ONTARIO PORK

Ontario Pork Research Final Report 18-006 Executive Summary

Reporting Date: September 20, 2021

Project Team

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Acknowledgements

The OMAFRA project team wishes to thank Ontario Pork for the funding provided to execute this research project. In addition, we wish to acknowledge the contributions made to this project by Ontario Pork Producers, Maximus Solutions and Harvest Measurements. The Pork Producers provided the project team open access to install air quality monitoring equipment and share air quality data. Maximus Solutions donated ventilation control system hardware, support and reporting on ventilation system settings and performance. Harvest Measurement provided technical support and data management beyond the original control scope. This project would not have been successful without the support provided by these project partners.

Introduction:

Existing pig barns typically manage environmental conditions through the monitoring of temperature only. There are number of critical environment parameters in pig barns which are currently not monitored which can have a significant impact on the air quality and comfort experienced by the pigs and stockpeople.   A key question for this research project was to determine the effect of improved air quality on both pig performance and cost of production.

Objectives:

The objectives of this project were to investigate the air quality conditions in pig barns and the impact of improved ventilation on pig health and performance.

1. Development of wireless technology to monitor ammonia, carbon dioxide, hydrogen sulfide methane, relative humidity and temperature. Demonstrate the ability of a ventilation fan being controlled autonomously by the barn gas monitoring system.
2. Data collection of barn gas conditions of a farrowing, a nursery and a finishing barn.
3. Incorporation of the barn gas data with ventilation system performance and pig performance to understand the cost of production impact of improved air quality.

Materials and Methods:

Three wireless barn gas monitoring systems were designed and built to allow continuous monitoring of air quality at each pig barn (farrowing, nursery and finishing). Each air quality sensor communicated with a system base station via radio frequency (RF) communication. The base station at each farm uploaded sensor data to the Cloud employing cellular communication where it was graphically displayed on a project website. The air quality sensor sets consisted of temperature, relative humidity, carbon dioxide, ammonia, hydrogen sulfide and methane.   Data was collected every 5 minutes from each air quality sensor.

The farrowing and finishing barns were targeted for long term data collection through the installation of barn gas sensors within the pig housing areas.   Temperature, relative humidity, carbon dioxide, hydrogen sulfide and methane data were captured at 5 minute intervals at both barns. In addition, ammonia concentration data was collected at the finishing barn. Ammonia data was not collected at the farrowing barn due to technical challenges in conjunction with barn access restrictions.

At the nursery barn, a more detailed research study was conducted where air quality was continuously monitored in 2 identical nursery rooms. The "control" nursery room employed traditional ventilation system settings. The "test" room ventilation system was updated with a number of changes intended to improve air quality including:

1. Increased Stage 1 minimum ventilation rates
2. Ceiling inlet re-positioning
3. Installation of actuated ceiling inlets
4. Modified room static pressure (SP settings) to support increased air inlet velocities

Maximus Solutions supported this project by supplying a ventilation and feed dispense management system which allowed the project team to collect critical data such as feed consumption, ventilation fan electricity consumption and gas heater operation time. In addition, pig weights, condition, treatments and mortality were collected manually. All of the data collected at the nursery barn was evaluated over multiple nursery pig production cycles to determine the impact of improved air quality on pig health, productivity and cost of production.

Results and Discussion:

Wireless barn gas monitoring technology was successfully designed and tested. A demonstration was conducted of the barn gas monitoring system wirelessly managing ventilation fan speed. Subsequently three barn gas monitoring systems were built and installed in a farrowing, a nursery and a finishing barn.

Long term data sets of air quality were collected in both a farrowing and finishing barn. In both cases, all data collected did not exceed Ministry of Labour exposure limits. The data collected in the farrowing barn indicated the average carbon dioxide concentration of 3463ppm was high compared to the project target of 2000ppm. In the finishing barn, the average carbon dioxide concentration of 2024ppm and peak ammonia level of 25.65ppm were above target. In both of these barns, ventilation system operational improvements are recommended which will improve air quality. These include

- Ensure barn gas laden air being exhausted from the barn is separated from the fresh air inlets to avoid sort circuiting.
- Adjust minimum ventilation stage fan speed to improve air turn over within pig housing area.
- Employ actuated ceiling inlets to maintain target static pressures within the pig housing area. The control of static pressure manages air velocity at the ceiling inlets. At high ventilation

stages, a lower static pressure is needed to maximize ventilation fan volumetric flow rate performance (0.03” WC is suggested). At lower ventilation stages, the static pressure needs to be increased (0.08” WC is suggested) to increase air inlet velocity and thereby promote mixing and dilution of the barn gases.

At the nursery barn, air quality, ventilation system operation, electricity/gas consumption, feed consumption and pig performance were monitored over 5 production periods. This data was subsequently employed to calculate the impact of the improved air quality on farm revenue in terms of cost of production and lost revenue opportunity. Evaluation of the data collected indicated that improved air quality did have a positive impact on cost of production and mortality rates. The fiscal benefits of improved average daily gain and reduced mortality compensated for the incremental increase in electricity costs through out the production cycles. The improved static pressure control possible through actuated ceiling inlet control was found to reduce gas consumption and provide more consistent conditions in the test room compared to the control room.

Conclusions:

Farrowing, nursery and finishing barns do require a designed ventilation system to manage air quality within the pig housing areas. Ventilation system performance is optimized through the use of a sophisticated ventilation system controller that must include automated static pressure management.

Within the farrowing and finishing barns, carbon dioxide and ammonia levels indicated that there is some room for improvement possible through the optimization of the existing ventilation system settings.

The data collection conducted in the nursery barn does indicate that improved air quality does have a positive impact on pig health and performance and thereby on cost of production as well as revenue generation. The associated reduction in cost of production justifies the increase in electricity and gas expense. A key outcome of this project is the demonstrated importance of active modulated static pressure control to manage static pressure levels within the pig housing areas. Active static pressure control is critical to manage air inlet velocities, especially in the cold winter months. Higher fresh air inlet velocities are required to promote mixing to improve air quality at pig level and also reduce heater gas consumption by driving the hot air at ceiling back into the pen. This effect was demonstrated in the final 2 production cycles in the nursery room. The gas consumption in the test room which employing actuated ceiling inlets was lower than that in the control room which employed counterbalanced ceiling inlets.

