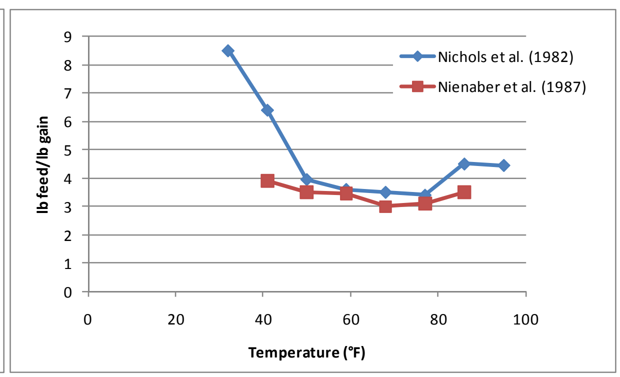


Figure 1. Temperature vs pig performance modified from Hahn et al. 1987. (Daily gain and feed conversion for grow-finish pig.)

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 et al (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 et al (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 and Granier (2001) 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 et al (2004b) 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 et al (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 et al (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.

Material and Methods

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.

An advisory team (members listed below) met three times on this project to debate, brainstorm, and prioritize design factors for the GPB. During the third meeting, 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 addition during the fall of 2009, some 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.

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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 and Discussion

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 (figure 2). 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.

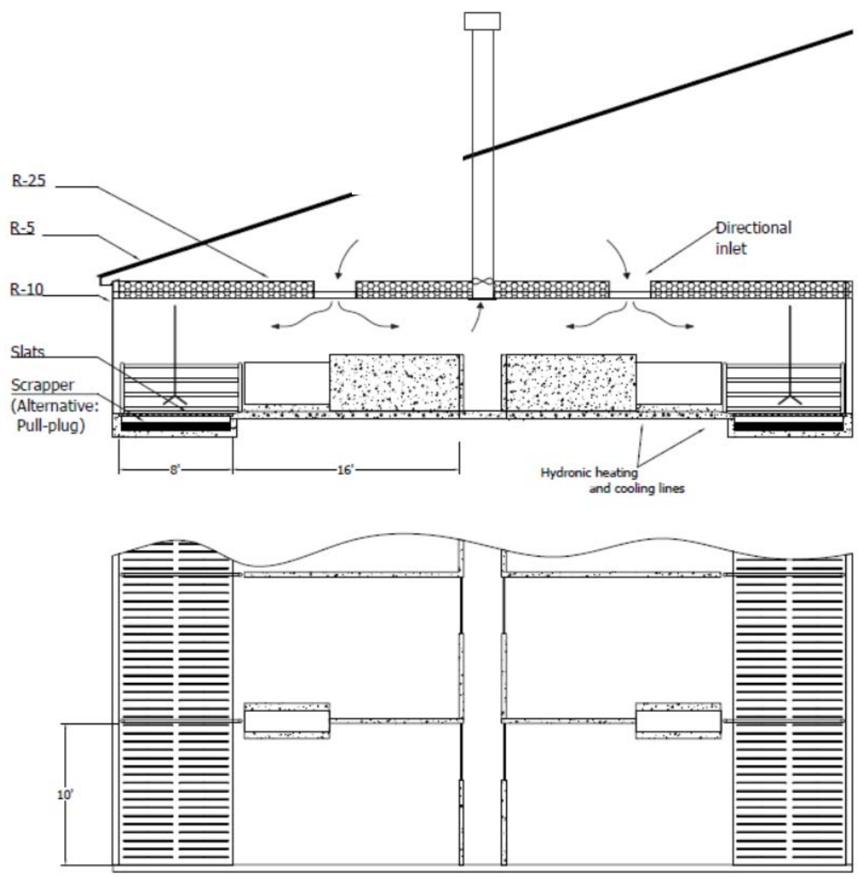

Figure 2. Half section and plan view of GPB A and B, partial slat barns.

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 with pen sizes 10’ x 24’ (16’ solid flooring and 8’ slats)
- Partial slats with scrapers (alternative pull plug)
- Cooling and heating of floor by geothermal system (heating @ 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

Versions C and D are a fully slatted barn with shallow pits or gutters and manure scrapers (figure 3). Cooling in version C 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 but 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.

