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Comparative Evaluation of Radiant and Forced Convection Heaters in Grow-Finish Swine Rooms

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ABSTRACT In cold climate production locations, space heating represents a significant proportion of total energy use in a hog production barn. The use of gas-fired infrared heating system presents a possible alternative for space heating in barns. In this work, an infrared radiant heater was compared with a conventional forced-convection heater by installing them separately in two identical 100-head grow-finish rooms and operating the heaters to maintain similar thermal environments in the two rooms. The energy consumption (natural gas and electricity), animal performance (ADG and ADFI), and air quality were monitored in both rooms. Results from three completed trials showed that the room with infrared radiant heating system consumed more natural gas but less electrical energy compared to the room with forced-air convection heater. Mean air temperature was slightly higher in the room with forced-convection heater than in the room with radiant heater, but air temperature distribution at various locations within each room was similar. Generally, the relative humidity, ventilation rate, gas concentrations (NH_3, H_2S, CO and CO_2), and pig performance were relatively similar between the rooms, indicating no significant impact of the type of heater on these parameters.

Keywords: swine barns, heater, radiant, infrared, forced convection, energy use

Introduction

Swine production entails energy-intensive processes such as space and creep heating, ventilation and lighting, feed and manure handling, power washing, among other things. Due to increasing energy prices, energy cost ranks third among the variable cost component of the total hog production cost. Thus, developing an energy efficient barn through implementation of different energy-saving strategies and improvement of management practices has been increasingly gaining interest among swine producers recently.

As reported by Barber et al. (1989), heating and ventilation are the major contributors to energy use in different types of swine barns. Many hog barns employ natural gas-fired convection heaters for space heating in production rooms. Gas-fired heaters have an efficiency of 80% while those that use coal or wood have a heating efficiency of 70% (MacDonald, 2002). However, due to the rapid increase in energy prices in recent years, the cost of natural gas has increased almost four-fold from \$0.11/m^3 in 1998 to \$0.42/m^3 in 2006 and electricity costs have gone from \$0.08/kWh to \$0.11/kWh (Huffman and MacDonald, 2006). Consequently, there is a need for a highly-efficient heating system that can result in a reduction of overall consumption of energy in swine barns.

In this research work, a gas-fired infrared radiant heating system was investigated as a possible option that can be adapted for space heating in barns. Unlike the forced-air convection heater that operates by heating the air mass near the ceiling which in turn needs to be physically moved to the animal occupied zones, the radiant heater transmits heat to surfaces (i.e., floor, pen wall, animals, etc.) through radiation heat transfer and thus, speeds up the heating process at the pig's level. MacDonald et al. (2003) reported that a gas-fired radiant heater used 23% lesser natural gas relative to the forced-air heater.

The overall goal of this study was to carry out a comparative evaluation of the two heating systems in terms of energy efficiency, and effect on hog performance and environmental conditions in the barn. Specifically, this work was aimed to determine the impact of the convection heater and radiant heater on a) energy efficiency, b) animal behavior, average daily gain, feed conversion and mortality rate, and c) indoor air quality (temperature, relative humidity, and gas concentration).

MATERIALS AND METHODS

The overall approach of this study was to compare the forced-air and infrared radiant heating systems installed separately in two identical grow-finish rooms over three trials spanning year-round ambient environmental conditions. During the course of the trials, a number of parameters pertaining to animal performance, thermal conditions, and air quality in the two rooms were monitored.

Description of Experimental Rooms Two grower-finish rooms at the Prairie Swine Centre Inc. (PSCI) barn facility in Saskatoon, SK were used in this study. The rooms were identical in terms of construction, pen configuration, animal capacity, care and management. The room has inside dimensions of 20.1 m (L) x 7.3 m x 3 m and has 20 pens that could accommodate 5 pigs each; each pen has fully slatted concrete flooring within the pen area. A 15.2-metre long gas-fired infrared radiant heater was installed in the Treatment room while the Control room had a gas-fired forced air heater installed. Both heaters have 23 kW capacities.