ONTARIO PORK

Ontario Pork Research Final Report 18-005

Date: September 20 2021

Introduction:

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The objectives of this project were to investigate the air quality conditions in pig barns and the impact of improved ventilation on pig health and performance.

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The farrowing and finishing barns were targeted for long term data collection through the installation of barn gas sensors within the pig housings areas. Temperature, relative humidity, carbon dioxide, hydrogen sulfide and methane data were captured at 5 minute intervals at both barns. In addition, ammonia concentration data was collected at the finishing barn. Ammonia data was not collected at the farrowing barn due to technical challenges in conjunction with barn access restrictions.

At the nursery barn, a more detailed research study was conducted where air quality was continuously monitored in 2 identical nursery rooms. The “control” nursery room employed traditional ventilation system settings. The “test” room ventilation system was updated with a number of changes intended to improve air quality including:

4. Increased Stage 1 minimum ventilation rates
5. Ceiling inlet re-positioning
6. Installation of actuated ceiling inlets
7. Modified room static pressure (SP settings) to support increased air inlet velocities

Maximus Solutions supported this project by supplying a ventilation and feed dispense management system which allowed the project team to collect critical data such as feed consumption, ventilation fan electricity consumption and gas heater operation time. In addition, pig weights, condition, treatments and mortality were collected manually. All of the data collected at the nursery barn was evaluated over multiple nursery pig production cycles to determine the impact of improved air quality on pig health, productivity and cost of production.

Results and Discussion:

The wireless air quality monitoring system developed specifically for this project was effective in gathering large barn gas data sets at the farrowing, nursery and finishing barns. At the nursery barn, additional data related to ventilation and heating system operation including ventilation fan electricity consumption and gas heater run time was collected through the Maximus Systems ventilation controller. The telemetry function of both data sources meant that data collection could continue throughout the COVID-19 pandemic period for the most part without significant problems.

Barn gases such as carbon dioxide, hydrogen sulfide, ammonia and methane all have exposure limits prescribed by the Ministry of Labour. These maximum limits are applicable for humans working within the barn.

Gas	Time-Weighted Average Limit(TWA) 8 hrs	Short-Term Exposure Limit (STEL)
Ammonia	25ppm	35ppm
Carbon Dioxide	5,000ppm	30,000ppm
Hydrogen Sulfide	10ppm	15ppm
Methane		5% vol Lower Explosive Limit

Table 1: Ministry of Labour Exposure Limits

The maximum target limits employed to evaluate the collected barn gas data are less than the Ministry of Labour exposure limits and were chosen to indicate barn gas levels that should be achievable in pig production. Note also that barn gas limits should be reduced due to the fact that the pigs are in the environment 24hrs per day.

Gas	Maximum Target	
Ammonia	10ppm	Toxic
Carbon Dioxide	2,000ppm	Asphyxiant
Hydrogen Sulfide	4ppm	Toxic
Methane	1% vol	Explosive at concentrations of 5% to 14.3% by volume
Relative Humidity	75%	RH >75% supports bacteria growth

Table 2: Project Gas Concentration Targets

An overview of results for each of the three barns is provided below. More detailed information is provided in the supplementary information document submitted with this report.

Farrowing Barn:

Data was collected within a farrowing room for the time period from November 2019 to September 2020. There were some challenges collecting a full data set at the farrowing barn. A combination of cellphone tower connection issues, Covid-19 biosecurity restrictions and damaged sensors due to pressurized water limited the amount of data collected at the Farrowing Barn.

Barn Gas		Overall	Summer (Jun/Jul/Aug)	Fall (Sep/Oct/Nov)	Winter (Dec/Jan/Feb)
Temperature	Avg (℃)	26.12	27.35	N/A	24.88
	Max (℃)	32.51	32.51	N/A	27.69
	Min (℃)	17.18	21.91	N/A	17.18
Relative Humidity	Avg (%)	43.41%	N/A	46.38%	43.28%
	Max (%)	91.68%	N/A	52.49%	91.68%
Carbon Dioxide	Avg (ppm)	3463 ppm	N/A	4070 ppm	3429 ppm
	Max (ppm)	5910 ppm	N/A	4880 ppm	5910ppm
Hydrogen Sulfide	Avg (ppm)	0.091 ppm	0.002 ppm	0.505 ppm	0.078 ppm
	Max (ppm)	4 ppm	1 ppm	1 ppm	4 ppm
Methane	Avg (% vol)	0.103% vol	N/A	0.002% vol	0.151% vol
	Max (% Vol)	0.3% vol	N/A	0.3% vol	0.06% vol

Table 3: Barn Gas Data – Farrowing Barn

The average Relative Humidity data collected were well within the 75% maximum target.

The carbon dioxide levels within the farrowing room, while not exceeding Ministry of Labour Exposure Limits, were found to on average exceed the project target of 2000ppm.

Low level hydrogen sulfide concentrations were measured in the farrowing barn with an overall average of 0.091ppm and peak reading of 4ppm throughout the data collection period. This average concentration is well below the Ministry of Labour Exposure Limit time weighted average of 10ppm.

Methane concentration levels within the farrowing room were also well below the lower explosive limit of 5% vol.

While consistently below the Ministry of Labour exposure limits, the carbon dioxide concentrations were higher than the general target of 2000ppm. There are opportunities to reduce the carbon dioxide concentrations within the farrowing room.

1. Employ automated static pressure management within the farrowing room to maintain optimal air velocity at the ceiling inlets. Carbon dioxide is a heavy gas at approximately 150% the weight of air. Fresh air entering the farrowing room through the ceil inlets need

to have some velocity to displace the accumulation of carbon dioxide gas building up from the floor.

2. Evaluate the minimum ventilation fan speed setting to ensure adequate turn over of air in farrowing room.
3. The wireless barn gas sensors were installed in the farrowing room at the second crate in from the access man door. It was the farm's practice to close some the ceiling inlets during cool/cold weather. In these conditions the ceiling inlet closest to the access man door was closed. This approach would tend to create a ventilation system dead zone with no turn-over of air in the room area near the door where the barn gas sensors were installed. Static pressure control within the farrowing room would eliminate need to manually open/close the ceiling inlets throughout the year as the inlet opening size would automatically modulate to maintain the static pressure set points. In addition, rotating the ceiling inlet closest to the door such that the opening faces the door and not the barn outside wall could also help to address a possible ventilation dead zone.

