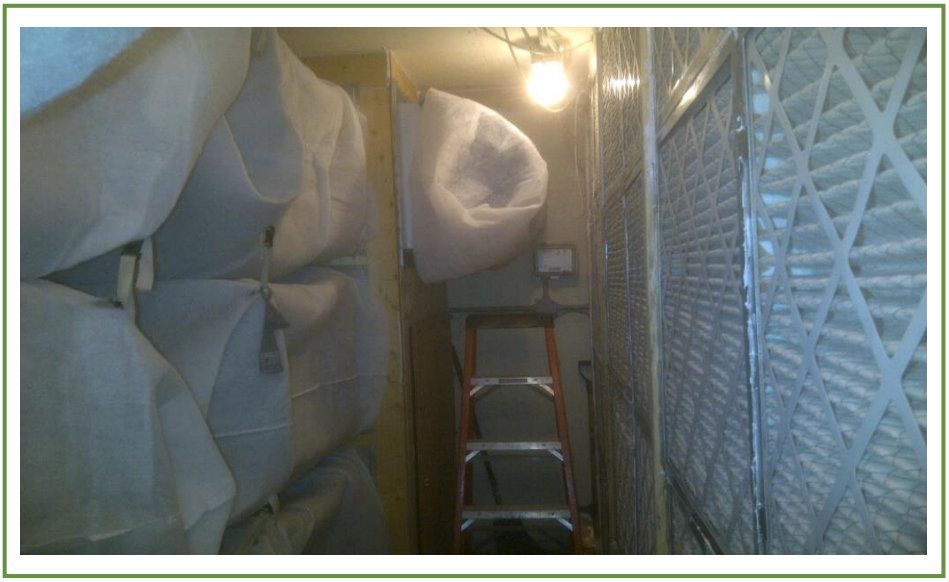
Innovative Biocontainment Concept With Air Filtration at the Exhaust Fans in a Quarantine Facility: Combination of Proven Technologies to Reduce Filter Clogging Rate



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Report

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Abstract

The purpose of the project was to test an innovative biocontainment system adapted to a swine quarantine facility to reduce the risk of airborne virus spread in case of contamination by pathogens and to test technologies for reducing to an acceptable level the clogging rate of prefilters and antimicrobial filters installed at the exhaust fans.

Trials took place in a 108-gilt quarantine section attached to the existing farrowing barn and ventilated by extraction. The fans and the air filtration system at the exhaust vent were located in a room dedicated to air processing built at the end of the quarantine area. The air inlets (in the attic spaces) were equipped with Noveko antimicrobial filters made up of 15 layers of filtering membranes to prevent backdraft of potentially contaminated air into the attic. At the exhaust vent (wall fans), the system included three filtration steps: a StuffNix or MERV 13 prefilter, Noveko prefilters and Noveko antimicrobial filters made up of 10 layers of filtering membranes.

Trials were conducted on four batches in an all-in, all-out configuration with a duration of 25 days each, except the first batch, which had a duration of 35 days, during which a different processing method was tested: batch 1) StuffNix prefilter and an ionization dust abatement system, batch 2) StuffNix prefilter with no ionization system, batch 3) DP-green® (MERV 13) prefilter and ionization system, and batch 4) DP-green® (MERV 13) prefilter with no ionization system.

The indoor and outdoor temperatures and static pressure at eight locations in the building were taken every ten minutes with a data acquisition system. The electric voltage on each of the fans was measured using voltage transmitters to estimate the fan airflow rate depending on the voltage and static pressure at the fan. Finally, total dust was sampled and air particles with a diameter of 0.3, 0.5, 1, 3, 5 and 10 µm were counted once a week on three sampling sites: inside the building, in between prefilters and antimicrobial filters, and downstream of antimicrobial filters.

The presence of the ionization system allowed for an average reduction of 43 to 60% in the concentration of particles of different sizes and 83% in total bacteria. The ionization system also enabled to significantly reduce dust mass concentration (64%) in the air of the building.

The presence of the StuffNix prefilter allowed for a slight reduction in dust mass concentration of 29 to 38%, which is much lower than the efficiency claimed by the manufacturer (70%). As for the number of particles in the air, this filter allowed reducing their quantity by 3 to 39% depending on the sizes of particles ranging from 0.3 to 10 µm. In terms of total bacteria, the filter did not cause a significant reduction with only 6 to 9% achieved. Considering the large number of dust particles and bacteria that did go through the prefilter, this was replaced with MERV 13 prefilters for the two subsequent trials. The change of prefilter was motivated by the importance of reducing the likelihood of contamination of the farrowing barn attached to the quarantine facility. The objective was to minimize the amount of particles coming out of the room and to keep the antimicrobial filter as clean as possible in order to optimize the efficiency of antimicrobial products contained in the filter fibre in inactivating microorganisms.

The MERV 13 prefilter allowed reducing dust mass concentration by 47 to 80%. As for particles in the air, this prefilter allowed reducing their quantity by 81 to 96% depending on the sizes of particles ranging from 0.5 to 10 µm, in line with expected results. This filter was more effective than the StuffNix prefilter in blocking the emission of 1 to 10-µm particles and total bacteria ($p < 0.05$).

Combining the MERV 13 prefilter and the antimicrobial filter ensured the capture of 54 to 98% of dust particles depending on their sizes and 96 to 98% of bacteria. Such combination allowed reducing dust mass concentration by 62 to 91%. There seems, however, to have been a re-

emission of 0.3 and 0.5-µm particles from the antimicrobial filter on batches 3 and 4. A release of 1, 3, 5 and 10-µm particles was also observed on batch 3. The re-emission of particles from the antimicrobial filter could be highlighted by the use of a prefilter more effective in capturing particles coming from the building (batches 1 and 2 as compared with batches 3 and 4) and the presence of an ionization system (batch 3 vs. batch 4). This re-emission phenomenon can be explained by the fact that the antimicrobial filters may have not been cleaned thoroughly between trials, as the same filters were employed during the four trials. Only the MERV 13 prefilters and those placed directly on antimicrobial filters were changed between trials.

The pressure gradient between the upstream and the downstream of the StuffNix prefilter varied very little with time, and this with or without an ionization system in operation. The pressure gradient varied between 0.09 and 0.18 inches of water gauge (in wg) depending on the airflow rate. Therefore, the prefilter did not clog up. However, the antimicrobial filters did clog up, which was unacceptable in this context.

Indeed, the pressure gradient at the antimicrobial filters gradually increased with time with the use of the ionization system, while it increased more quickly without the ionization system (with the StuffNix prefilter). With or without ionization, on the side of the filters of ventilation stage 2, the pressure gradient was about 0.04 to 0.05 in wg lower than that on the side of stage 1. Therefore, the filters on the side of ventilation stage 2 were less dirty, which is logical since fans on this side operate less often than those on the side of stage 1.

Globally, during the two trials with the StuffNix prefilter, the pressure at the fans always remained below 0.50 in wg, which is the maximum acceptable pressure according to the fan specifications.

During the two trials with the MERV 13 prefilters, the fans on the side of ventilation stage 2 operated very little, if any. Since the pressure differential increased very little in the autumn during trials 3 and 4, this indicates that the MERV 13 prefilters, in autumn conditions, could be employed in several breeding facilities on condition that no health concerns were observed in the facility. The ionization system would have allowed reducing the cleaning frequency of the filters and prefilters by nearly half, which would result in a substantial reduction of operating costs. All of this will need to be validated during the warm season. As for the antimicrobial filters, the pressure differential did not increase with time depending on a given airflow rate, which means that the MERV 13 prefilters perform well.

The differential pressure was never problematic during the two trials with the MERV 13 prefilter conducted in the autumn, and no maintenance was necessary during the trials. The prefilters were changed only in between batches and the antimicrobial filters were cleaned. The pressure differential at the fans remained nearly always below 0.25 in wg, while the system was designed for a pressure of 0.50 in wg. Therefore, no maintenance of the air filtration system was necessary during the trials. However, trials will be required during summer time to validate the impact on the clogging rate and on the pressure gradient. It is possible that filters need to be changed in the summer, as the pressure gradient at the fans is 0.45 in wg with new prefilters and filters when all ventilation stages are in operation. There remains then about only 0.05 to 0.20 in wg of autonomy as regards clogging, which remains to be validated. On the face of it, this does not seem to be a problem. Thus, the power of the fans seems to be adequate. In order to get this appropriate autonomy, the motor power was oversized and the impellers were adapted accordingly, while keeping a fan design as typically used in the industry.

During the first two trials (using the StuffNix prefilter), the amount of air filtered after 25 days was similar with a variation of only 9% (11.83 vs. 10.74 million m^3 of air), which allows comparing the clogging and efficiency of filters. While with the MERV 13 prefilter, the amount of air filtered was 87% bigger in the trial with the ionizer than that without this ionization system (5.02 vs. 2.68

million m³ of air). Therefore, unlike the trials with the StuffNix prefilter, the trials conducted in the autumn with the MERV 13 prefilter are not comparable.

