RESEARCH REPORT

ENVIRONMENT

Title: Determining PM and Odor Emission Reductions of a Geothermal Heating/Cooling System in a Grow-Finish Building **- NPB #12-128**

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Industry Summary:

Throughout the U.S. there is a regulatory push to lower emissions of varies air pollutants from swine production facilities. The primary objective of this project was to determine if reductions in particulate matter (PM) and odor emissions would occur by installing a geothermal heating and cooling system in a grow-finish building. A secondary objective of the study was to estimate if the emissions reductions and any pig performance advantages from implementing a geothermal system could justify the economic investment of this alternative energy source.

The project was conducted over an approximate 12 month period at a full-scale swine grow-finish facility with 16 rooms of 400 pigs/room located in western Minnesota. The building had a deep well, geothermal system installed to provide the heating and cooling for four of the 16 rooms in the building. The pig flow for the facility consisted of groups (400+ head) of pigs of the same sex that weigh 55 to 60 lbs/pig entering a room every week, which alternates between barrows and gilts. During the study period, two rooms of barrows that were in the block of four rooms with the geothermal heated and cooled system were compared to two rooms of nearly similar sized barrows that were in the block of 12 rooms that had a conventional ventilation and heating system. For this study, a 24+ hour average total suspended particles or TSP (consisting of dust particules approximately smaller than 20 microns in diameter) sample was collected simultaneously in one of the geothermal rooms and one in the conventional rooms. Also duplicate odor samples were collected consecutively in 10 liter Tedlar™ sample bags from two of the conventional and two of the geothermal rooms as well as two from the ambient or outside air which served as background sources.

Both odor and PM emissions were lower in the rooms that had the geothermal heating and cooling system compared to the conventional ventilated rooms. This result was probably due to the lower ventilation rates that were present in the geothermal rooms, since the air samples collected in both rooms had quite similar odor and PM concentrations. Improvement in pig performance such as ADG and FE in the geothermal rooms was expected but no difference in performance was found. A possible reason why pigs did not group faster and/or were more feed efficient was that 2014 was an unusually cool year in western Minnesota and thus the cooling

benefit that the geothermal systems provided was not be captured. Also, in an effort to assess the viability of using a geothermal system, estimated annual electric energy use for the conventional and geothermal rooms were made and the geothermal rooms required approximately 20 % more in electrical energy than the conventional rooms. Based on the results that pig performance was not improved and that energy use in the rooms with the geothermal heating/cooling was actually slightly more than the conventional rooms, the return on investment is marginal at best with only slight reductions in odor and PM emissions having some positive benefit.

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, Odor Emissions, Particulate Emissions, Environmental Footprint, Economic Viability

Scientific Abstract:

A study was conducted at a commercial, full-scale swine grow-finish facility located in western Minnesota. The facility consists of 16 rooms that hold 400+ pigs each plus some smaller rooms for utilities, office space, and a half room for temporary and/or overflow pig housing. The pig flow for the facility consist of groups (400+ head) of pigs of the same sex that weigh 55 to 60 lbs/pig entering a room every week, which alternates between barrows and gilts. The dimension of each 400+ head room is 60 ft. x 60 ft. for a nominal pig density of nine ft^2/pig. The barn's layout consisted of two rows of rooms with a center access hallway for loading/ unloading pigs plus exterior hallways that served as air tempering plenums. The ventilation system provided a maximum or summer ventilation rate of approximately 100 cubic feet per minute (cfm)/pig in the conventional rooms and 1/2 of this total or ≈ 50 cfm/pig for the geothermal rooms. Four of the 16 rooms in the building have a ground (deep wells) source or geothermal system that tempers the incoming ventilation inlet air, while the remaining 12 rooms had no tempering of the inlet air. The geothermal system consisted of 3 geothermal heat exchangers, with 32 thermal deep well loops for each exchanger. In total, the geothermal system includes 96 wells that are roughly 250 ft. deep. All 16 rooms in this barn had a "sort" feeding system vs. the more common barn layout with long/narrow pens and fence line feeders. Manure was collected by a fully slatted floor over a deep pit (8 ft. deep) under each room. Each room's deep pit had one pull plug in the bottom of the pit floor that transferred manure to a central sump, which was then pumped to a large outside buried concrete pit with a concrete cover. Results found that both odor and PM emissions were lower in the rooms that had the geothermal heating and cooling system compared to the conventional ventilated rooms. This result is probably due to the lower ventilation rates that were present in the geothermal rooms, since the air samples collected in both rooms had quite similar values of odor and PM concentrations. The odor emissions measured in this study is similar in magnitude to other reported values of 10 to 12 $OU/s/m^2$ (Jacobson, et al., 2007) and 5.0 $OU/s/m^2$ (Heber, et al., 1998). The same was the case for PM emissions measured in this study when compared to another study (PM_{10} emissions of 0.15 to 0.75 g/d/pig, Jacobson, et al., 2007) after adjusted to TSP values. No improvement in pig performance was found in pigs in the geothermal rooms vs. those in the conventional rooms. A possible reason why this was not found was that 2014 was an unusually cool year in western Minnesota. Also, the fossil fuel use on electrical energy use, in the conventional rooms was an estimated $3.10 per pig place while the geothermal rooms spend $3.70 or about 20% more. Thus, based on the results that pig performance was not improved and that energy use in the rooms with the geothermal heating/cooling was actually slightly more than the conventional rooms, the return on investment in the geothermal system is marginal at best. The only positive return seems to be a slight reduction in the emissions of odor and particulate matter.