Finishing Barn:

Data was collected within the finishing barn for the time period from January 2020 to May 2021. Data points from each sensor in the barn was captured every 5 minutes.

Barn Gas		Overall	Spring (Mar/Apr/May	Summer (Jun/Jul/Aug)	Fall (Sep/Oct/Nov)	Winter (Dec/Jan/Feb)
Temperature	Avg (℃)	23.10	23.71	23.22	N/A	22.37
	Max (℃)	32.07	31.60	32.07	N/A	25.07
	Min (℃)	6.75	6.75	16.12	N/A	12.11
Relative Humidity	Avg (%)	66.30%	50.98%	76.36%	N/A	57.36%
	Max (%)	100.00%	80.58%	100.00%	N/A	80.07%
Carbon Dioxide	Avg (ppm)	2024 ppm	2551 ppm	993 ppm	2,402 ppm	2024 ppm
	Max (ppm)	6910 ppm	6500 ppm	3880 ppm	6910 ppm	5650 ppm
Hydrogen Sulfide	Avg (ppm)	0.05 ppm	N/A	0ppm	.009ppm	.367ppm
	Max (ppm)	3 ppm	N/A	0ppm	3 ppm	1 ppm
Methane	Avg (% vol)	0.08% vol	0.204% vol	0.013% vol	.001% vol	0% vol
	Max (% vol)	0.29% vol	0.29% vol	0.14% vol	0.07% vol	0% vol
Ammonia	Avg (ppm)	10.27 ppm	10.27 ppm	N/A	N/A	N/A
	Max (ppm)	25.65 ppm	25.65 ppm	N/A	N/A	N/A

Table 4: Barn Gas Data – Finishing Barn

The average relative humidity levels within the finishing barn did achieve an overall average of less than 75% throughout the data collection period. Average relative humidity did, however, exceed the 75% maximum target over the summer months of June, July and August. There were also periods of high relative humidity within the barn during the other season periods.

The average Carbon dioxide levels did exceed the 2000ppm target during the spring, fall and winter periods.

Low level hydrogen sulfide concentrations were measured in the finishing barn with an overall average of 0.05ppm with a peak reading of 3ppm throughout the data collection period. This average concentration is well below the Ministry of Labour Exposure Limit time weighted average of 10ppm.

Methane concentration levels were well below the lower explosive limit of 5% vol.

The ammonia data was limited to the spring of 2021 due to technical challenges with sensor development. The maximum ammonia average concentrations captured during this time period were significantly higher than the 10ppm target.

Three areas for potential improvement indicated by the data collected during this project are relative humidity, carbon dioxide and ammonia concentrations.

As previously discussed, high relative humidity during the summer season is difficult to control. Due to the minimal temperature difference between the barn environment and outdoors, moist air entering the barn during higher humidity weather will increase the relative humidity within the pig space. However, humidity can be controlled during the winter and shoulder seasons with the ventilation system. It is recommended that the Stage 1 minimum ventilation rate be increased to remove the respired moisture from the barn more quickly. In addition, any additional sources of moisture, such as wet floors, leaking water nipples or unvented gas heaters, should also be minimized such that the least amount of moisture needs to be removed during these low ventilation rate times of the year.

Average carbon dioxide concentrations during the cooler times of the year, and the peak concentration during the entire year, can be minimized through the ventilation system as well. Again, it is recommended that the Stage 1 minimum ventilation rate be increased to remove respired carbon dioxide from the barn more quickly. Carbon dioxide concentrations can also be reduced slightly by venting the gas heaters to the outdoors. In addition, it is recommended that full height ventilation stacks be installed on the Stage 1 and Stage 2 pit fans to minimize the recycling of exhaust air back into the barn space. During the more detailed investigation of the ventilation system at the nursery barn during this project, it was shown that ventilation stacks on minimum fans decreased the indoor carbon dioxide concentration by approximately 500ppm upon installation.

Ammonia concentrations measured during the period of mid March and mid to late April were excessively high and of concern. If these peaks were caused by manure agitation or transfer from the pit, the producer is reminded to ensure that ventilation systems must be significantly increased during these operations for both pig and personnel safety. The other concern with high ammonia levels is its effect on electrical components within the barn. Ammonia will cause corrosion of electrical components and can cause deterioration, arcing and potential fire. Once again, increasing the Stage 1 and Stage 2 pit fans to minimize the concentrations of ammonia within the barn is recommended.

It must be noted that increasing the minimum fan speeds must be accompanied by adjusting the barn air inlets. It has been shown through the more detailed nursery barn portion of this project that appropriately adjusted air inlets promote better mixing of the barn air and promote better pig performance and comfort. Based on that data, it is recommended that the inlets be adjusted to provide 0.07 to 0.08 inches of water static pressure for Stages 1, 2 and 3 to provide better air mixing, eliminate dead spots and promote pig comfort. Coupled with an increase in the Stage 1 and Stage 2 pit fan minimum speeds, and other recommendations detailed above, it is anticipated that gas concentrations can be lowered to more productive levels. It is strongly recommended that inlet settings be checked at least four times per year, using a reliable manometer. In addition, consideration should be given to automatic control of static pressure through the ventilation controller for more consistent control in all weather. During the warmest portion of the summer, static pressure can be lowered to approximately 0.03 inches of water to increase volumetric flow through the barn and maintain appropriate indoor temperature. Care must be exercised, however, if cooler nights are anticipated. Again, automatic control through the ventilation controller would be most reactive and consistent.

Finally, it should be noted that increasing minimum fan speeds and static pressures within the barn need not cause any increase in production costs. Detailed analysis of the data collected in the nursery barn portion of this project, including detailed electricity usage, gas heating usage, feed consumption and treatment records, indicate that pig are more comfortable, healthy and grow better with improved indoor air quality. While the data does indicate that the overall cost per pig is increased with improved ventilation strategies, the overall cost per kilogram of pig produced is lower during all seasons of the year.