Each room was operated on a negative pressure ventilation system. Fresh air entered the room through 10 modular inlets distributed along the ceiling of each room and exhausted through three sidewall fans. Underneath the pen area was the 0.6-metre deep manure pit. The pit had a total of 4 channels running lengthwise of the room and periodically drained by gravity by pulling the drain plugs at each end of the pit. Both rooms were operated with identical set points for the heating and ventilation system, and managed according to typical production practices.

Animal and Room Preparation Prior to the start of the experiment, both rooms were cleaned and disinfected thoroughly. The feeders and manure pits were emptied and washed. Sensors and monitoring instruments were calibrated to ensure that each system was in working order before the start of the test.

Weaned pigs weighing around 20 kg to 35 kg were used in the experiment. The animals were weighed, sorted by gender and distributed equally to the two rooms such that the average starting weights between the rooms were within ± 2 kg of each other and there was equal number of male and female pens in each room. Standard grow-finish diets were provided to the pigs and were weighed before putting into the feeders.

Experimental Procedure Three trials were undertaken in this study to determine the performance of the heaters covering seasonal variation in ambient conditions throughout the year. Thermocouples, relative humidity (RH) sensors, and fan-speed sensors were deployed in each room to monitor thermal parameters while electrochemical gas sensors were used for monitoring gas levels (ammonia, hydrogen sulphide, carbon dioxide, and carbon monoxide) in the room. Monitoring devices were attached to lights, recirculation fan, exhaust fans, and heaters to log voltage and current readings. The natural gas consumption of each heater was recorded using a diaphragm-type gas meter installed on the supply line to each heater. A pulser module installed on the gas meter allowed electronic logging of the readings from each meter; in addition, the meter readings were also recorded manually. Signals from various sensors were logged in a datalogger (CR1000, Campbell Scientific, Logan Utah, USA) every 10 minutes except for current sensors used to monitor the duty (on/off) cycle of heaters which were logged every minute. The locations of the sensors within each room are shown in Figure 1.

The impact of the two heating systems on hog performance was also assessed. The assessment was based on the comparison of the average daily gain, feed conversion, mortality rate and days to market. During the course of the trial, the animals were weighed three times; at the start, middle and end of the test. The average growth rates from the start to the middle of the trial, and from the middle to the end of the trial were used in computing the average daily gain (ADG) of pigs in each room. Average daily feed intake (ADFI) was calculated by dividing the total weight of feed loaded to the feeders throughout the test by the total number of pigs and number of days on feed. Days to market refers to the average number of days from moving the pigs into the grow-finish room until they reach market weight of 115 kg. Daily health checks were also done to monitor the health status of the animals.

Cost analysis was conducted after three trials. All the expenses incurred throughout the study from the cost of the heater to the installation and operational costs were recorded. The cost of employing the infrared radiant heater in a production room was compared to the use of the conventional forced-convection heating system.