Introduction:

Odor emissions from swine finishing facilities remain one of the most important concerns to pork producers. The impact of odor on nearby neighbors is a critical issue when siting pig production facilities. Also, particulate matter (PM) or dust emissions from pork production facilities are a growing problem for the pork industry since it also can create nuisance issues for nearby residents. Odor and PM emissions have some synergistic relationship since odorous gases can be absorbed by dust particles and transported from a pig building to nearby private and public facilities.

Meanwhile the U.S. pork industry, along with other animal species is being strongly encouraged to reduce their environmental impact by major retailers who are under pressure from a number of consumer groups. Thus, the U.S. pork industry needs to be the leader in investigating new pig housing systems that will address challenges that are imposed on production facilities including generation of hazardous gases, odor, PM, and GHG emissions plus conserve resources such as energy and water in the production of pork.

This research addressed the important practical questions as to the feasibility of utilizing an increasingly available alternative energy source (geothermal) to reduce odor and PM emissions for the most common of the U.S. pork production buildings, the grow-finishing facility. Also this study, along with the closely related and parallel MPB funded project, economically evaluated the use of geothermal energy in the grow-finish production phase of pork production.

Objectives

This project determined if any reductions in particulate matter (PM) and odor emissions occur with a geothermal heating and cooling system installed on a grow-finish building in western Minnesota. The research also provided an overall economic analysis of the geothermal systems. Specifically the objectives for the proposed research include:

- Measure the difference in PM and odor emissions in two 400 head swine grow-finish rooms with a geothermal air tempering system compared to two 400 head conventionally ventilated rooms in the same building.
- Measure the return on investment of a geothermal air tempering system in a grow-finish pig building in Minnesota and the Midwest considering the potential improvement in pig performance, reduced emissions and energy use.

Materials and Methods

This project was conducted at a commercial grow-finish facility in western Minnesota (figure 1). This facility started receiving pigs from an adjacent sow-nursery facility in the summer of 2012, but the geothermal cooling/heating system was not completed in four of the rooms until June of 2013. The facility consists of 16 rooms that hold 400+ pigs each plus some smaller rooms for utilities, office space, and a half room for temporary and/or overflow pig housing. The pig flow for the facility consist of groups (400+ head) of pigs of the same sex that weigh 55 to 60 lbs/pig entering a room every week, which alternates between barrows and gilts. The dimension of each 400+ head room is 60 ft. x 60 ft. for a nominal pig density of 9 ft^2/pig. The barn's layout consisted of two rows of rooms with a center access hallway for loading/ unloading pigs plus exterior hallways that served as air tempering plenums (figure 2).

Four of the 16 rooms in the building have a ground (deep wells) source or geothermal system that tempers the incoming ventilation inlet air, while the remaining 12 rooms had no tempering of the inlet air. The geothermal system consisted of 3 geothermal heat exchangers (figure 3), with 32 thermal deep well loops for each exchanger. In total, the geothermal system includes 96 wells that are roughly 250 ft. deep. All 16 rooms in this barn had a "sort" feeding system (see figure 4) vs. a more common barn layout with long/narrow pens and fence line feeders. Manure was collected by a fully slatted floor over a deep pit (8 ft. deep) under each room. Each room's deep pit had one pull plug in the bottom of the pit floor that transferred manure to a central sump, which was then pumped to a large outside buried concrete pit with a concrete cover.

Figure 1. Outside view of 6400 head (16 rooms @ 400 pigs/room) grow-finish facilities where measurements were made comparing geothermal tempered & conventional rooms.

Figure 2. Exterior wall hallway that supplies inlet air to the 12 conventional rooms in the grow-finish barn.

Figure 3. One of three geothermal heat exchangers or radiators that transfers energy from the geothermal system to the incoming air of 4 of the 16 rooms in the grow-finish barn.

Figure 4. One of the grow-finish rooms of 400 pigs with a "sort" feeding system

Data was collected at this facility during seven, 24-hour periods between July, 2013 and June, 2014 (July, 2013; August, 2013; November, 2013; January, 2014; April, 2014; May, 2014; and June, 2014). An estimate of the thermal impact on room temperatures in both the geothermal and conventional rooms can be seen in figure 5. This chart shows the range of ambient (outside), tempering hallway or "geo inlet", and temperatures inside the conventional and geothermal rooms that were measured during these seven monitoring visits to the farm.