In total, filtration and ionization systems result in additional costs of $36,400. However, the addition of such systems allowed building the quarantine facility attached to the farrowing barn and generated construction savings estimated at $39,600 as compared with a quarantine facility built 100 m away from the farrowing barn. Other savings could be possible (transportation costs, working time); however, even if the costs of the biocontainment concept can be offset by savings related to the construction of a quarantine facility remote from the farrowing barn, the difference is minor (about $3,200) and might even prove to be negative depending on the project (physical location, building plan, size, etc.)

Nevertheless, the choice of investing in a biocontainment concept should be based mainly on the risk of PRRS contamination that replacement gilts represent to the herd of sows from the farrowing barn. The introduction of health problems into the herd of sows can have serious consequences on herd productivity, with 1 to about 4 less weaned piglets per year, according to a recent study (Klopfenstein *et al.*, 2013). Based on a price of $35 per piglet, this represents a loss of revenue of $35 to nearly $140 per sow. In addition, one may wonder about the need to filter the air from quarantine facilities built near the farrowing barn, typically at about 100 m. This possibility would result in promoting, from an economic perspective, the construction of the quarantine facility as part of the farrowing barn.

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1. Introduction

1.1 Problem and Context Setting

It is now recognized that some pathogens, among which the Porcine reproductive and respiratory syndrome virus (PRRSv), Influenza and *Mycoplasma hyopneumoniae* (*M. hyo*), are transmitted through the air (Desrosiers, 2004). These pathogens are carried on dusts called bioaerosols. The PRRSv as well as *M. hyo* can travel in the air on a distance up to a little more than nine kilometres (Dee *et al.*, 2009; Otake *et al.*, 2010). The PRRSv causes major economic losses when a breeding facility is affected. According to a Canadian study, this cost might total $250 to $460/sow/year (chronic PRRS or new acute outbreak) (Mussel, 2010). Since the beginning of the years 2000, a number of research studies conducted by Dr. Scott Dee and Dr. Laura Batista have demonstrated that the installation of appropriate filters in buildings together with an adequate biosecurity protocol was effective in preventing PRRSv contamination.

Considering the very difficult economic situation that has been prevailing for several years in the pork industry and to offset economic losses from PRRSv contaminations, pork producers have been encouraged to establish or improve their biosecurity procedures on the farm, including through the implementation of quarantine facilities. However, the majority of quarantine facilities that were built so far did not consider that a contaminated herd can release viruses through the air coming out of the fans and contaminate surrounding breeding facilities along several kilometres. As a result, there are currently many quarantine facilities that put at risk neighbouring breeding facilities in case of contamination. The installation of an efficient air filtration or processing system at the exhaust fans could solve this issue.

Furthermore, the industry currently suggests that quarantine buildings be set up in a different site from the farrowing barn when the size of the unit allows it, which generates significant construction and operating costs (e.g., access road, services, electrical power, manure pit, transportation, labour cost, etc.) These significant costs result in fewer quarantine facilities being constructed for farrowing and farrowing-finishing facilities. Indeed, many such sites are still not equipped with quarantine facilities in Canada, due to the prohibitive costs involved in their installation and operation.

In 2010, in Ontario, Dr. Brent Jones tested an air filtration concept installed at the exhaust fans in a commercial farrowing barn that had just been contaminated by the PRRSv in order to avoid contaminating a very close neighbouring breeding facility. This biocontainment concept used in an emergency situation was very interesting, but the dust released by the facility clogged up the filters in less than three days, thus making its application difficult (Jones, 2011, South West Ontario Veterinary Services, personal communication).

Therefore, the main challenge with the concept of filtration at the exhaust fans of buildings to avoid virus propagation lies in early clogging of the filtration system due to dust and in its maintenance. In the case of a quarantine biocontainment concept, it is important to find one or more solutions to the dust release issue, since the air must be filtered at the exhaust fans about 50% of the time during the year, which is the duration required to confirm that animals are naïve following their entry into the building.

The development of an efficient and less expensive biocontainment concept adapted both to existing and new quarantine facilities will allow protecting surrounding breeding facilities against virus propagation in case of contamination, while fostering the installation of new quarantine facilities, which will result in increased biosecurity of reproductive herds.

Therefore, considering that:

- A quarantine facility constitutes an important link in ensuring the health security of a farrowing house;
- Quarantine facilities built on adequately isolated sites are expensive;
- It is scientifically accepted that the PRRS virus can be airborne and can be carried over 9.2 km;
- Several hog barns that are used as quarantine facilities are located less than 9.2 km from other farms and run the risk of bringing about contamination should there be a problem in the quarantine facility;
- Certain types of filters installed at the air inlet have proven to be effective in controlling the airborne propagation of the PRRS virus;
- Air filtration at the exhaust fan can form part of a biosecurity program. Example: a regional project for control and eradication of PRRS in order to protect surrounding farms also under control (Area Regional Control and Elimination (ARC&E) installation projects are currently underway in some Canadian provinces);
- The large amount of dust coming from the barns quickly clogs filters and makes maintenance difficult and costly.

The objective was to develop a concept allowing for air filtration at the outlet of quarantine facilities in order to:

- Solve the problem of rapid clogging of the filters and evaluate the costs and benefits;
- Protect farrowing houses and other pork environments from quarantine facilities either existing or under construction;
- Build new quarantine facilities directly attached to farrowing houses in order to significantly reduce setup and operation costs;
- Foster the construction of quarantine facilities by reducing building and operation costs in order to provide health security to the herd.

Research in the literature and communications with suppliers suggest that a very promising avenue is to combine the following four processes, due to their performances and low cost:

Step 1: Antimicrobial filters (Noveko, Qc, Canada) with 15 antimicrobial membrane layers will be installed at the air inlet to avoid contaminated air backdraft from the air inlet during a possible outbreak inside the quarantine barn;

Step 2: Removal of dust particles by Electrostatic Particulate Ionization (EPI) (Baumgartner Environics Inc., MN, U.S.A.) The objective of this system will be to decrease dust buildup on the filters;

Step 3: A prefiltration system (Big Dutchman, MI, U.S.A.) adapted to highly dusty conditions. The prefiltration system must capture the majority of particles that have not been removed through the ionization process. This way, the antimicrobial filter installed downstream should stay clean longer, maximizing the efficiency of antimicrobial agents within the filter fibre in inactivating pathogens;

Step 4: A filter with ten antimicrobial membrane layers whose efficiency in relation to PRRSv, influenza and mycoplasma has been evaluated by American researchers from the University of Minnesota and, in Canada, by researchers from the Université de Montréal in collaboration with the CDPQ. This step of the process aims to block and to destroy any virus possibly coming out through the fans.

1.2 Literature Review

1.2.1 Dust in Swine Barns

Dust is considered to be one of the contaminants that are found in hog barns. Dust concentration in hog barns varies greatly and depends on several factors, including the age and activity of the animals, the type of feed and feed system, the ventilation, the number of animals and the relative humidity (Vancoillie, 2004).

According to Choinière and Munroe (1993), dust is made up of both organic and inorganic substances that can be found in different shapes and sizes. Organic dust represents between 70 and 90% of the dust and is composed, among others, of dried excrement, hair, skin cells, viruses and bacteria. Inorganic dust is made up of particles from building materials.

A study carried out by Maghirang *et al.* (1997) on dust concentration and particle distribution in the nursery showed an overall average dust concentration of 0.72 mg/m³, varying from 0.12 to 2.14 mg/m³.

A French study has revealed the influence of certain factors, including the age of the hogs and the season, on dust concentration in the farrowing house, in the nursery and in growth facilities. The results demonstrated that the dust concentration was higher in the nursery, followed by the finishing barn and the farrowing house (average of 6.3 mg/m³, 3.7 mg/m³ and 2.5 mg/m³ respectively over all seasons) (Guingand, 1999).

1.2.2 Methods of On-Farm Dust Reduction and Description of the Ionization Principle

There are various methods for controlling dust inside a barn: food additives, sprinkling with water or oil, ventilation, electrostatic particle filters, negative ionization, filtration and air-washing systems (Chenard *et al.*, 2002). According to Chenard *et al.* (2002), ionization consists in introducing an electrical charge into an electrical field. The surfaces of the piece of equipment become the collecting electrode and the negatively charged particles are attracted to these surfaces. Factors such as the spatial distribution of the dust, the air movement, the dispersion of the collected particles and the thickness of the layer of accumulated particles on the surfaces will affect the effectiveness of the process. For barns with air filtering at the exhaust vent, the ionization process is worth considering because it allows for significant reduction of the concentration of airborne dust and reduces the rate of clogging in the air filtration system. In fact, the rate of filter clogging poses the main problem for installing this kind of barn given the major outlays required to maintain and upkeep such filters.