Nursery Barn:

Following a period of baseline data collection in 2 adjacent nursery rooms, data was captured over 5 subsequent production cycles of approximately 60 days each. This duration allowed conditions under summer, fall, winter and spring conditions to be evaluated. One of the nursery rooms (Room 8) was maintained as the control room employing traditional ventilation methods. The second nursery room (Room 7) incorporated a number of updates and ventilation system setting changes to improve ventilation rates and thereby improve air quality.

Baseline

Air quality data was collected in both nursery rooms for a period of time to establish the baseline. Evaluation of the baseline data highlighted the need to implement some updates to the existing barn systems including:

1. Installation of Ventilation Fan Stacks: Measurement of carbon dioxide levels at the barn fresh air inlets indicated that barn gases vented out of the nursery rooms were being short circuited back into the rooms through the eaves, especially under low wind conditions. Stacks were installed to exhaust the fans above the barn roof line. This improvement benefitted all the nursery rooms in the barn.
2. Ceiling Inlet Maintenance and Modifications: Both nursery rooms initially employed counter-weighted ceiling inlets. In the control room 8, the counterweights were maintained to ensure proper inlet operation. In the test room 7, the ceiling inlets were replaced with actuated units. This allowed the ceiling inlet opening size to be actively adjusted by the Maximus control system in response to changing ventilation system settings. In addition, the ceiling inlets were relocated to the opposite side of the nursery room such that the inlet openings were facing into the pens and not into the pen access aisleway.

Production Cycles

The 5 production cycles monitored encompassed the following dates:

Cycle	Room	Fill Date	Ship Date
1 Summer	7 (Test)	Thurs Jul 9 2020	Tues Sep 8 2020
	8 (Control)	Thurs Jul 16 2020	Tues Sep 15 2020

2 Fall	7 (Test)	Thurs Sep 10 2020	Tues Nov 10 2020
	8 (Control)	Thurs Sep 17 2020	Tues Nov 17 2020
3 Winter	7 (Test)	Thurs Nov 12 2020	Wed Jan 6 2021
	8 (Control)	Thurs Nov 19 2020	Tues Jan 19 2021
4 Winter	7 (Test)	Fri Jan 15 2021	Tues Mar 16 2021
	8 (Control)	Thurs Jan 21 2021	Tues Mar 23 2021
5 Spring	7 (Test)	Thurs Mar 18 2021	Tues May 18 2021
	8 (Control)	Thurs Mar 25 2021	Tues May 25 2021

Table 5: Production Cycles

Temperature Management

Nursery pig production requires a specific room temperature profile be maintained throughout the production cycle. The Maximus Solutions ventilation system controller monitored room temperature through the use of a thermocouple installed approximately midway in room height.

A wireless temperature sensor was included with the air quality sensors at pig level inside the pen for production cycles 1, 2 and 3. For production cycles 4 and 5, additional wireless temperature sensors were installed at ceiling level to monitor temperature gradient within the room.

Barn Gas		Cycle 1		Cycle 2		Cycle 3		Cycle 4		Cycle 5	
		Rm. 7	Rm. 8	Rm. 7	Rm. 8	Rm. 7	Rm. 8	Rm. 7	Rm. 8	Rm. 7	Rm. 8
Temp. Difference (Tpen – Tsetpoint)	Avg (℃)	3.6	4.1	0.8	1.05	N/A	-1.22	1.02	0.09	1.78	1.53
Temp. Difference (Tceiling – Tsetpoint)	Avg (℃)	N/A	N/A	N/A	N/A	N/A	N/A	0.72	0.40	1.18	0.83

Table 6: Nursery Room Temperature Differentials

The interpretation of this temperature data was dependent on ambient conditions outside the barn. During the summer months outside temperatures are often hotter than pen temperature setpoints. During this time period, the effectiveness of the ventilation system would be evaluated by the minimum difference between pen temperature and setpoint temperature. The data for cycle 1 demonstrated that the nursery room 7 ventilation system was able to maintain a tighter temperature control by being on average 3.6℃ warmer than the setpoint temperature. In comparison, control nursery room 8 was on average 4.1℃ warmer. This result tended to suggest improved ventilation in nursery room 7 did a better job of managing the heat being generated by the pen occupants than in nursery room 8.

In the cold winter months, ambient outside temperatures are less than the setpoint temperature and heat is generated inside the nursery room by both the pigs and the gas heater. In this case, the ventilation system which provided the maximum positive temperature difference between pen and set point temperatures was more effective in driving the heat collecting at ceiling level back into the pen. The temperature differences in cycle 4 demonstrated this effect keeping in mind that the setpoint temperature was measured at the nursery room mid-height. In nursery room 7, the pen temperature was on average 1.02℃ higher than the setpoint temperature while in nursery room 8 the pen temperature was only 0.09℃ higher than the setpoint temperature. This result also tended to suggest that the improved ventilation and static pressure control in nursery room 7 was more effective in maintaining higher temperatures in the pen.

Impact of Production Cycle 4 Room 7 Static Pressure Setting Change on Pen Temperature

A static pressure setting change was implemented in nursery room 7 during the early portion of production cycle 4. This ventilation system setting change served to demonstrate the impact of higher static pressure settings at low ventilation stage in order to increase fresh air inlet velocities from the ceiling inlets. The ability to actively and remotely adjust static pressure settings within the nursery room highlights the benefit of actuated ceiling inlets controlled by the Maximus system controller.

Time Period	SP	Average Temp Diff (Tceiling – Tpen)
Jan 22 2021 1200hrs to Jan 26 2021 1200hrs	0.05”WC	2.52℃
Jan 26 2021 1205hrs to Feb 2 2021 1200hrs	0.08”WC	0.90℃

Table 7: Impact of SP Setting Change on Temperature Differential

This static pressure setpoint change was conducted in January 2021 when ventilation stage 1 was in operation. Increasing the static pressure setting from 0.05”WC to 0.08”WC had the related effect of increasing inlet air velocity and thereby mixing of air within the nursery room. The effect of the improved mixing was demonstrated by the reduction in average temperature differential between the pen and ceiling from 2.52℃ to 0.90℃. This effect is further evidenced by the reduction in gas heater operation and thereby gas consumption discussed later in this report.