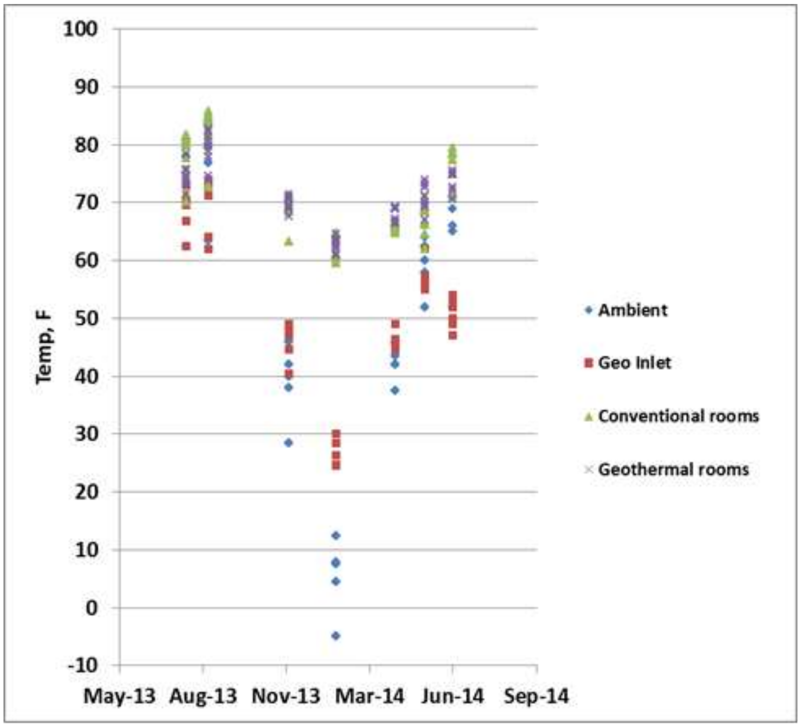

Figure 5. Ambient, hallway, and room temperature ranges during the 7 visits to the farm over an 11-month period (July, 2013 to June, 2014).

An example of the thermal impact on room temperatures for the Aug, 2013, 24 hour data collection (warmest day that was monitored) shows that the maximum outside or ambient temperature recorded that day was 84°F while the maximum room temperatures measured inside were 86°F and 83°F for the conventional and geothermal rooms respectively.

Odor and PM measurement were made on the following four dates: August, 2013, November, 2013, May, 2014, and June, 2014 sampling dates. Two duplicative air samples were collected in 10 liter Tedlar bags, along with temperature and humidity measurements, inside two grow-finish (barrows) rooms (1 geothermal rooms and 1 conventional rooms) plus in both of the outer hallways that supplied inlet air to the rooms twice during the 24 hour period of data collection. The air samples in these bags were returned to the campus and analyzed for odor within 24 hours by the University of Minnesota olfactometry laboratory. Also, during this 24 hours period, a MiniVol Portable Air Sampler (Airmetrics, Eugene OR) was deployed in a geothermal and in a conventional room which measured TSP at the start of the data collection and stopped at the end of the period (approximately a 24 hour). The collection filter was weighed before and after sampling in the air quality laboratory on the St. Paul campus.

Airflow data from each room was recorded from each of the room's ventilation controllers used at the farm. Anemometers in the exhaust air ducts calculated and displayed the ventilation rates for each room. Thus with the concentration data for the air parameters (gases) measured and airflow rates, emission or flux rates were calculated for the days that data was collected.

Pig performance data was obtained from initial pig weights before entering the rooms and final weights from the farm's weigh scales used in the sort feeding system to show how animals performed for four paired (geothermal vs. conventional) groups of barrows between January and June of 2014. Also, an estimate of the costs to operate the geothermal system was done and an attempt to quantify the economic impact of the integrated geothermal system compared to the conventional rooms in this building.

Results

As background for this study, the airflow or ventilation rates for the geothermal and conventional grow-finish rooms are shown in figure 6, which is taken directly from the final report in the parallel MPB funded project. The private company that designed the ventilation system provided a maximum or summer ventilation rate of approximately 100 cubic feet per minute (cfm)/pig in the conventional rooms and 1/2 of this total or ≈ 50 cfm/pig for the geothermal rooms. The rationale for this design decision is not completely known but the assumption was that significantly less air would need to be exchanged in the 4 rooms where the inlet air was tempered (cooled) by the geothermal system. As seen in figure 6 and expected from the ventilation system design, the air exchange measured in the geothermal rooms during the four warm months of sampling dates were roughly 1/2 of that found in the conventional rooms. During the three cool/cold days of sampling slightly more air exchange occurred in the geothermal rooms compared to conventional rooms since the warmer inlet air provided by the geothermal system allowed for greater room air exchange to maintain a similar room temperature. However, it appears that only providing 1/2 of the air exchange in the geothermal rooms compared to the conventional rooms was inadequate or borderline, as seen in figure 7 during the warm sampling days, since sufficient amounts of moisture were not being removed in the geothermal rooms during the warm weather collection dates since consistently higher relative humidity levels were recorded in the geothermal rooms during 3 of the 4 warm weather days.