The Electrostatic Particulate Ionization (EPI) system lets the user remove a percentage of the particles present in the air using the ionization principle. According to the manufacturer, this ionization will also aid in controlling pathogens since the negative ions interfere with the cellular functioning of the microbes, with the result that several microbes are destroyed by the EPI system (EPI, 2011).

1.2.3 Effectiveness of Ionizers on Air Quality

Researchers have proven the effectiveness of dust reduction using ionization. In the field of poultry production, Mitchell *et al*. (2004) have demonstrated the effectiveness of air ionization in significantly reducing airborne dust (average reduction of 61%), ammonia (56%) and bacteria (67%). Hagen (2011) mentions that inside nursery barns equipped with an EPI system from Baumgartner Environics Inc., researchers measured a reduction of 57.7% of 10-micron particles, 47.8% of 2.5-micron particles, 43.1% of 0.05-micron particles and 55% less ammonia.

The efficiency of the EPI system was evaluated by Lopez *et al.* (2009) in a broiler chicken production. The study demonstrated that using the EPI system reduced the concentration of 10-

and 2.5-micron particles by 36% and 10% respectively, but did not, however, have any effect on microorganisms, odours or ammonia. The authors mention that the rate of reduction was far higher at the start of the growth process and that it decreased over time since dust generation increases exponentially with the growth of chickens raised on litter.

As a result, it appears that ionization can significantly reduce dust concentration in a quarantine facility and thus decrease the clogging rate of an air filtration system installed at the exhaust fans since, according to the literature, the dust emissions are less than in nursery and far less than inside a broiler chicken house.

In addition, the ionization system is worth looking into because it is easy to install, requires very little maintenance and consumes very little energy. Consumption for the present project – a 36' x 82' quarantine facility containing 108 sows – was only 103 watts. Moreover, it is affordable: $13,500 for this kind of farm building (based on a supplier's quote). It should be noted that major economies of scale can be made where larger buildings are concerned.

1.2.4 Effects of Dust and Particles on Animals and Farm Workers

According to Carpenter (1986), dust irritates the airways and this can reduce resistance to respiratory illness. The size and shape of the particles has an impact on how deeply they penetrate into the respiratory system. It is estimated that particles of more than 10 microns are stopped in the nose, those from 5 to 10 microns are stopped by the upper part of the respiratory system and those less than 5 microns get to the lungs.

1.2.5 Effectiveness of the Big Dutchman StuffNix Prefiltration System

The StuffNix prefilter is the trade name of a dust prefilter composed of a one- or two-layer accordion-style filter wall. It is currently used in European poultry barns, where the air is heavy with dust, in order to filter the air at the exhaust area. According to the manufacturer, the StuffNix separates the dust particles from the air flow using a principle of separation by centrifugal force. This is an innovation. According to Big Dutchman (2010), the StuffNix permits a total dust reduction of up to 70%. The prefilter has been adapted for dusty conditions. The design is fully made of plastic, meaning that it can be cleaned with a vacuum cleaner or broom. Its life cycle is estimated at 5 years, the cost is very reasonable (from $0.38/cfm or $6,000 for a 108-sow quarantine facility - figures based on a quote from Big Dutchman for a one-layer system), and there are no operational costs except for regular maintenance. However, the system produces some additional pressure drop to the system, which needs to be compensated by the fans to maintain the desired airflow rate. Thus, the energy consumption increases slightly.

1.2.6 Effectiveness of a Noveko Antimicrobial Air Filter System

Antimicrobial air filters, made by the Quebec company Noveko, are the final stage in a process that aims at preventing live viruses from getting outside the quarantine building in case of contamination by the PRRS virus, influenza and mycoplasma. This type of filter, with 10 layers of membranes equipped with antimicrobial agents, is installed upstream of the exhaust vents, but downstream from the StuffNix. Several studies carried out in Quebec and at the University of Minnesota have proven the efficiency of the antimicrobial filter in preventing airborne transmission of the PRRS virus, mycoplasma and influenza (Batista *et al.*, 2008, 2009; Dee *et al.*, 2011).

1.3 Objectives and Hypotheses

1.3.1 General Objective

To test an innovative biocontainment system adapted to a swine quarantine barn to prevent virus spreading into the atmosphere in case of contamination by pathogens and to test technologies that may reduce, to an acceptable level, the clogging rate of a prefilter and its antimicrobial filters installed upstream at the exhaust fans.

1.3.2 Specific Objectives

- To measure the efficiency of the EPI system in reducing dust concentration in the building's ambient air;
- To measure the efficiency of the StuffNix air prefilter and of the Noveko antimicrobial air filter to block dust particles and pathogens;
- To measure the impact of the EPI system on the clogging rate and the maintenance frequency of the StuffNix air prefilter, designed for dusty environments;
- To measure the impact of the EPI system and StuffNix air prefilter on the clogging rate and the maintenance frequency of the air filter with antimicrobial agents;
- To measure the impact of the whole process on pressure drops in the ventilation system;
- To measure the impact of the ionization and ventilation system on energy consumption;
- To define the design criteria of the EPI system, the StuffNix prefilter, the Noveko antimicrobial filter and, the ventilation system;
- To carry out a cost/benefits analysis;
- To determine the success criteria leading to the establishment of this type of process on a larger scale;
- To write a technical guide.

1.3.3 Hypotheses

The following hypotheses will be verified in the project:

- The EPI system allows a reduction of at least 50% in dust concentration as mentioned in the literature;
- The ionization system allows the user to reduce the cleaning frequency of the prefilter by half;
- The StuffNix prefilter blocks 70% of the dust as mentioned by the manufacturer;
- The resulting clogging rate of antimicrobial filters will allow for a single cleaning of the filters between each batch of gilts;
- The EPI system does not generate any stray voltage affecting the pigs;
- The process is technically and economically viable and can be reproduced on a larger scale for both existing and new buildings.

2. Methodology

2.1 Building and Animals

Trials were conducted in a quarantine area attached to the existing building of a 1,200-sow farrowing barn (Figure 1). The quarantine facility was able to accommodate up to 108 gilts. This quarantine facility is separated from the farrowing house by airtight walls and doors to prevent any personnel, material or air movements between the two sections. The exhaust fans and air filtration system were located in a 1.83 x 4.88 m room dedicated to air processing built at the end of the quarantine area. Four oversized 500-mm diameter fans (Multimax; 0.5 HP; 1640 RPM; 2.3 Amp; 230 V) provided building ventilation. Four recirculation fans (915 mm in diameter) also ensured the comfort of sows and came into operation before the third ventilation stage.

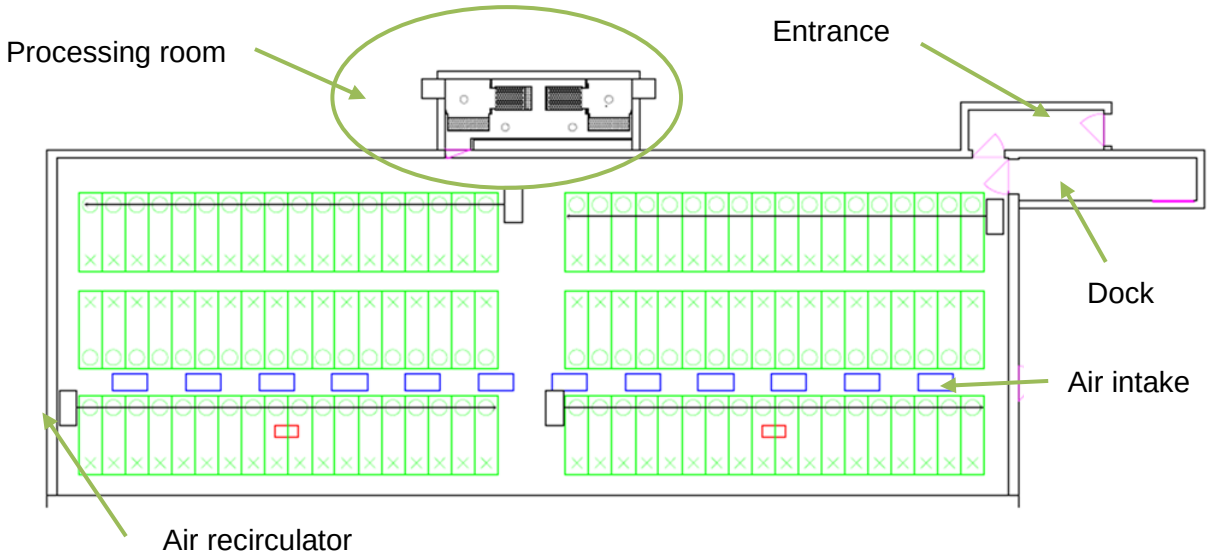

Figure 1 Layout of Quarantine Area

An ionization dust abatement system (EPI®, Baumgartner Environics, MN, U.S.A.) was installed in the quarantine area. The system was made up of a power block generating negative ions under high voltage and emits them into the air through six[1] stainless steel spiked lines (Figure 2). A winch system allowed moving the lines further away from or closer to the ceiling in order to optimize the ion production level depending on how dirty the room walls were.