Air Quality

Barn Gas		Cycle 1		Cycle 2		Cycle 3		Cycle 4		Cycle 5	
		Rm. 7	Rm. 8	Rm. 7	Rm. 8	Rm. 7	Rm. 8	Rm. 7	Rm. 8	Rm. 7	Rm. 8
Relative Humidity	Avg (%)	63.94	61.24	61.66	59.43	54.70	58.00	55.46	53.71	54.84	52.95
	Max (%)	81.90	73.30	78.60	70.10	61.50	63.90	73.06	90.46	67.47	70.79
Carbon Dioxide	Avg (ppm)	946	2412	2353	2667	N/A	N/A	3430	3075	1961	1499
	Max (ppm)	2370	5060	4930	5170	N/A	N/A	7500	13100	4800	3800
Hydrogen Sulfide	Avg (ppm)	0	0	N/A	0	N/A	0	0	0	0	0
	Max (ppm)	0	0	N/A	0	N/A	0	0	0	0	0
Methane	Avg (ppm)	0.00001	0.119	0.000007	0.246	0.33	0.0002	0.31	0.000005	0.27	0.01
	Max (ppm)	0.02l	0.3	0.01	0.42	0.38	0.42	0.02	0.04	0.40	0.01
Ammonia	Avg (ppm)	N/A	N/A	N/A	N/A	N/A	N/A	5.93	5.05	5.89	4.52
	Max (ppm)	N/A	N/A	N/A	N/A	N/A	N/A	13.82	13.19	23.95	12.73

Table 8: Barn Gas Data – Nursery Barn

The average Relative Humidity data collected were well within the 75% maximum target.

The average Carbon Dioxide levels did vary throughout the 5 production cycles. During production cycle 1 in the summer months, the average carbon dioxide concentration of 946ppm in test room 7 was significantly less than the average of 2412 in the control room. Average carbon dioxide concentrations were similar in both rooms and exceeded the 2000ppm target during production cycles 2 and 4. Technical issues combined with Covid19 restrictions limited the barn gas data collected during production cycle 3. The 2000ppm carbon dioxide concentration target was achieved in both test rooms in production cycle 5. In this case, the average concentration was higher in test room 7 than in control room 8.

No measurable hydrogen sulfide concentrations were measured throughout the 5 production cycles.

Methane concentration levels measured through all 5 production cycles were well below the lower explosive limit of 5% vol.

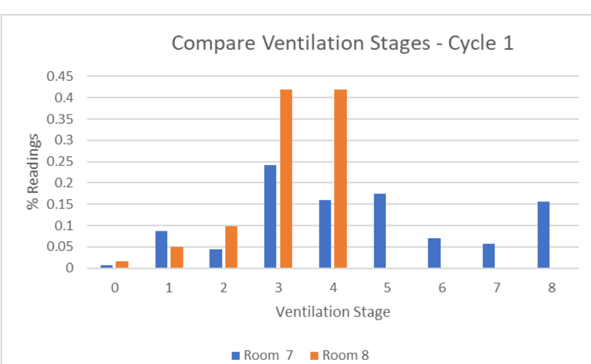
The ammonia data was limited to the spring of 2021 due to technical challenges with sensor development. The maximum ammonia average concentrations captured during this time period were higher than the 10ppm target.

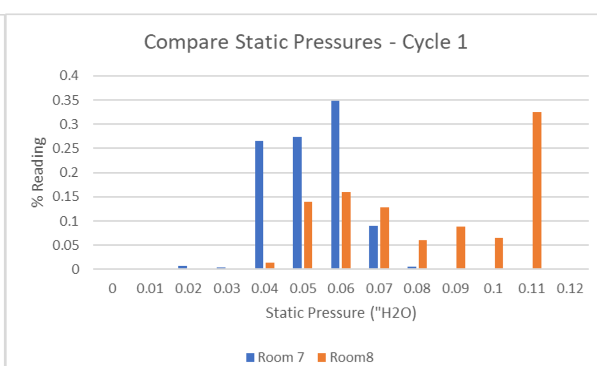
Ventilation System Operation

The existing barn ventilation system is primarily focused on managing temperature. The collection of ventilation system stage and room static pressure data throughout the 5 production cycles provides an insight into the effectiveness of the ventilation systems ability to manage barn gases.

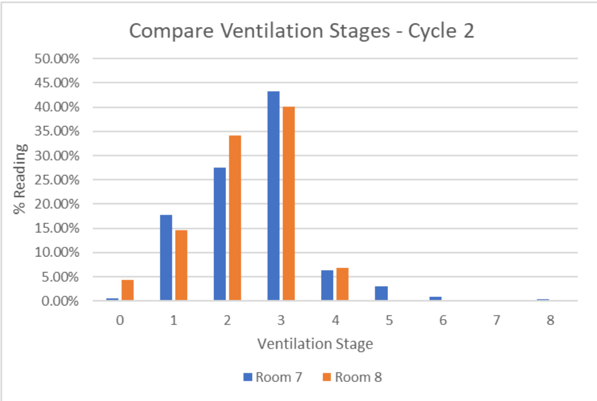
The charts below summarize the ventilation performance for the 5 production cycles.