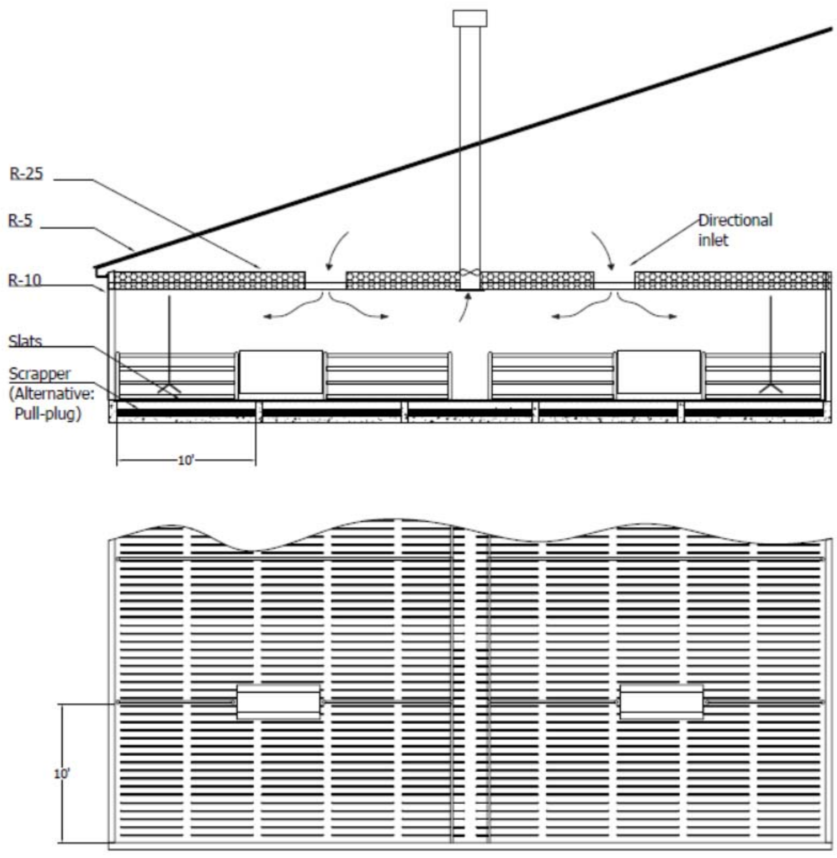

Figure 3. Half section and plan view of GPB C and D, full-slat barns.

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

GPB Features and Assessment

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 (total ventilated or TV barns) or naturally ventilated year around or just during warm conditions, such as curtain sided (CS) barns. 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 (Figure 4) systems (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 1969). This approximate rate of heat removal was confirmed by Spillman and Hinkle (1971) with similar rates reported. This latter study reported no effect 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 1969 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.

Figure 4. Partially slatted pen

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

Figure 8. Slatted area of pen with waterer

BTU/hr/pig. This removal rate would increase significantly with animals lying on the floor as noted above (140 BTU/hr/pig).

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 tube heat exchangers.

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 (Coefficient of Performance) of 3 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.

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, a large 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 plugs are pulled in shallow manure gutters.

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. It should be noted 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 versions A and C 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. However, we have made some relative estimates for energy (divided into electrical and LP) use and the air emission compared to our reference TV barn in Table 2.

Table 2. 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)	-	-	--

The electrical energy use will likely only increase in the version A design from 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 boiler 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 versions B and D, about the same for version C and maybe slightly more for version A. However, when expressed on a production (pounds 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 major 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 more 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 paper. 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 ideal and 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. 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 3, 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.

Table 3. 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	$56	$56	$56	$56
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	9.03	3.12
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-facility cost & interest on average facility investment/ year/facility)

Information and data that influenced the economic estimates

When barn temperatures exceed 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 Version B and modified this value for the other GPB Versions based on best professional judgment considering reduced humidity, lower air velocities and better 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. 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.

Conclusions

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 designs. 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 paper 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.

Moving the swine industry forward to a more sustainable production facility was the focus of this project. Results 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 paper is a critical next step in moving the industry forward in sustainable pig finishing production.

Acknowledgements

This project was supported by the Minnesota and National Pork Board.

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