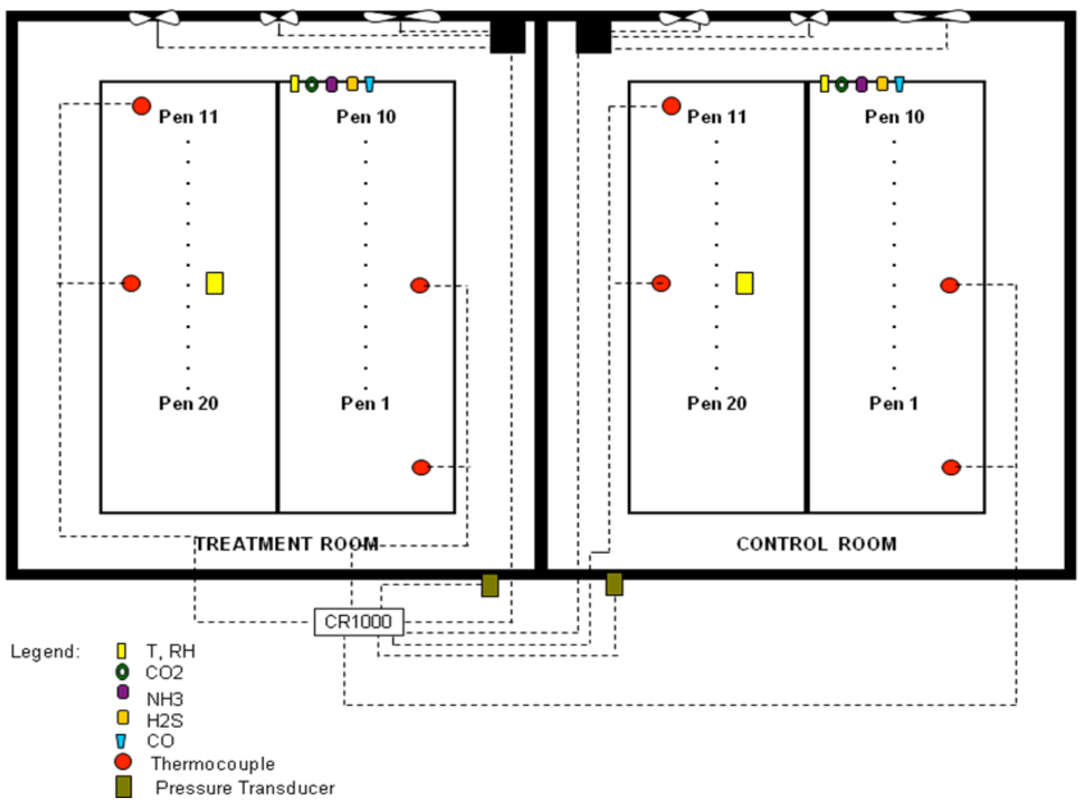


Figure 1. Location of sensors in each room.

RESULTS AND DISCUSSION

Gas and electrical energy consumption Figure 2 shows the weekly average gas consumption in both rooms during the trials. Both heaters were barely in operation after Week 7 since pigs at this growth stage were already large enough to generate their own heat and sustain the required setpoint temperature, thus supplemental heat was no longer needed. For all three trials, the weekly total gas consumption over the course of a trial was higher in the radiant heater room compared to the forced-convection heater room by an average of 12.1 m^3. This difference was evident from the recorded duty cycle of the heaters which showed that on weekly average, the radiant heater ran about 41 minutes more than the forced-air heater (Table 1).

Throughout the 13-week test period, average weekly electrical consumption was relatively similar in both rooms, with the operation of the ventilation fans in response to prevailing ambient conditions mainly influencing the week to week variation in electrical consumption (Figure 3). Total electricity use over the course of a trial was slightly higher in the forced-convection heater room than in the infrared radiant heater room by about 1.9 kWh. This difference could be attributed to the additional electrical energy use by a recirculation fan in the forced-convection heater room, which is an integral part of the heating and ventilation system necessary to distribute heat more uniformly throughout the room.