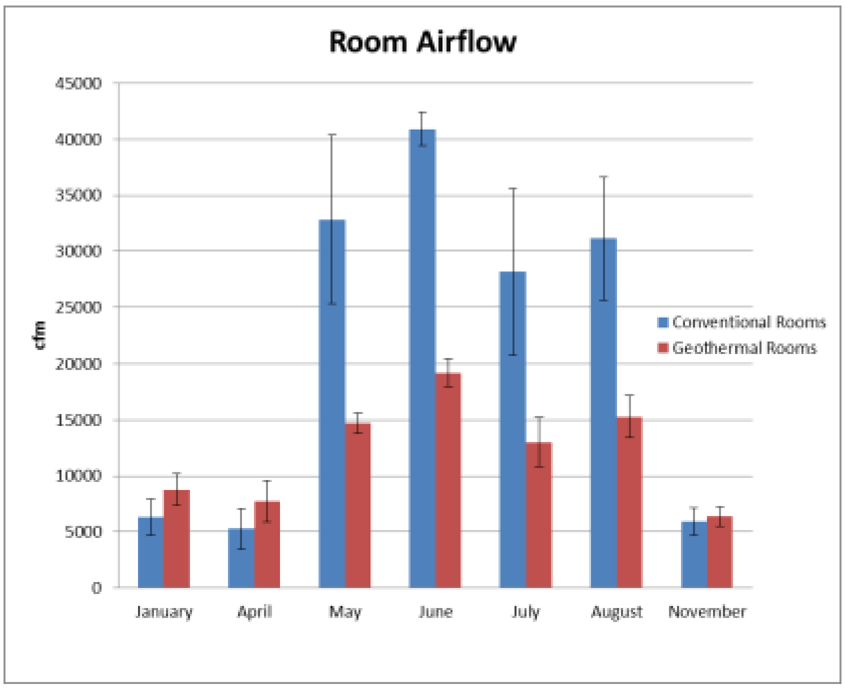

Figure 6. Ventilation rates for the Conventional and Geothermal grow-finish rooms during the seven, 24-hour monitoring periods.

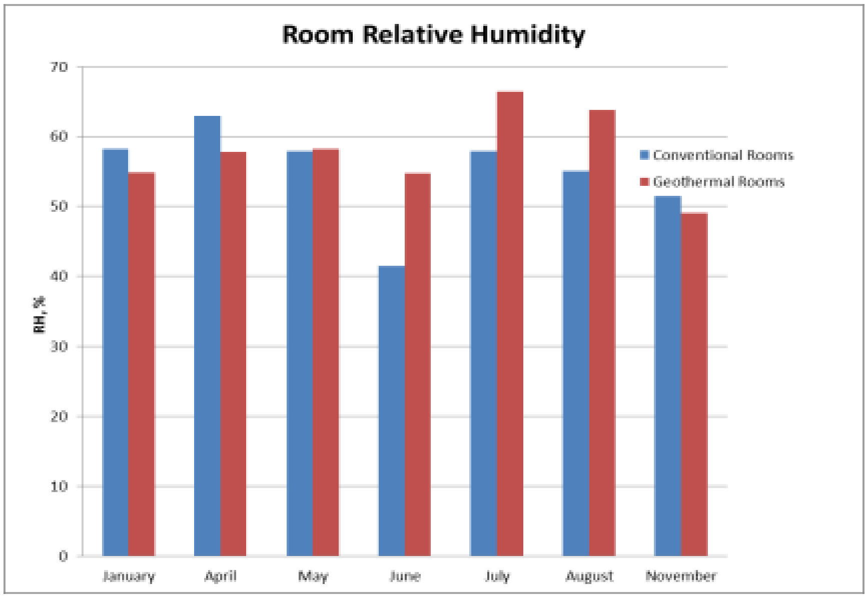

Figure 7. Relative Humidity for the Conventional and Geothermal grow-finish rooms during the seven, 24-hour monitoring periods.

Odor samples were collected during the "warm" collection dates at the farm, which included August, 2013, November, 2013, May, 2014, and June, 2014 sampling dates. The odor emissions during these days from the grow-finish rooms are shown graphically in figure 8. As can be seen the odor emissions are consistently lower in the geothermal rooms probably due to the lower ventilation rates in those rooms. During these four warm weather dates (total of six comparisons since both AM and PM samples were collected in August and May), odor concentrations were only slightly higher in the geothermal rooms but when multiplied by the ventilation rates, the conventional rooms all emitted larger amounts of odor compared to the geothermal rooms.