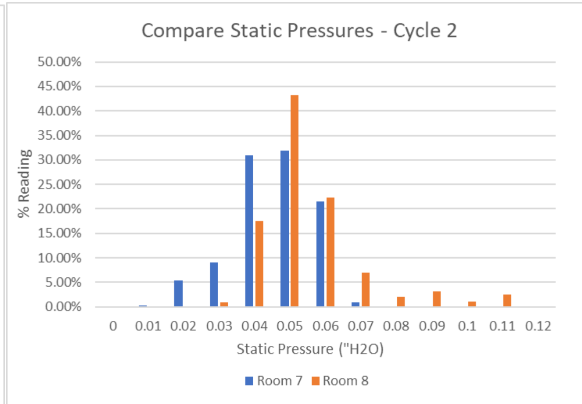
Production Cycle 1



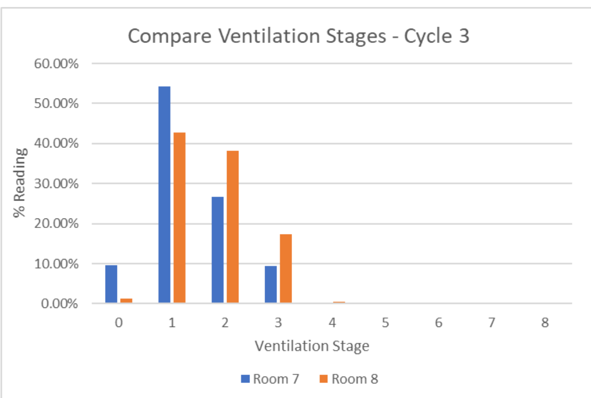


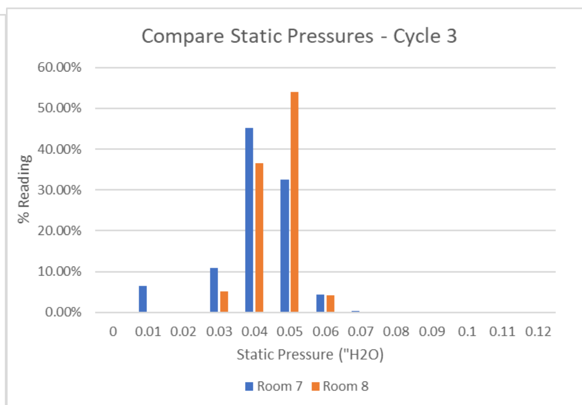
Production Cycle 2



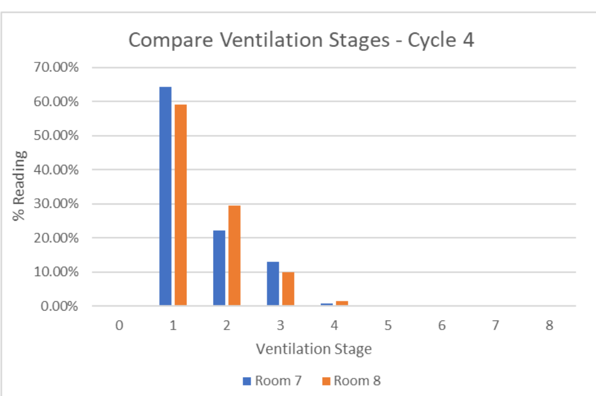


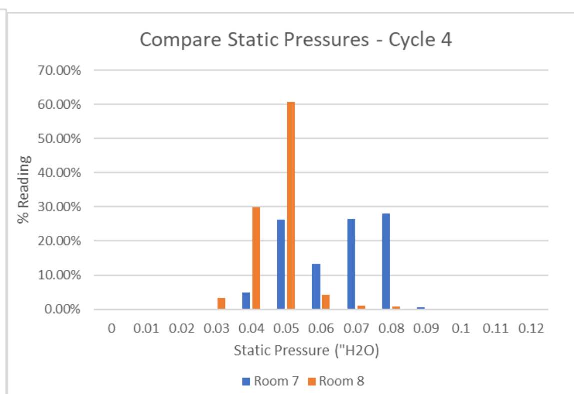
Production Cycle 3





Production Cycle 4





Production Cycle 5

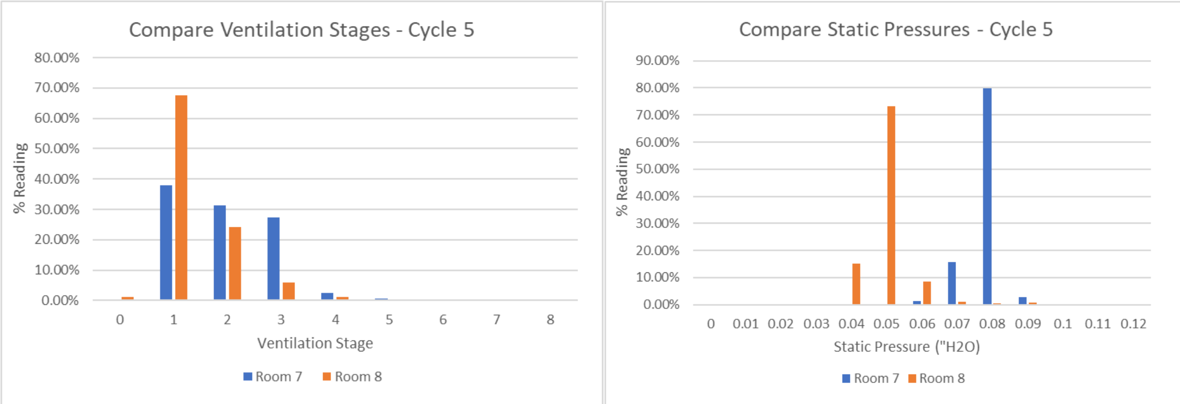


Figure 1: Ventilation System Performance

Average Static Pressure per Production Cycle

Production Cycle	Avg SP – Test Room 7	Avg SP – Control Room 8
1	0.0527” WC	0.0829” WC
2	0.0457” WC	0.0539” WC
3	0.0417” WC	0.0463” WC
4	0.0648” WC	0.0473” WC
5	0.0783” WC	0.0491” WC

Table 9: Average Static Pressure per Cycle

Increasing ventilation stage corresponds to increasing fan speeds and increased number of fans. The net effect is an increased volumetric flow rate of fresh air through the nursery room. A high flow rate is useful in the hot summer months to manage heat build up in the nursery room. Increasing the room static pressure has the effect of increasing air velocity at the ceiling inlets. It also, however, has a negative effect on the overall volumetric flowrate.

These effects are demonstrated in the ventilation system performance and air quality data.