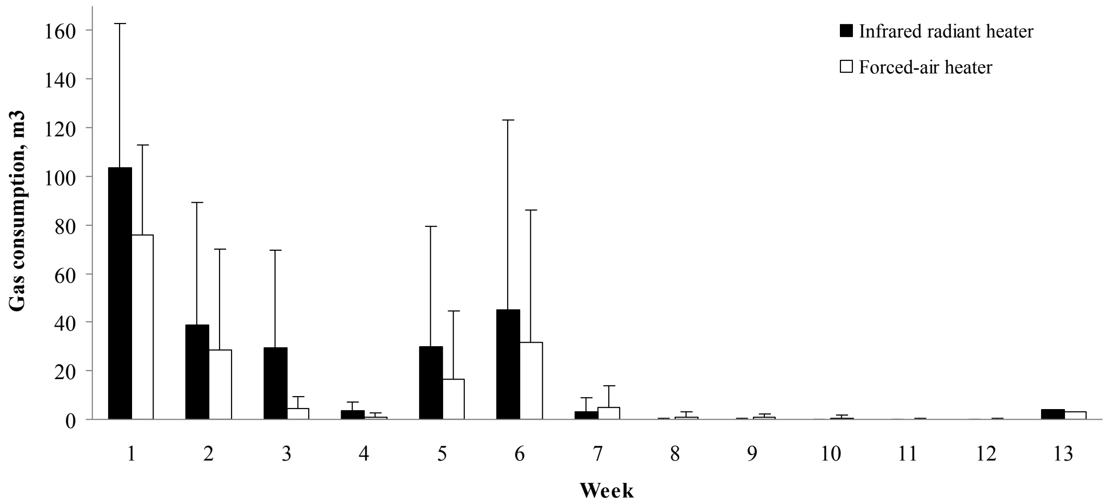


Figure 2. Average weekly gas consumption in the two rooms over 3 trials. Error bars represent standard deviation of weekly gas consumption for the 3 trials.

Table 1. Weekly average duty cycles (min) recorded from both heaters.

Week	Forced-air heater	Radiant heater
1	1950.5	1938.0
2*	4279.0	4004.0
3*	1475.0	1375.0
4*	315.0	469.0
5	1466.5	1895.5
6	2848.5	2944.5
7	447.0	432.5
8	95.0	179.0
9	72.0	117.0
10	49.5	6.0
11	0.0	0.0
12	0.0	0.0
13	0.0	0.0
Weighted mean	866.39	907.52

*Recorded value represents only a single trial due to technical problem with the sensor.

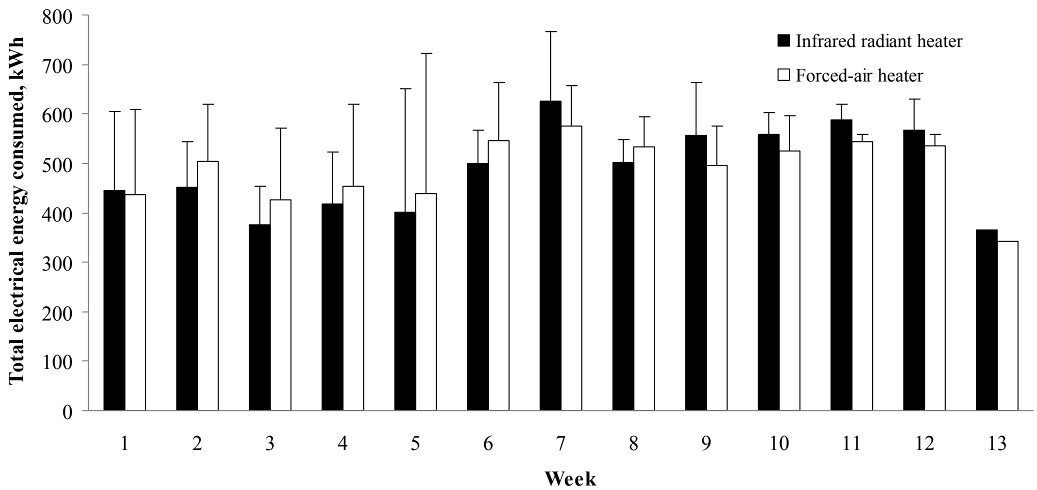
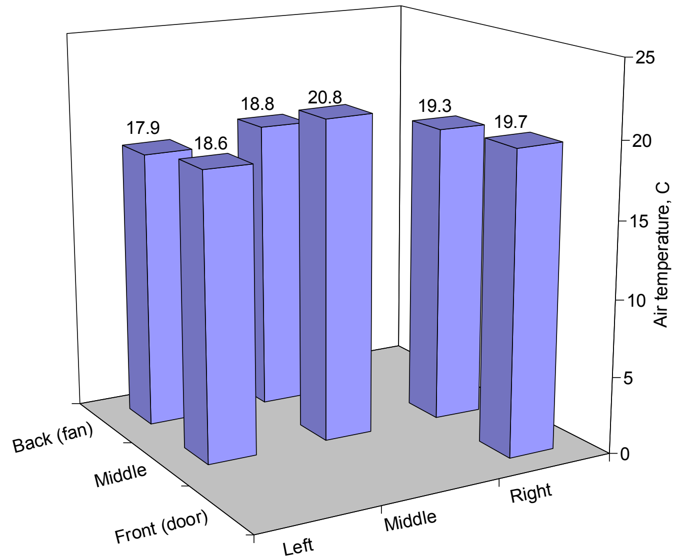