[1] Twice the number of lines normally recommended by the manufacturer.

Figure 2 Ionization System Spiked Lines and Isolator

2.2 Experimental Layout

The experimental unit for this experiment represents a batch. Trials were conducted on four batches in an all-in, all-out configuration with a duration of 25 days each, except the first batch, which lasted 35 days. Two trials took place without the ionization system being in operation, and two others with the system active. The filtration system at the air intake (attic space) included Noveko prefilters and filters made up of 15 layers of filtering membranes at each air inlet. At the air outlet, in the air processing room, the system included three filtration steps: prefilters, Noveko prefilters and antimicrobial filters made up of 10 layers of filtering membranes (Figure 3). All antimicrobial filters were protected by the manufacturer's prefilter.

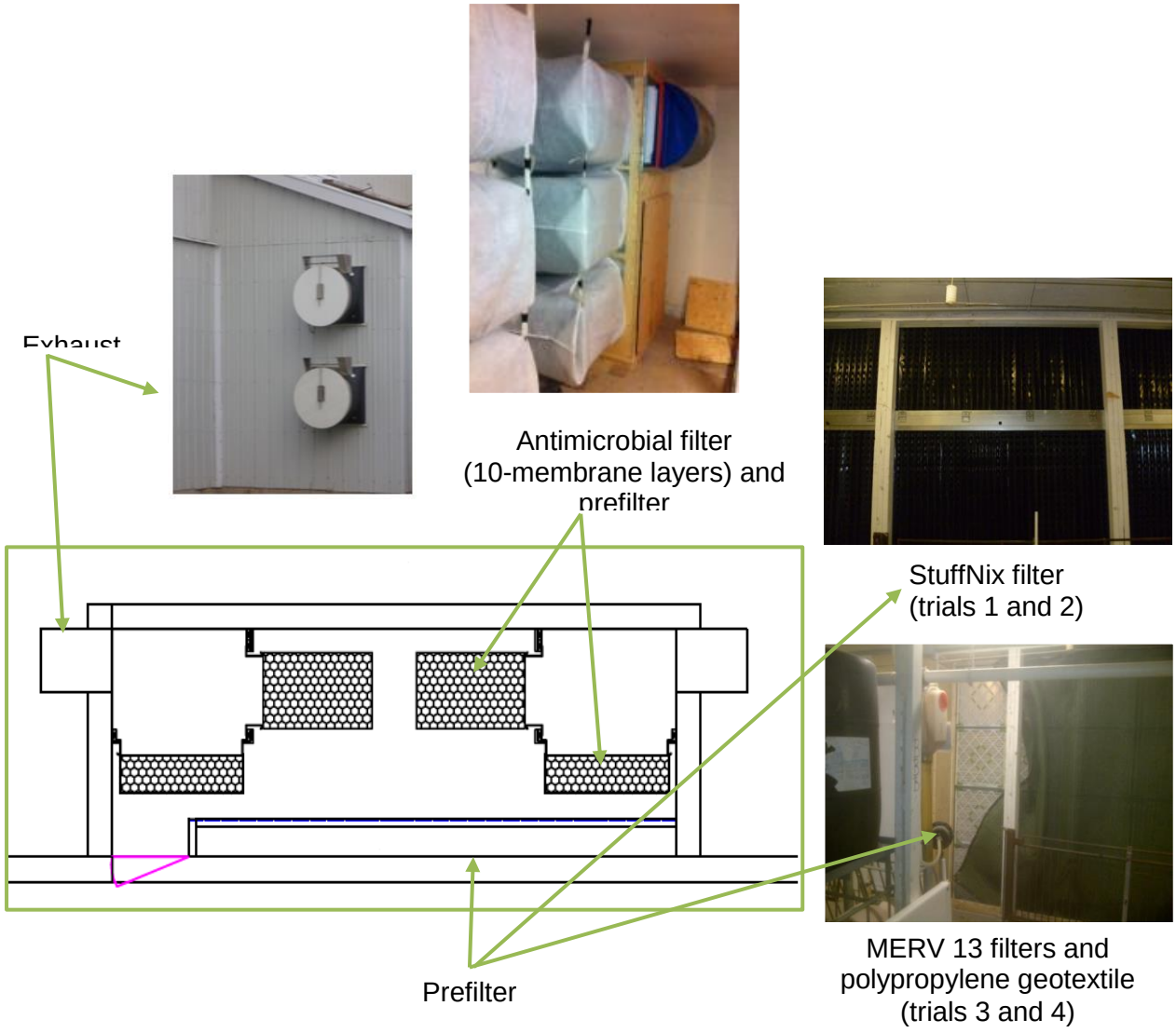

Figure 3 Air Processing Room

The StuffNix filter (Big Dutchman, Vechta, Germany) was used as a prefilter in the first two batches and was replaced with MERV 13 DP-green® folded prefilters (DP13-STD2-205, Clacor, Jefferson, IN, U.S.A.) combined with a polypropylene geotextile (Pyramat®, Proprex, Chattanooga, TN, U.S.A.) for the last two batches.

Table 1 Treatment Description

Lot	Treatment	Description	Duration
1	StuffNix with ionizer	With ionizer and StuffNix prefilter	35 days
2	StuffNix without ionizer	Without ionizer and StuffNix prefilter	25 days
3	MERV 13 with ionizer	With ionizer and DP-green® prefilter	25 days
4	MERV 13 without ionizer	Without ionizer and DP-green® prefilter	25 days

2.3 Data Gathering

2.3.1 Temperature and Static Pressure Measurements

The outdoor temperature and static pressure in the buildings were measured every ten minutes using a data acquisition system (HOBO® Energy logger pro H22, Bourne, MA, U.S.A.). A temperature probe (Onset Computer Corp., S-THB-M008) was placed outdoors and eight pressure transducers (Veris Industries, PXU, Portland, OR, U.S.A.) connected to the data acquisition system were installed in the quarantine facility to measure the pressure gradient between the following points:

1. Between the upstream and downstream of a Noveko antimicrobial filter installed at an air inlet;
2. Between the downstream of a Noveko antimicrobial filter installed at an air inlet and the inside of the room;
3. Between the room and outdoors;
4. Between the upstream and downstream of prefilters;
5. Between the upstream and downstream of Noveko antimicrobial filters on the side of ventilation stage 1;
6. Between the upstream and downstream of Noveko antimicrobial filters on the side of ventilation stage 2;
7. Between outdoors and the downstream of Noveko antimicrobial filters on the side of ventilation stage 1;
8. Between outdoors and the downstream of Noveko antimicrobial filters on the side of ventilation stage 2.

The indoor temperature was recorded every ten minutes using two data acquisition devices (HOBO® Energy logger U10-003, Onset, Bourne, MA, U.S.A.)

2.3.2 Fan Voltage Measurement

The electrical voltage of each fan was measured using voltage transducers (Onset Computer Corp., T-MAG-SPT-300) connected to the terminals of the fan's electronic board.

2.3.3 Airflow Rate Calculation

The airflow rate of the fans was determined based on the voltage (rotational speed) and static pressure at the fan. The static pressures at the fans taken through pressure probes could not be used. As a result, they were determined by adding the following four pressures: upstreams of the Noveko filter located at the air intake, at the air intake, at the prefilters and at the Noveko exhaust filters. An airflow rate prediction curve according to the speed of fans and static pressure was established before fans were installed in the quarantine facility. To this end, a fan was calibrated for different speed percentages and according to different static pressures on a test bench.

2.3.4 Design Validation

The ventilation system design was accomplished to have a maximum temperature differential of 3°C in warm period for 165-kg gilts. In order to validate that the quarantine room temperature did not exceed the outdoor temperature by 3°C, the differential between the temperature measured by the outdoor probe and the mean of the two indoor probes during trial 1 was evaluated. This differential was calculated for indoor temperatures above the desired temperature (18.9°C) and for temperatures under 24.4°C, i.e., before recirculation fans come into operation.

2.3.5 Stray Voltages

In order to make sure that the ionization system does not cause any stray voltages likely to disturb sows, an expert evaluation was performed. According to the expert's report, the level of stray voltage was not affected by the operation of the ionization system. The average and maximum daily voltage levels remained the same whether the system was operating or not. He recommends, however, that the EPI line be insulated (using the insulating tube supplied by the manufacturer) when the distance between the latter and metal structures is lower than 12 in.