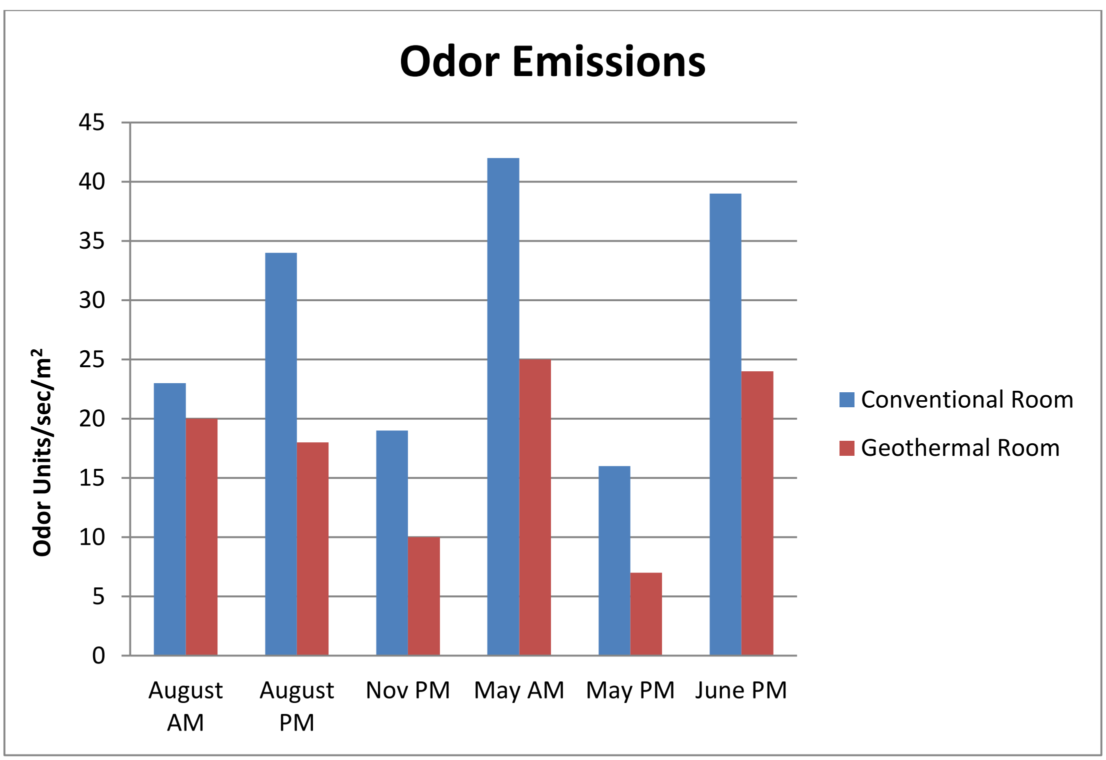

Figure 8. Comparison of Odor Emissions for geothermal vs. conventional grow-finish rooms.

The PM emissions for these same four warm weather sampling dates are given in figure 9. The particulate matter measured was total suspended particles or TSP since concentration of dust was relatively low in these rooms. Unlike odor emissions, there was not as a consistent trend in PM emissions during the study. During the two summer sampling, which typically is when PM emissions are the greatest, we did see a 20 to 30% reduction in PM emission in the geothermal rooms compared to the conventional rooms. However, during the late fall sampling (November) we saw no difference in PM emissions between the rooms while in the spring (May) we saw a significant spike (nearly double) in PM emissions from the geothermal room compared to the conventional room.

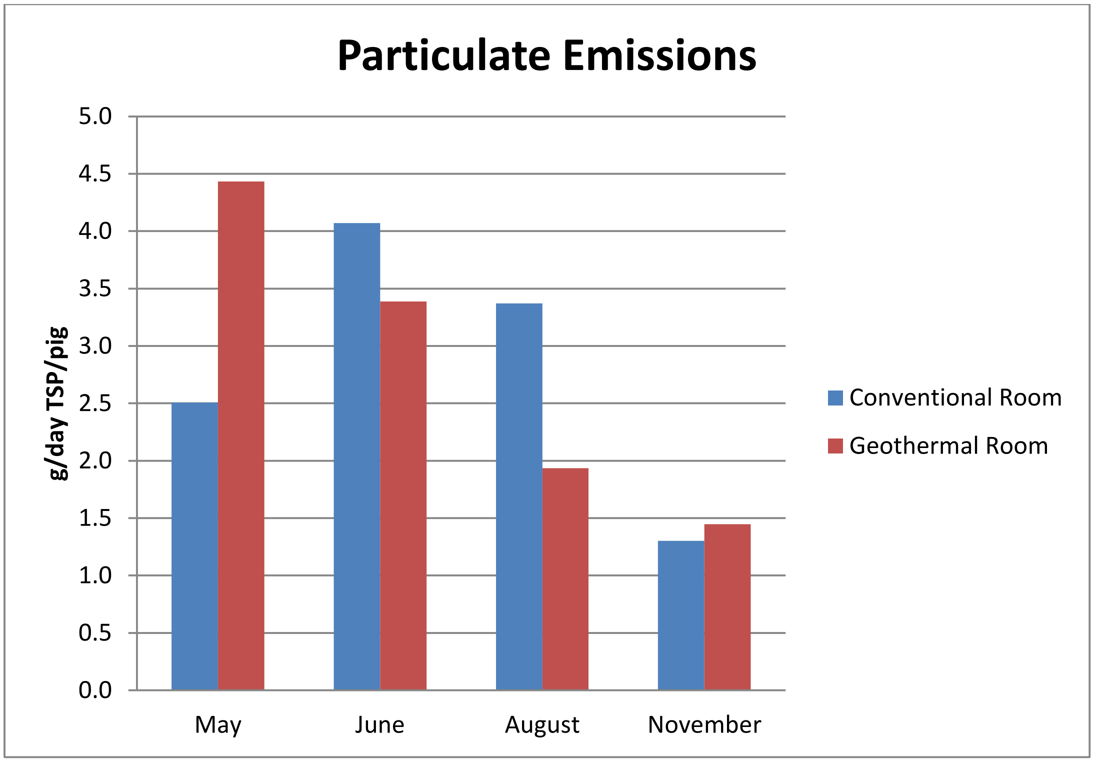

Figure 9. Comparison of PM (Total Suspendable Particles -TSP) Emission for geothermal vs. conventional grow-finish rooms.