Production cycle 1 covers the hot summer months. The cycle 1 ventilation stage chart indicates that test room 7 ventilation system spent more time at high stages and lower static pressures throughout the production cycle than control room 8. Ventilation stages 0 through 4 corresponds to increasing fan speeds and increasing number of fans in operation. Ventilation stage 5 through 8 corresponds to reducing nursery room static pressure achieved by increasing the ceiling inlet opening size. The combination of maximum ventilation stage and minimum static pressure achieves the highest possible volumetric flow rate of fresh air through the nursery room to both manage heat and air quality. The carbon dioxide concentration results for production cycle 1 confirms the effect of the improved nursery room pen ventilation. The average carbon dioxide concentration for the test room 7 with improved ventilation was 946ppm compared to 2412ppm for the adjacent control room 8. The peak carbon dioxide concentration of 2370ppm in test room 7 were also significantly reduced from the 5060ppm peak in control room 8.

Production cycle 4 covers the cold winter months. Both room 7 and room 8 spent the majority of the time in ventilation stage 1. The reduced ventilation rates were required to maintain temperature setpoints within the rooms while limiting the gas heater operating times. Static pressure set points within the Maximus controller were increased in test room 7 for this production cycle and the minimum stage 1 fan speed was increased to 80% (compared to 45% in room 8). The increased static pressure setting within test room 7 was intended to increase the inlet air velocity into the room, thereby increasing mixing of the incoming fresh air with any built-up barn gases.

The carbon dioxide data collected in production cycle 4 indicate the impact of the ventilation system adjustment in test room 7. While the average carbon dioxide concentrations in both nursery rooms were similar, the peak concentration in test room 7 was significantly less than in control room 8. These results might be indicating that the stage 1 fan size in this particular farm is somewhat undersized to maintain the volumetric flowrate sufficient the control barn gases at the higher static pressures setting needed for increased air inlet velocity.

Production cycle 5 covers the transition spring months. As the outside temperatures increased, the ventilation system in test room 7 started to spend more time at higher ventilation stages than in control room 8.   The static pressure in test room 7 remained at a relatively high 0.08” WC for the majority of the production cycle duration. This is a higher static pressure reading than anticipated and it is suspected that there was a mechanical issue with the ceiling inlet actuator that limited its ability to maintain target static pressure settings in test room 7.   As noted previously, the high static pressure in test room 7 has the effect of increasing fresh air inlet velocities but concurrently reduces the volumetric flow rate supplied by the ventilation fans.   For this production cycle, average and maximum carbon dioxide concentrations in test rom 7 exceeded those of control room 8.

Electricity and Heating Gas Consumption

Barn Gas		Cycle 1		Cycle 2		Cycle 3		Cycle 4		Cycle 5	
		Rm. 7	Rm. 8	Rm. 7	Rm. 8	Rm. 7	Rm. 8	Rm. 7	Rm. 8	Rm. 7	Rm. 8
Total Electricity	kWh	422.39	338.13	236.95	199.91	167.06	157.79	177.56	165.18	246.56	221.20
Electricity Cost	$	$54.92	$43.96	$30.80	$25.99	$21.72	$20.51	$23.08	$21.47	$32.05	$28.76
Total Propane	L	0	0	264.56	157.06	621.20	310.70	694.20	607.20	250.40	359.60
Propane Cost	$	$0.00	$0.00	$113.50	$67.38	$266.49	$133.29	$297.81	$260.49	$107.68	$154.62

Table 10: Electricity and Gas Consumption per Cycle

Total electricity consumption and associated cost was higher in test Room 7 than in control room 8 for each of the 5 production cycles monitored. This corresponds with the more time spent in test room 7 at higher ventilation stages and higher minimum stage 1 speed.

Total propane consumption and associated cost was higher in test room 7 than in control room 8 for production cycles 2, 3 and 4. Total propane consumption in test room 7 was less than control room 8 for production cycle 5. The results highlight the importance of maintaining recommended static pressure levels especially at low ventilation stages. The average static pressure readings in test room 7 ranged from 0.041” WC to 0.046” WC for production cycle 2 and 3. Static pressure settings were increased during production cycle 4 (average 0.065” WC) and maintained through production cycle 5 (average 0.078” WC). This suggests that for cycle 2 and 3, the fresh air inlet velocities entering the nursery room were too low to promote mixing and movement of hot air at ceiling back down past the thermocouple controlling gas heater operation and into the nursery pen. The improved mixing associated with higher fresh air inlet velocities during cycle 4 and 5 supported a reduction in gas consumption.

Pig Performance

	Cycle 1			Cycle 2			Cycle 3		
	Rm. 7	Rm. 8	StdDev	Rm. 7	Rm. 8	StdDev	Rm. 7	Rm. 8	StdDev

Initial Avg Pig Weight (kg)	7.28	7.60	1.26	7.52	7.84	1.61	7.0	7.1	1.44
Final Avg Pig Weight (kg)	37.09	35.45	2.74	38.80	38.18	2.82	28.2	30.5	4.49
Avg Daily Gain (kg/pig/day)	0.49	0.46	0.03	0.51	0.50	0.03	0.39	0.43	0.06
Avg Daily Feed Intake (kg/pig/day)	0.82	0.82	0.04	1.00	0.92	0.08	0.72	0.80	0.10
Feed to Gain Ratio (kg/kg)	1.8	1.8	0.11	2.0	1.8	0.15	1.8	1.9	0.19
% Mortality	4.02	7.14	-	2.63	3.29	-	11.9	2.6	-
Treatment Cost per Pig ($ excl vaccines)	0.10	0.56	-	0.14	0.11	-	0.11	0.07	-

	Cycle 4			Cycle 5		
	Rm. 7	Rm. 8	StdDev	Rm. 7	Rm. 8	StdDev
Initial Avg Pig Weight (kg)	7.8	7.9	1.46	8.0	7.9	1.38
Final Avg Pig Weight (kg)	35.6	34.1	2.74	38.7	33.6	3.94
Avg Daily Gain (kg/pig/day)	0.52	0..48	0.04	0.50	0.42	0.03
Avg Daily Feed Intake (kg/pig/day)	0.89	0.78	0.11	0.90	0.77	0.08
Feed to Gain Ratio (kg/kg)	1.8	1.8	0.11	1.8	1.9	0.13
% Mortality	6.8	9.1	-	2.63	3.29	-

Treatment Cost per Pig ($ excl vaccines)	0.29	0.19	-	0.02	0.07	-

Table 11: Pig Performance per Cycle

Higher average daily weight gains were achieved in test room 7 with improved ventilation for every production cycle except cycle 3. During production cycle 3, a pig health issue unrelated to air quality did impact room performance. Equal or higher average daily feed intake and lower mortality for all production cycles except cycle 3 was also achieved in test room 7.