2.3.6 Total Dust and Bacteria Concentrations

Total dust was sampled once a week on three different sampling sites: inside the building (before the filters), between the prefilter and the Noveko antimicrobial filter, and after the Noveko antimicrobial filter. At each sampling site, total dust was collected in triplicate using a preweighed 37-mm polyvinyl chloride (PVC) filter (pore size 0.8 µm, SKC Inc., Eighty Four, PA, U.S.A.) or a polycarbonate (PC) filter (pore size 0.8 µm, SKC Inc.) housed in a closed-face cassette (SKC Inc.) with a Gilian GilAir5 Tri-Mode Air Sampling pump (Sensidyne, LP, Clearwater, FL, U.S.A.) calibrated at 2 L/min (DryCal DC-2 flowmeter, Bios International Corp., Butler, NJ, U.S.A.) Sampling was done for 8 hours. The PVC filters were then weighed in a controlled chamber (temperature and relative humidity). Total dust concentrations were expressed as milligrams of total dust per cubic meter of air.

Total dust was extracted from PC filters in order to quantify total bacteria by PCR. PC filters were first suspended in 5 mL sterile salt solution containing 0.025% Tween 20. Suspensions were then mixed with a Multi-Pulse Vortexer (Glas-Col, Terre Haute, IN, U.S.A.) for 15 minutes at room temperature. Total DNA was extracted from 1.5 mL of the suspensions using the QIAamp DNA Mini kit (QIAGEN, Mississauga, ON, Canada) according to the manufacturer's instructions for tissue with the required modifications for bacteria. The 16S rDNA of eubacteria were quantified by PCR with the FP 16S rDNA (5'-GGTAGTCYAYGCMSTAAACG-3') and RP 16S rDNA (5'-GACARCCATGCASCACCTG-3') primers and the TaqMan probe 16S rDNA (FAM-TKCGCGTTGCDTCGAATTAAWCCAC-TAMRA) located at nucleotide 799, 1044, and 951 (*E. coli* numbering), respectively, as published by Bach and colleagues (Bach *et al.*, 2002). Amplifications were carried out with the DNA Engine Opticon 2 system (Bio-Rad, Hercules, CA, U.S.A.) Quantification was done with a standard curve of *E. coli* genomic DNA preparation. Data were acquired with the Opticon Monitor software (version 2.02.24) and analyzed by linear regression of the log10(target number copy) = f(Threshold Cycle) function. PCR efficiencies were determined using $E = 10^{(-slope)}-1$. Total bacteria concentrations were expressed as total bacteria per cubic meter of air.

In parallel with dust sampling, air particles with a diameter of 0.3, 0.5, 1, 3, 5 and 10 µm were counted using a Particle Counter Model 3315 (Met One, Loveland, CO, U.S.A.) on three different sites: inside the building (upstream of the filtration system), between the prefilter and the Noveko antimicrobial filter, and downstream of the Noveko antimicrobial filter. Airborne particles were counted once a week at a rate of 28.3 L/min for 5 minutes (141.5 L of air sampled).

2.3.6.1 Statistical Analyses

The continuous data were expressed using mean ± standard deviation. Bacteria count and particles sizes measured in the air without any filter were analysed using a two-way statistical design with interaction factors to compare conditions (filter A vs. filter B) associated with and without EPI. Measurements were log10 transformed to stabilize variances. Dust data were analyzed using two statistical approaches as some measures were censored: survival analysis methods using a normal distribution as well as nonparametric methods using ranks were applied. Both methods gave similar results.

For analyses in which filters (3 levels: without prefilter and filter) were included in the statistical models, a three-factor ANOVA was performed with interaction terms using the approaches mentioned above. *A posteriori* comparisons were made using contrasts. The results were considered significant with p-values < 0.05. All analyses were performed using the statistical software package SAS version 9.3 (SAS Institute Inc., Cary, NC, U.S.A.)

3. Results and Discussion

3.1 Environmental Conditions

3.1.1 Design Validation of the Ventilation System – Air Filtration

Within the framework of this project, the design of the low-flow ventilation system was validated to check the temperature variation between the inside and the outside of the room depending on the airflow rate present. The initial objective was to have a variation less than 3°C for outdoor temperatures between 19 and 24.4°C, i.e., when only the fans of ventilation stages 1 and 2 were operating. By way of example, if the outdoor temperature was 19°C, the objective was to ventilate enough to keep the indoor temperature below 22°C. The fans of ventilation stages 1 and 2 at maximum speed delivered 11,250 CFM at 0.2 in wg of static pressure, which corresponded to a flow rate reduced to 104 CFM per gilt, while the conventional ventilation flow rate is about 180 to 200 cfm/gilt in the summer. From 20.3°C, the exhaust fans of ventilation stages 1 and 2 were operating at full capacity and the recirculation fans, of the on/off type, were not yet operating, like the two fans of ventilation stage 3. Thus, during trial 1, 71% of the temperatures recorded in the room exceeded the outdoor temperature by 3°C when the latter was between 18.9 and 24.4°C. In 64.5% of the time, the variation was between 3 and 6°C and in 6.9% of the time between 6 and 9°C, which is too high in the latter case (Table 2). The largest variations were observed between 22 and 24.4°C. However, the sows do not seem to have been uncomfortable during the project. Since recirculation fans reduce the temperature felt by the animals by 6°C due to the speed of the air, they could not be started earlier as the temperature felt would have been below the desired temperature.

Table 2 Frequency of Occurrence (%) of Temperature Variations (ΔT) Between Indoor and Outdoor Temperature During Trial 1

Outdoor temperature, °C	Temperature variation, °C			
	-3 to 0	0 to 3	3 to 6	6 to 9
≥ 18.9 - <20	**0.0%**	**1.2%**	**20.8%**	**5.2%**
≥ 20 - <22	0.4%	6.9%	25.6%	1.7%
≥ 22 - <24.4	2.0%	18.1%	18.1%	0.1%
Total	**2.4%**	**26.2%**	**64.5%**	**6.9%**

It is noteworthy that from an indoor temperature of 24.4°C, the recirculation fans came into operation to cool down the animals and for security reasons, a third variable-flow ventilation stage came into operation when the indoor temperature reached 29°C. The maximum flow rate thus amounted to 205 cfm per gilt (conventional ventilation rate). The idea was to operate the third ventilation stage as little as possible in order to reduce the filter clogging rate and pressure drop.

Several parameters can explain the variations of more than 3°C. Besides the accuracy of measuring equipment, filter and prefilter clogging can lead to a loss of efficiency of fans, and thus to increased temperatures in the room. The accuracy of the prediction equation of the heat released by the animals and the weight considered for the calculations that were used to design the ventilation system can also be questioned. Indeed, the heat balance performed to determine the ventilation need was made for 165-kg gilts due to be covered while, during the trials, sows were pregnant and heavier (about 200 kg) and must have released more heat. Also, the heat production from the animals was considered based on calm animals, while it increases significantly when animals become restless, for example during the feeding period.

3.1.2 Outdoor Temperature

The outdoor temperature was higher during the two trials conducted in the summer using the StuffNix prefilters as compared with the trials conducted during the autumn using the MERV 13 prefilters. Therefore, it is difficult to compare the two types of prefilters as regards the clogging rate of the air filtration system.

During the two trials conducted in the summer using the StuffNix prefilter, temperatures generally remained between 20 and 30°C (Figure 4). After 25 days, the total amount of filtered air was similar with a variation of only 9% (11.83 vs. 10.74 million m³ of air, Figure 5). This allows evaluating the efficiency of the ionization system and the clogging rate of the air filtration system at the exhaust fans.

As for the two trials conducted in the autumn using the MERV 13 prefilters, the total amount of filtered air was 1.9 times higher in the trial with the ionizer than without the ionizer (2.68 vs. 5.02 million m³ of air, Figure 5), which makes it difficult to compare these last two trials.