To address the return on investment objective, some of the results from the parallel study (MPB funded project) is given. Pig performance (Average Daily Gain, ADG and Feed Efficiency, FE) for four paired groups of barrows during this study are included below (figures 10 and 11). Mortality averaged 3.4% ± 0.5 and 2.7% ±1.1 for the geothermal and conventional rooms respectively. The paired rooms of barrows differed slightly in age (from 2 to 3 weeks) since the pig flow was one room being filled each week with 400+ pigs of a single sex. Only grow-finish rooms housing barrows were selected since they did NOT have pigs removed before the end of the grow-finish period as rooms containing gilts did at this farm since this was a multiplier herd for a genetics company. No consistent differences in either ADG or FE were seen between these four paired sets of barrows raised in the geothermal vs. the conventional rooms over a roughly six month period spanning January to June of 2014. Also, pig (barrow) performance values compared well to the NPB's 6 year mean benchmarking data of 1.75 lb/day and 2.75 lb feed/lb gain for conventional finishers (includes barrows and gilts), especially since barrows typically have a higher ADG and lower FE compared to gilts.

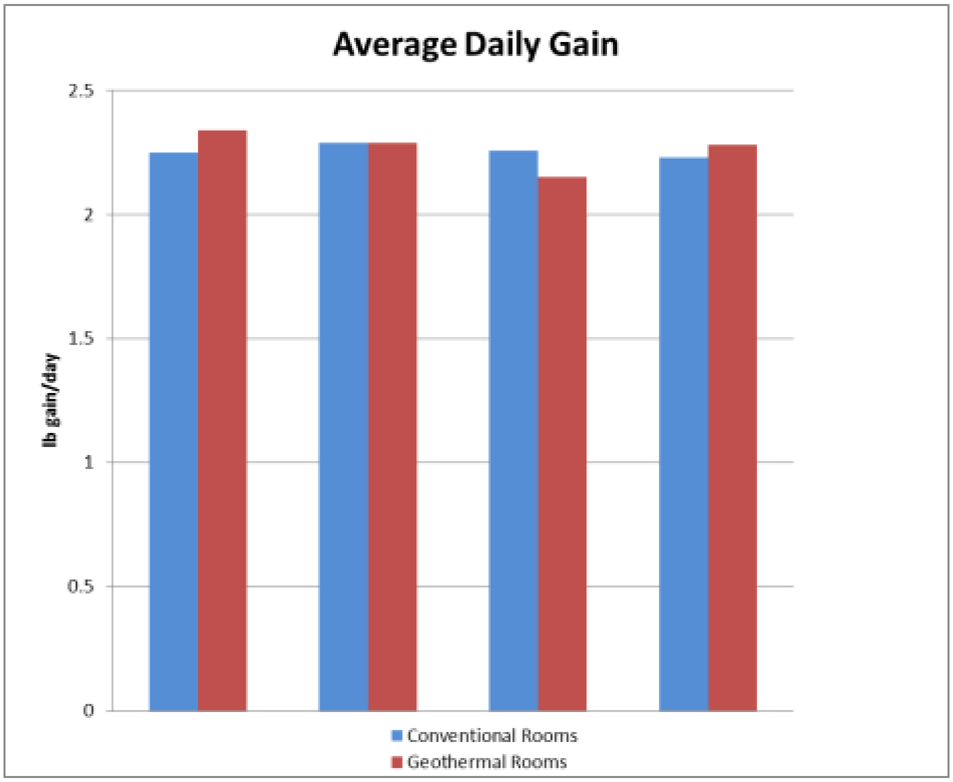

Figure 10. ADG for 4 paired groups of barrows from January to June, 2014

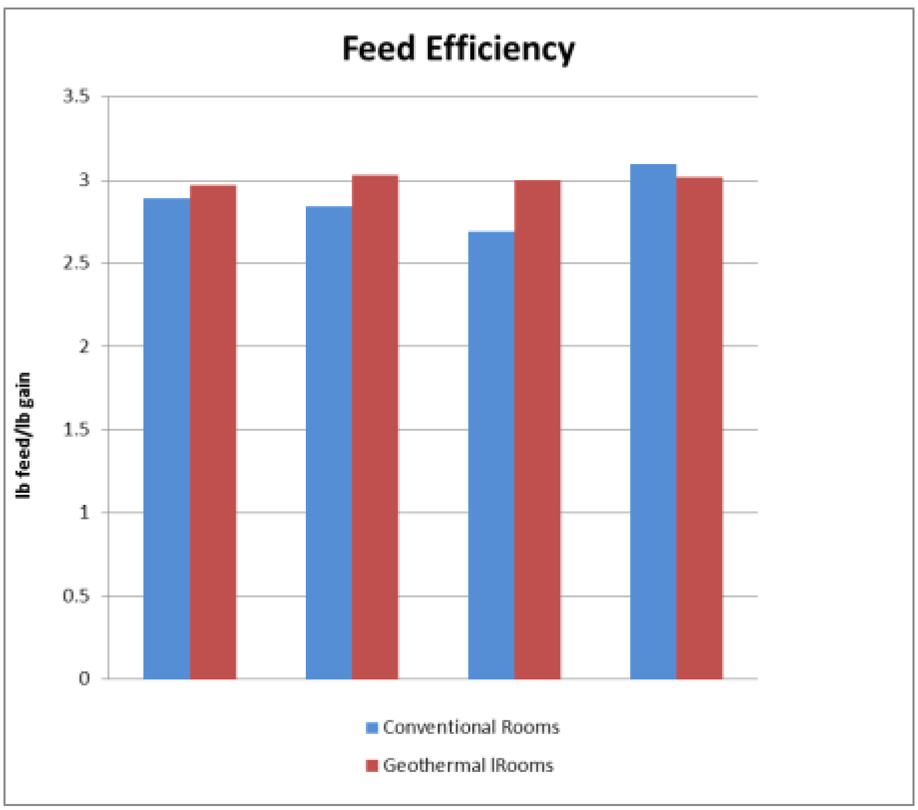

Figure 11. FE for 4 paired groups of barrows from January to June, 2014.

An estimate of the electrical energy used for operating ventilation fans and the geothermal cooling system in the geothermal and conventional grow-finish rooms is listed below:

- An estimate of the total annual electrical energy use for operating the ventilation fans is 31 and 21 (kWh/pig place/year) for the conventional and geothermal grow-finish rooms respectively. This assumes an energy efficiencyof 17 cfm/watt for the exhaust fans in both rooms and run times of 60% and 80% of the maximum ventilation capacity for the conventional and geothermal rooms respectively over a calendar year.
- The geothermal system also has electric powered water pumps that circulated the water through each geothermal heat exchanger and the 250 ft. deep wells. Assuming 1/4 of the pumping energy for the 3 geothermal heat exchangers to supply cooling /heating to the four geothermal rooms and a combine power requirement of 3 kW for the three water circulation pumps, the total annual energy used to circulate this water for each of the four geothermal rooms, would be 16 kwh/pig place/year.