Figure 3. Average weekly electrical energy consumption in both rooms over 3 trials. Error bars represent standard deviation of electrical energy use for 3 trials.

Temperature, relative humidity and ventilation Figure 4 shows the average air temperature readings at different locations within the two rooms. Despite the same setpoints used for both rooms for all trials, the overall mean temperature from all locations in each room was significantly higher (P<0.05) in the forced-convection heater room (19.2 °C) than in the radiant heater room (18.4 °C). Within each room, temperatures near the middle of the room were slightly higher than those at the peripheral locations of the room, particularly near the outside wall with the exhaust fan. Comparison of the deviation from the mean temperature at the various locations in each room showed no significant differences (P>0.05), indicating similar uniformity in temperature distribution in both rooms.

Relative humidity readings were monitored at the middle and near the exhaust fan in both rooms. Generally, the average RH at the middle of the control room (55.5 %) was significantly higher (P<0.05) than in the treatment room (52.3 %). Near the exhaust, the average RH readings were relatively higher (58.9 % to 59.2 %) than at the middle of the room (52.3 % to 55.5 %), but no significant difference (P>0.05) was observed between the two rooms.

The overall mean ventilation rate in the radiant heater room (2,050 L/s) was slightly higher than in the forced-convection heater room (1,870 L/s), but due to wide variation in ventilation rate values throughout the trials, the differences between the two rooms were not significant (P>0.05).



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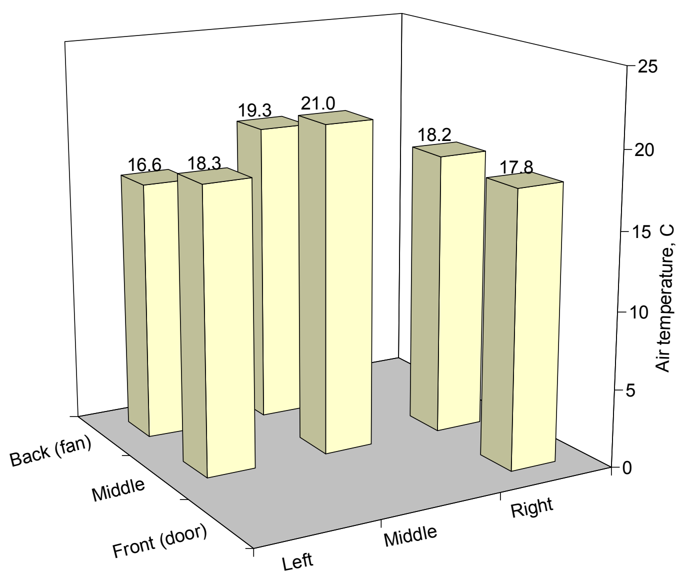

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Figure 4. Average air temperature measured at various locations in the forced-convection heater room (A) and the radiant heater room (B).