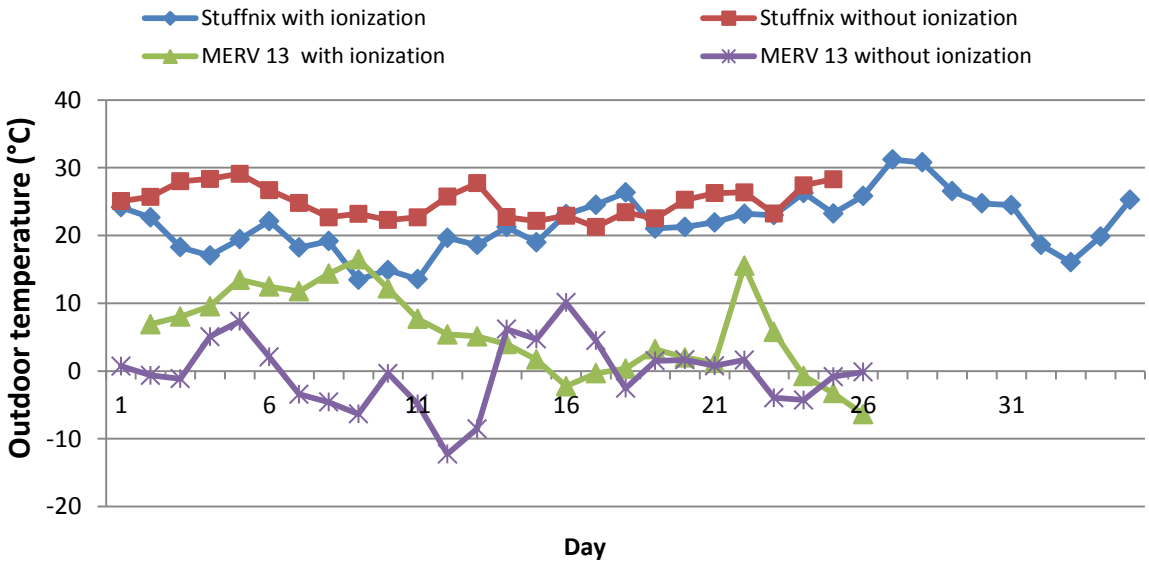

Figure 4 Evolution of Mean Outdoor Temperature During Trials

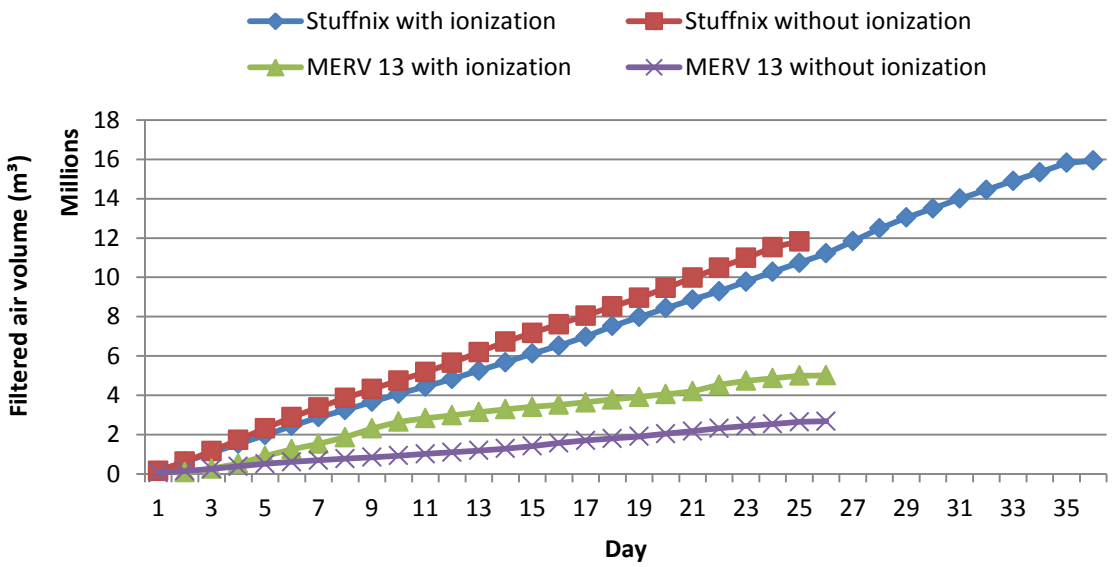

Figure 5 Cumulative Volume of Filtered Air at Exhaust Fans as per the Trial

3.2 Dust and Bacteria

The ionization system was able to reduce particles of different sizes by 43 to 60% (Table 3). The reductions associated with 10, 5, 3 and 1-µm particles ($p < 0.0011$) were more significant than those for 0.5 and 0.3-µm particles. Globally, there were 33,852 particles/L of air and 18,021 particles following the activation of the ionization system. The lowest percentage of reduction was associated with 0.3-µm particles that are the most difficult particles to capture by filtration ($p = 0.0389$, CDC, 2009). Our results are similar to those obtained by Hagen (2011) in nurseries and the observed reduction for 0.05-µm particles is even higher (60% vs. 43%).

Table 3 Reduction of Particles by the Ionization System

Particle sizes	With ionizer (particles/L)		Without ionizer (particles/L)		Reduction, %*	*P*
	Mean	SD	Mean	SD		
0.3 µm	15,053.0	11,731.4	26,501.8	9,752.7	43	0.0389
0.5 µm	1,462.9	663.6	3,674.9	1,780.9	60	0.0018
1 µm	939.9	292.6	2,226.1	1,660.8	58	0.0003
3 µm	268.6	78.4	658.7	561.8	59	0.0006
5 µm	245.2	70.0	578.8	486.2	58	0.0011
10 µm	86.2	28.6	215.5	164.0	60	0.0009
Total	18,021.2	12,296.8	33,851.6	10,812.7	47	0.0135

*The percentage of reduction = [(particle number in the building without the ionization system - particle number in the building with the ionization system) / particle number in the building without the ionization system] X 100

The ionization system was able to reduce total dust ($p < 0.05$) and bacteria[2] ($p < 0.05$) in the building (Table 4). Our results are similar to those of Mitchell *et al.* (2004).

Table 4 Reduction of total dust and bacteria concentrations by the ionization system

Parameters	With ionizer		Without ionizer		Reduction, %*	*P*
	Mean	SD	Mean	SD		
Total dust (mg/m³)	0.062653	0.000571	0.172811	0.082053	64	0.0079
Total bacteria (bacteria/m³)	2.18E+07	1.14E+07	1.27E+08	1.11E+08	83	0.0005

The StuffNix prefilter was able to slightly reduce total dust by 29 to 38% (Table 5), which is less than the 70% efficiency claimed by the manufacturer. The prefilter also reduces particles of different sizes by 3 to 39%. This prefilter seems to be adapted for dust of more than 5 to 10 µm. As for total bacteria, this prefilter did not generate a significant reduction with only 6 to 9% achieved. Dust concentrations in the building were low and the StuffNix prefilter, which has been developed for dusty environments like in poultry production, was not suitable for our building. The StuffNix prefilter was then replaced with a MERV13 prefilter for the next batches even if pressures remained acceptable with the StuffNix prefilter. We also wanted to reduce the risk of contamination for the farrowing barn located next to the studied building. Our objective was to keep the antimicrobial filter as clean as possible to allow antimicrobial products located in the fibers to act on microorganisms.

Table 5 Reduction of Total Dust and Bacteria Concentrations and Number of Particles by the Prefilter and the Noveko Antimicrobial Filter

Parameters	Sampling Sites	Batches			
		1	2	3	4
Total Dust (mg/m³)	Building	0.063057	0.114791	0.062249	0.230831
	After the prefilter	0.044957	0.070827	0.032846	0.046810
	Reduction, %	29	38	47	80
	After the filter	0.036430	0.019991	0.023833	0.021832
	Reduction, %	42	83	62	91
Total Bacteria (bacteria/m³)	Building	2.35E+07	3.70E+07	2.02E+07	2.16E+08
	After the prefilter	2.21E+07	3.37E+07	2.18E+06	7.71E+06
	Reduction, %	6	9	89	96
	After the filter	3.73E+06	6.66E+06	7.64E+05	4.21E+06
	Reduction, %	84	82	96	98
0.3 µm (nb)	Building	1.65E+04	2.73E+04	1.35E+04	2.56E+04
	After the prefilter	1.58E+04	2.64E+04	1.53E+03	9.47E+03
	Reduction, %	4	3	89	63
	After the filter	1.20E+04	2.47E+04	**7.94E+05***	**1.19E+04**
	Reduction, %	27	10	58	54
0.5 µm (nb)	Building	1.46E+03	2.57E+03	1.46E+03	4.77E+03
	After the prefilter	1.33E+03	2.28E+03	1.07E+02	9.12E+02
	Reduction, %	10	12	93	81
	After the filter	1.12E+03	2.17E+03	4.84E+02	9.68E+02
	Reduction, %	24	16	67	80
1 µm (nb)	Building	9.40E+02	1.03E+03	9.47E+02	3.42E+03
	After the prefilter	8.27E+02	9.75E+02	6.14E+01	4.37E+02
	Reduction, %	12	5	94	87
	After the filter	7.70E+02	9.96E+02	2.86E+02	3.84E+02

Parameters	Sampling Sites	Batches			
		1	2	3	4
	Reduction, %	18	3	70	89
3 µm (nb)	Building	2.77E+02	2.83E+02	2.61E+02	1.03E+03
	After the prefilter	1.17E-02	1.93E+00	1.11E-01	8.19E-01
	Reduction, %	16	3	94	89
	After the filter	1.96E+02	2.37E+02	7.14E+01	8.62E+01
	Reduction, %	29	16	73	92
5 µm (nb)	Building	2.69E+02	2.52E+02	2.22E+02	9.05E+02
	After the prefilter	1.92E+02	2.19E+02	1.28E+01	9.40E+01
	Reduction, %	28	13	94	90
	After the filter	1.30E+02	1.75E+02	4.80E+01	5.40E+01
	Reduction, %	52	31	78	94
10 µm (nb)	Building	9.54E+01	1.08E+02	7.63E+01	3.22E+02
	After the prefilter	5.82E+01	7.63E+01	4.09E+00	2.53E+01
	Reduction, %	39	29	95	92
	After the filter	2.30E+01	9.61E+01	1.29E+01	8.41E+00
	Reduction, %	76	11	83	97
0.3-10 µm (nb)	Building	1.96E+04	3.16E+04	1.65E+04	3.60E+04
	After the prefilter	1.85E+04	3.02E+04	1.74E+03	1.10E+04
	Reduction, %	5	4	89	69
	After the filter	1.43E+04	2.83E+04	6.51E+03	1.34E+04
	Reduction, %	27	10	60	63

* Values in red indicate a concentration increase after the filter as compared with after the prefilter.