- Thus the estimated annual electric energy use for the conventional rooms is 31 kWh/pig place, while it is 21 + 16 = 37 kWh/pig place for the geothermal rooms. Thus, geothermal rooms are requiring about 20 % more in electrical energy for the environmental (ventilation) control system.

Based on the results that pig performance was not improved and that energy use in the rooms with the geothermal heating/cooling was actually slightly more than the conventional rooms, the return on investment is marginal at best. The only positive return seems to be a slight reduction in the emissions of odor and particulate matter.

Discussion

As seen from the results, odor emissions are consistently lower in the rooms that had the geothermal heating and cooling system compared to the conventional ventilated rooms. This result is primarily due to the lower ventilation rates that were present in the geothermal rooms, since the air samples collected in both rooms had quite similar odor concentrations. Odor emissions are calculated by multiplying the odor concentration by the airflow rate from each room, thus a lower emission level will result in the rooms with lower ventilation or airflow rates. The odor emissions measured in this study is similar in magnitude to other reported values of 10 to 12 $OU/s/m^2$ (Jacobson, et al., 2007) and 5.0 $OU/s/m^2$ (Heber, et al., 1998). Although, there may have been up to a 40% reduction in the odor emitted during one (May, 2014) of the sampling dates, because of the nature of odor sensory, this may not be perceived as a significant reduction in odor impact by individual living near the facility. Often a reduction of 50% or greater in odor emission is needed before the impact can be detected by individuals.

The PM emissions were generally lower in the geothermal rooms compared to the conventionally ventilated rooms and this can be explained for the same reasons used for the odor emissions response, namely the lower ventilation or air exchange rates in the geothermal rooms. There was one exception which occurred in the May, 2014 sampling where the geothermal room had a larger PM emission rate than the conventional room. After reviewing the raw data, there is no obvious reason that explains this result other than a random event or some type of pig activity in the geothermal room during sampling that did not occur in the conventional room. The particulate matter measured was total suspended particles (TSP) which include all particulates 20 microns in diameter and less. The PM emissions found in this study are in the same range as found in recent studies (PM_{10} emissions of 0.15 to 0.75 g/d/pig, Jacobson, et al., 2007) when adjusted to TSP values.