Cost of Production

Partial Budget

Units are $/1000 kg gain

Cost	Cycle 1			Cycle 2			Cycle 3		
	Rm. 7	Rm. 8	Diff	Rm. 7	Rm. 8	Diff	Rm. 7	Rm. 8	Diff
Feed	$862.44	$878.19	-$15.75	$922.08	$891.3	$30.78	$1007.41	$962.83	$44.58
Medicine (ex Vacc)	$4.27	$24.63	-$20.36	$4.70	$3.61	$1.09	$5.91	$2.88	$3.03
Electricity	$12.90	$11.48	$1.42	$6.69	$5.85	$0.84	$7.48	$5.97	$1.51
Propane	$0.00	$0.00	$0.00	$24.64	$15.17	$9.47	$91.73	$38.79	$52.95
Total	$879.61	$914.30	-$34.69	$958.10	$915.93	$42.18	$1112.53	$1010.46	$102.07

Cost	Cycle 4			Cycle 5		
	Rm. 7	Rm. 8	Diff	Rm .7	Rm. 8	Diff
Feed	$1057.52	$1072.47	-$14.95	$1044.13	$1054.87	-$10.74
Medicine (ex Vacc)	$11.35	$8.54	$2.82	$0.82	$2.93	-$2.12
Electricity	$6.17	$6.69	-$0.53	$8.61	$8.82	-$0.12
Propane	$79.57	$81.21	-$1.64	$28.92	$47.42	-$18.49
Total	$1154.61	$1168.91	-$14.30	$1082.48	$1114.04	-$31.56

Table 12: Cost of Production per Cycle

Units for the cost of production data for each production cycle provided above are in $ per 1000 kg weight gain. Feed costs by far constitutes the highest component for the cost of production. The additional consumption of electricity in test room 7 for increased ventilation rates was limited to a maximum of $1.51 per 1000kg weight gain in production cycle 3.

The cost of propane for heating was higher in test room 7 than in control room 8 for production cycles 2 and 3. An increase in propane cost for test room 7 was anticipated due to the increased ventilation rates in that nursery room. However, the effect of increased air inlet velocity to promote mixing on propane consumption is demonstrated in production cycle 4 and 5. In each case, the cost of propane per 1000 kg gain in test room 7 was less than in control room 8 regardless of the increased ventilation rates.

Overall, the cost of production per 1000kg weight gain was lower in test room 7 with improved ventilation over control room 8.

Mortality

	Cycle 1			Cycle 2			Cycle 3		
	Rm. 7	Rm. 8	Diff	Rm. 7	Rm. 8	Diff	Rm. 7	Rm. 8	Diff
Mortality %	4.0%	7.1%	-3.1%	2.6%	3.3%	-0.7%	11.9%	2.6%	9.3%
Pigs Lost	7	12	-5	4	5	-1	19	4	15
Est. Pig Value	$75	$75		$70	$70		$70	$70	
Est. Opportunity Loss	$524.61	$899.64	-$375.00	$279.83	$350.06	-$70.22	$1332.80	$276.64	$1056.16

	Cycle 4			Cycle 5		
	Rm. 7	Rm. 8	Diff	Rm. 7	Rm. 8	Diff
Mortality %	6.8%	9.1%	-2.3%	4.7%	6.4%	-1.7%
Pigs Lost	10	13	-3	6	9	-3
Est. Pig Value	$78	$78		$80	$80	
Est. Opportunity Loss	$779.69	$1015.01	-$235.33	$479.88	$720.16	-$240.28

Table 13: Mortality per Cycle

The mortality % rate was lower in test room 7 than in control room 8 for each of the production cycles except production cycle 3. In that case, a pig health condition not related to this project significantly increased the mortality. Each pig mortality represents a lost opportunity for revenue generation on the part of the pork producer.

Conclusions:

The data collection conducted in the farrowing, nursery and finishing barns demonstrated the wireless barn gas monitoring technology employing RF and cellular communication can be used in pork production barns to monitor air quality. Some additional development in sensor design to withstand operating conditions is required. In addition, careful cellular antenna design to stabilize communication to the nearest cell tower is required.

Measurable barn gases were found in all barns but they did not exceed Ministry of Labour Exposure Limits to barn stockpeople. In the farrowing, nursery and finishing barns tested, relative humidity, methane and hydrogen sulfide concentrations were quite low and effectively managed by the barn ventilation systems. The carbon dioxide and ammonia levels were higher and demonstrated an opportunity for improvement through optimizing performance of the existing ventilation systems in each of the 3 barns.

Ventilation system design and maintenance is important. For example, the installation of stacks on the pit fan exhausts at the nursery barn to avoid the short circuiting of barn gases from ventilation fans exhaust back into barn through eave inlets. Also, ceiling inlets should be located and oriented to provide fresh air into the pens themselves.

Increased ventilation rates within a nursery room did not significantly increase electricity consumption and did have a beneficial impact on pig health demonstrated by increased daily gain, increase daily feed intake and reduced mortality.

Active control of nursery room static pressure was found to be critical to manage fresh air inlet velocities especially during time periods at low ventilation stage. A static pressure setting of 0.08” WC at ventilation stage 1 did provide fresh air inlet velocities that promoted mixing within the nursery room. The research results also indicated an associated reduction in heating gas consumption. During hot periods at high ventilation stages, a reduced static pressure setting as low as 0.03” WC allowed the ventilation fans to operation at maximum efficiency to maximize air turnover in the room.

The data collected and evaluated through this project indicate that improved ventilation rates and optimized static pressure control did have a positive impact on nursery farm cost of production and revenue generation. A cost of production evaluation covering feed, medicines, electricity and propane measured in $ per 1000 kg gain resulted in reduced costs for 3 of 4 production cycles measured. The results for production cycle 3 are discounted due to non-related pig health issues. Nursery room revenue generation was also increased through reduced mortality rates for all production cycles except cycle 3.