The MERV13 prefilter was able to reduce dust concentrations by 47 to 80% (Table 3). This prefilter allowed reducing the amount of air particles ranging from 0.5 to 10 microns by 81 to 96% and 0.3-micron particles by 63%. This is in line with expected results. The MERV13 was then more efficient than the StuffNix prefilter to diminish 1 to 10-µm particles and total bacteria concentrations ($p < 0.05$). However, 0.3-µm ($p = 0.29$) and 0.5-µm ($p = 0.2$) particles, and total dust concentrations ($p = 0.08$) were not more efficiently reduced by the MERV13 than by the StuffNix despite the major numerical difference. The combination of the MERV13 prefilter and the Noveko antimicrobial filter was able to capture from 54 to 98% of particles and 96 to 98% of bacteria. These combinations also reduced the total dust by 62 to 91%. In the 3rd and 4th batches, we observed a re-emission of 0.3-µm and 0.5-µm particles from the filter. A re-emission of 1, 3, 5 and 10-µm particles was also observed in the 3rd batch. The re-emission of particles from the filter was shown from the use of the efficient MERV13 prefilter (in the 3rd and 4th batches) and the ionization system (3rd vs. 4th batches). This re-emission phenomenon can be explained by the fact that the antimicrobial filters may have not been cleaned thoroughly between trials, as the same filters were used during the four trials. Only the prefilters placed directly on antimicrobial filters were changed between trials.

3.3 Static Pressure

The pressure gradient between the upstream and downstream of the StuffNix prefilter varied very little with time, and this with or without an ionization system in operation (Figure 6). The pressure gradient varied between 0.09 and 0.18 in wg depending on the airflow rate. Therefore, the prefilter did not clog up. However, the antimicrobial filters did clog up, which was unacceptable.

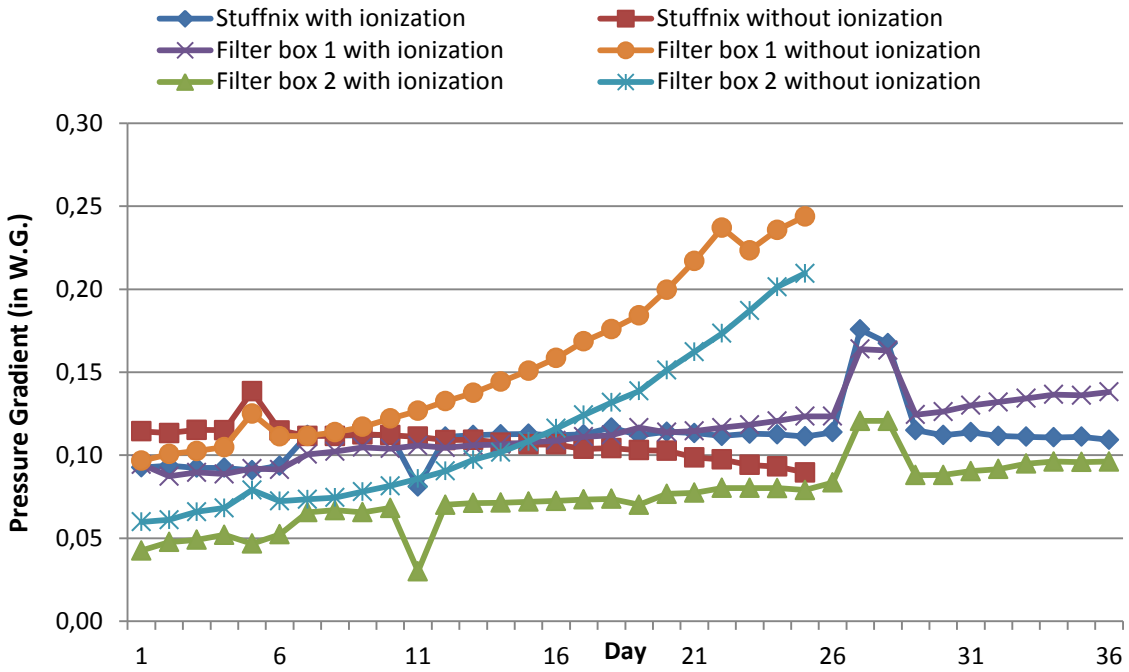

Figure 6 Evolution of Pressure Gradient Between the Upstream and Downstream of the StuffNix and Between the Upstream and Downstream of Antimicrobial Filters at the Exhaust Vent (trials 1 and 2)

Indeed, the pressure gradient at the antimicrobial filters increased gradually with time in the presence of the ionization system while it increased more rapidly without the ionization system. With or without ionization, on the side of the filters of ventilation stage 2, the pressure differential was about 0.04 to 0.05 in wg lower than that of stage 1. Therefore, the filters on the side of ventilation stage 2 were less dirty, which is logical since fans on this side operate less often than those on the side of stage 1.

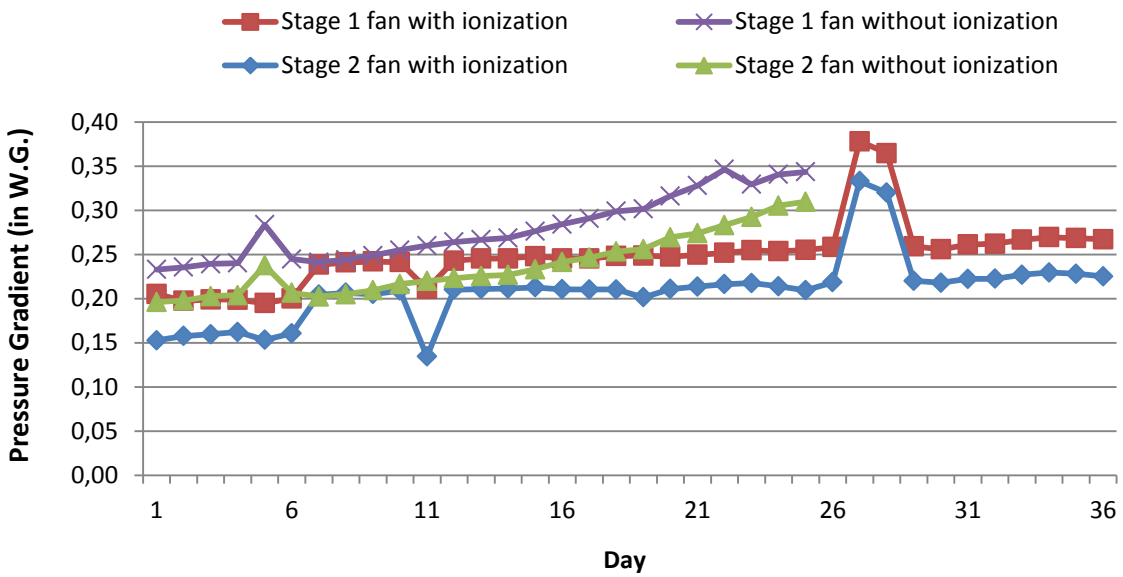

Figure 7 Evolution of Pressure Gradient Between the Upstream and Downstream of Exhaust Fans (trials 1 and 2)

Globally, during the two trials with the StuffNix prefilter, the pressure at the fans always remained below 0.50 in wg, which is the maximum acceptable pressure according to the fan specifications (Figure 7). According to a linear regression analysis, before reaching this differential pressure, the volume of filtered air would be 1.7 times higher in the presence of the ionization system than without it. Therefore, the ionization system would have allowed reducing the cleaning frequency of the filters and prefilters by nearly half.

During the two trials with the MERV 13 prefilters, the fans on the side of ventilation stage 2 operated very little, if any. The pressure at these filters remained steady around 0.01 in wg, except during three heat peaks during the trial with the ionization system (Figure 8). It should be noted that the pressure should have been null and it is slightly positive due to the zeroing of the acquisition device. During the three heat peaks, the pressure gradient at the prefilter and antimicrobial filters on the side of stage 1 increased. The remainder of the time, the pressure gradient at the MERV 13 prefilters remained relatively steady around 0.03 in H_2O, while that at the antimicrobial filters on the side of stage 1 fluctuated more depending on the temperature (Figure 6 and Figure 2). The higher pressure gradient at the prefilters and filters with the ionization system at trial 3 as compared with trial 4 without ionization is explained by the higher ventilation rate generated by a warmer outdoor temperature. Since the pressure gradient increased very little in the autumn during trials 3 and 4, this indicates that the MERV 13 prefilters, in autumn conditions, could be used in several breeding facilities on condition that no health concerns were observed in the facility. This would result in a substantial reduction of operating costs. All of this will need to be validated during the warm season.