Improvement in pig performance in the geothermal rooms was expected and a possible reason why this was not found was that 2014 was an unusually cool year in western Minnesota. The University of Minnesota maintains a weather station at the West Central Research and Outreach Center (WCROC) located at Morris, MN which is located about 40 miles east of the farm site. This station recorded no (zero), 90°F or greater days during 2014 compared to a high of 18 days where the maximum temperature was 90°F or greater in 2007. The number of 90°F or higher days during the past 8 years for Morris is given in figure 12.

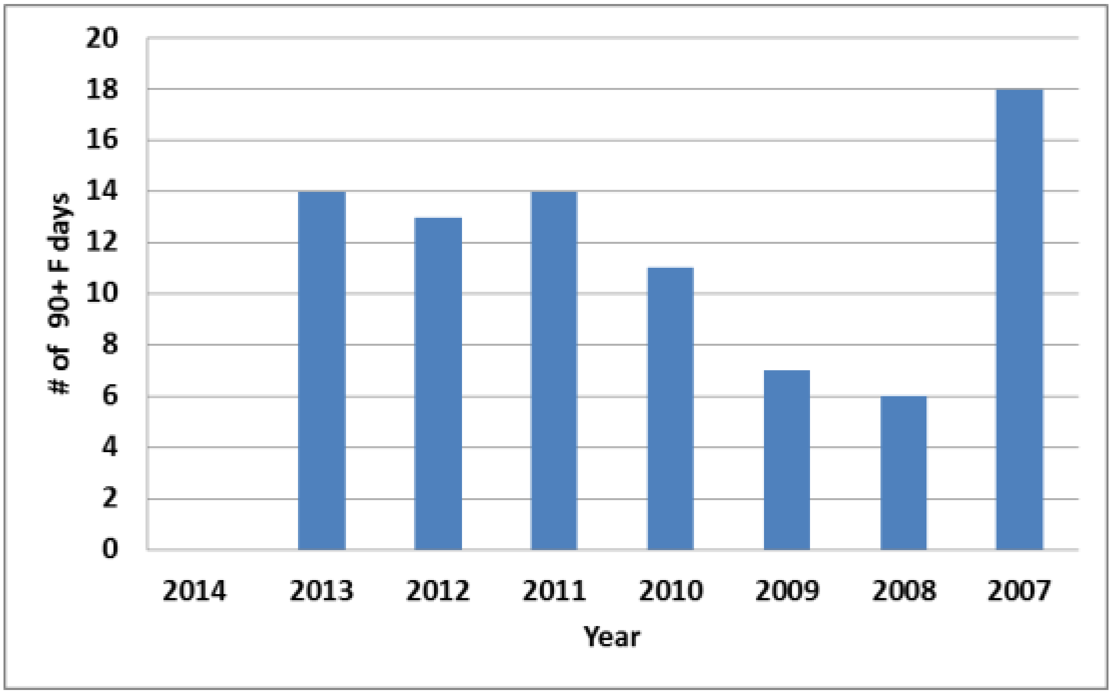

Figure 12. Number of 90°F or greater maximum temperature at U of MN's WCROC's weather station near Morris, MN located about 40 miles east of farm site

Table 1 was generated to compare the cost of fossil fuel energy use for the geothermal vs. conventional grow-finish rooms in this building assuming an electricity cost of $0.10/ kWh. Each grow-finish room in this building did have a direct fired propane heater but the run times and thus propane use for these heaters was not recorded. Theoretically, these heaters would operate less for the four geothermal rooms since some supplemental heat is being supplied during cool/cold ambient conditions by the geothermal system. The total run times for these heaters, even for the conventional rooms, were very low, since pigs entering these room averaging 55 to 60 lbs. Thus basing the fossil fuel use on electrical energy only, we see that the conventional rooms expend an estimated $3.10 per pig place while the geothermal rooms spend $3.70 or about 20% more. The energy used to pump the water through the deep well geothermal systems exceeds the energy savings advantage that the geothermal rooms have over the conventional rooms in ventilation fan energy use.

Table 1. Comparison of ventilation and supplemental heating ?? energy usage between conventional and geothermal grow-finish rooms.

Type of grow-finish Room	Equipment	**$/pig place/yr** of electrical energy use ($0.10/kwh)	**$/pig place/yr** of Propane use ($2/gal)	**$/pig place/yr**
Conventional	Ventilation fans	$3.10		**$3.10**
	Direct fired heaters		???	
Geothermal	Ventilation fans	$2.10		**$3.70**
	Water circulation pumps	$1.60		
	Direct fired heaters		???	

In summary, even though the geothermal heating/cooling system evaluated in this study technically reduces odor and particulate matter (PM) or dust emissions from a grow-finish facility, it is felt that this reduction is modest at best and does not justify the large capital investment (estimated at $250,000 for the 4-400 head rooms or 1600 pigs) and the 20% higher energy cost it takes to operate the geothermal system as configured. These results should not be used to stop investigating the use of alternative energy systems like geothermal to reduce PM, GHG and other gas emissions and reduce heat stress in confined pigs. More positive or beneficial results from this facility could probably be accomplished if slight modifications in some design features and operation of pumps and other equipment plus if the study was done during a year that saw warmer daytime and nighttime temperatures that better represents the historical weather data from this area of the state.

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