Gas concentrations Table 2 shows the mean concentrations of different gases monitored over the course of the trials. Hydrogen sulphide (H_2S) and carbon monoxide (CO) concentrations in both rooms were usually at levels barely detectable by the respective sensors with typical levels below 1 ppm. As expected, concentrations of H_2S were observed to spike to considerably high levels (>90 ppm) during pit pulling events (i.e., emptying of manure pits). Ammonia (NH_3) and carbon dioxide

(CO_2) levels were similar in both rooms with average concentrations below 10 and 2000 ppm, respectively. Among these various gases, only CO_2 levels were found to differ significantly ($P<0.05$) between the two rooms, with higher values in the control room compared to the treatment room. This can be attributed to the operation of the forced-convection heater, which vented combustion gases into the airspace, whereas the radiant heater was vented to the outside of the barn.

Table 2. Weekly average concentrations (in ppm) and standard deviations (SD) of various gases monitored in the two rooms over the 3 trials.

Gas	Forced-air heater		Radiant heater		
	Mean	SD	Mean	SD	p-value
NH_3 (n=34)	6.13	4.78	5.88	3.81	0.82
CO (n=25)	0.25	0.46	0.26	0.47	0.90
H_2S (n=29)	0.46	0.82	0.29	0.68	0.09
CO_2 (n=20)	2012.25	1048.26	1373.78	538.81	0.02

Pig performance As shown in Table 3, the average daily gain (ADG), average daily feed intake (ADFI), mortality rate, and average days to market in both control and treatment rooms were relatively similar over the course of the trials. Mean ADG values from all trials were 0.97 kg/day and 0.98 kg/day while ADFI values were 2.32 kg/pig-day and 2.38 kg/pig-day for the control and treatment rooms, respectively. Average mortality rates from all trials were 2.0 % and 0.63 % while average days to market were 93.5 days and 91.3 days for the control and treatment rooms, respectively.

Table 3. Hog performance in the control and treatment rooms.

Trial	ADG (kg/day)		ADFI (kg/day-pig)		Mortality rate (%)		Average Days to Market	
	Forced-air heater	Radiant heater	Forced-air heater	Radiant heater	Forced-air heater	Radiant heater	Forced-air heater	Radiant heater
1	0.94	0.99	2.07	2.02	4	1.9	100.8	100.7
2	0.93	0.94	2.47	2.59	0	0	98.6	96.3
3	1.03	1.06	2.43	2.52	2	0	81.1	76.9
Mean	0.97	0.99	2.32	2.38	2.00	0.63	93.5	91.3

Cost analysis Table 4 summarizes the expenses incurred after three trials. The total cost of using the radiant and forced-air heating systems are $7,372.84 and $3,179.26, respectively. The difference can be attributed mainly to the higher labour and capital costs of the radiant heater. Also, with natural gas priced at 26.71 cents per cubic meter and electricity at 10.22 cents per kilowatt-hour, the radiant heating system incurred a total operational cost of $2,021.33. This value is 3.3 % higher than the $1,956.65 incurred by the forced-convection heating system.

Table 4. Capital, installation and operational costs of each heater.

Associated cost	Radiant heater	Forced-air heater
Capital cost, $	2,688.90	750.00
Installation cost, $	2,662.61	472.61
material and supplies	122.61	122.61
labour	2,390.00	200.00
gas permit	150.00	150.00
Operational cost, $	2,021.33	1,956.65
electricity ($ 0.1022 per kWh)	1,816.52	1,823.70
gas ($ 0.2671 per m^3)	204.81	132.95
TOTAL COST, $	7,372.84	3,179.26

IMPLICATIONS Trends observed from these trials showed no major differences in the overall energy use (natural gas and electrical energy) between the rooms with infrared radiant heater and forced-convection heater systems. Both heater types had similar uniformity in air temperature distribution within the room. Gas concentrations (ammonia, hydrogen sulfide, carbon monoxide and carbon dioxide) and animal performance were not significantly affected by the type of heater used.

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