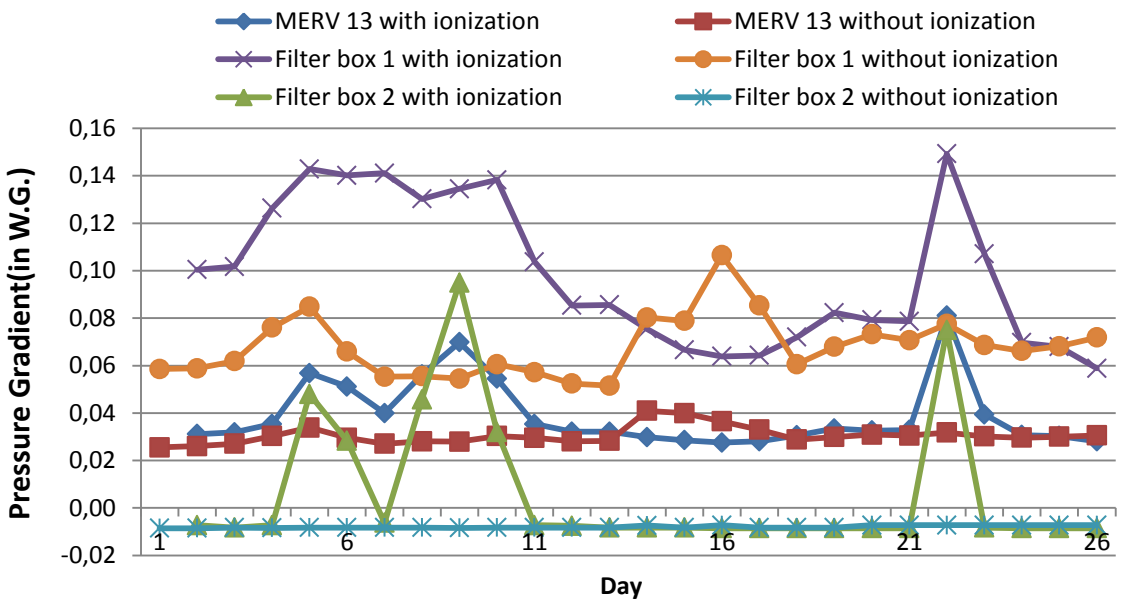

Figure 8 Evolution of Pressure Gradient Between the Upstream and Downstream of MERV 13 Prefilters and Between the Upstream and Downstream of Antimicrobial Filters at the Exhaust Vent (trials 3 and 4)

The differential pressures between the upstream and downstream of fans evolved depending on the outdoor temperature rather than the clogging rate, since the ventilation system was not operating at full capacity (Figure 9 and Figure 4). The fans of stage 3 never came into operation, while those of stage 2 operated from time to time depending on outdoor temperature peaks, which explains the pressure peaks during the trials with the MERV 13 prefilter. The pressure gradient was never problematic during the two trials with the MERV 13 prefilter conducted in the autumn. It remained nearly all the time below 0.25 in wg, while the system was designed for a pressure of 0.50 in wg. Therefore, no maintenance of the air filtration system was necessary during the trials. However, trials will be required in the summer to validate the impact on the clogging rate and the pressure gradient. It is possible that filters need to be changed in the summer, as the pressure gradient at the fans is 0.45 in wg with new prefilters and filters when all ventilation stages are in operation. There remains then about only 0.05 to 0.20 in wg of autonomy as regards clogging, which remains to be validated. However, on the face of it, this does not seem to be a problem. Thus, the power of the fans seems to be adequate. The motor power was oversized and the impellers were adapted accordingly, while keeping a fan design as typically used in the industry.

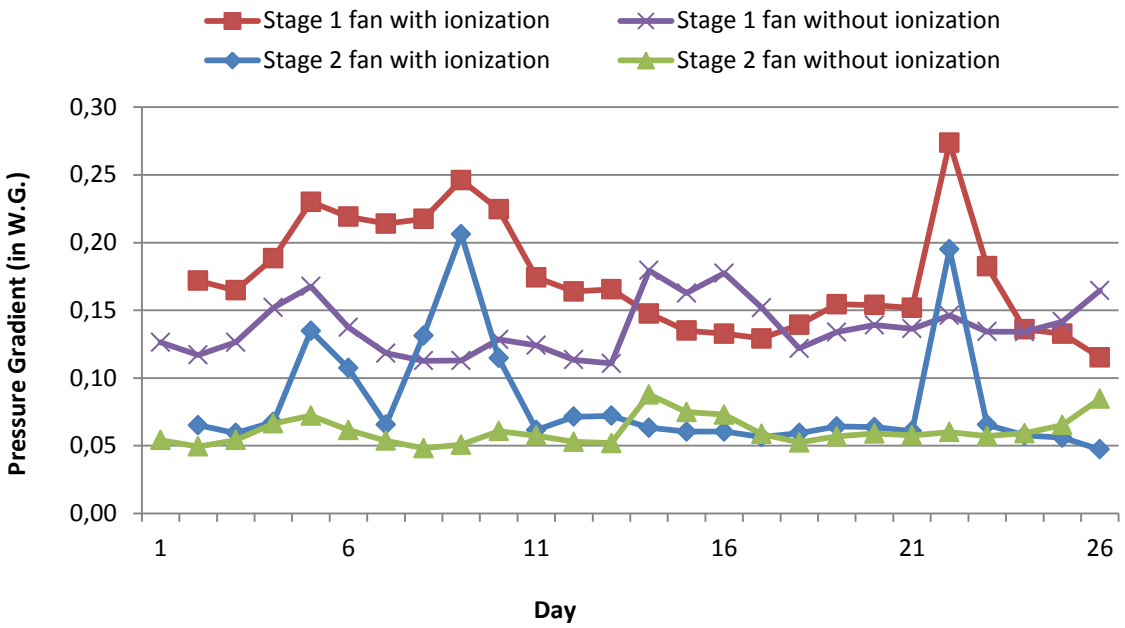

Figure 9 Evolution of Pressure Gradient Between the Upstream and Downstream of Exhaust Fans During Trials 3 and 4 Using MERV 13 Prefilters

4. Economic Analysis

The economic analysis of this quarantine biocontainment system will mainly focus on two questions: additional costs and construction savings. Several cost elements are similar both for attached quarantine facilities under filtered air and remote, unfiltered ones. This includes, for example, the fans or the lighting system. Major expenses are related to filters ($10,050), prefilters ($1,250), the ionization system ($18,700), labour cost ($5,775) and hardware ($625). In total, the filtration and ionization systems result in additional costs of $36,400 for the construction of the quarantine facility.

However, the addition of the air filtration system coupled to an ionizer made it possible to attach the quarantine facility to the farrowing barn. This proximity generates construction cost savings as compared with a quarantine facility that would be built at a distance from the farrowing barn (Table6), e.g., 100 metres away. Indeed, a remote quarantine facility would require additional infrastructure and equipment, whereas integrating the quarantine facility to the main building allows sharing them.

Table6 List of Possible Additional Costs for the Construction of a Quarantine Facility 100 m Distant From the Farrowing Barn

Type of Expense	Estimated Cost
Access path ($107/m², 100 m passage)	$15,000
Electric line ($56/m, along 100 m)	$5,600
Service box	$2,500
Shaft ($20/ft at 500 ft depth + infrastructure)	$10,000
Temporary manure storage	$4,000
Pump	$2,500
Total	**$39,600**

Sources: Francis Pouliot, Eng. CDPQ and Christopher Robitaille, Jr. Eng., personal communications, 2013

Depending on the case, these costs can vary. Among others, the distance between the road and the quarantine facility will affect the cost of the access path and electric line. Also, the presence of existing buildings that can be converted into quarantine facilities could reduce renovation costs. Knowing that the PRRSv can travel up to 9.2 km, one may question the need to filter the exhaust air of quarantine facilities located in the vicinity of farrowing barns (e.g., about 100 to 500 m and maybe more), which would, from an economic perspective, lead to opt for attaching the quarantine facility to the farrowing barn.

In spite of everything, the above-mentioned elements represent costs of $39,600 for the remote facility, which is higher than the cost of the attached quarantine facility ($36,400). Other savings might, however, be considered. Among other things, in the case of the construction of a farrowing barn, attaching a quarantine facility to the main building would enable economies of scale during the construction, the largest being the cost of the concrete for the foundation of the quarantine facility, which would be integrated to the cost of the concrete of the farrowing barn.

In addition, integrating a quarantine facility to the farrowing barn offers the advantage of reducing transportation costs (no transport trailer, no fuel) and the work time (transportation, cleaning of the trailer). It is also interesting to note that an attached quarantine facility can ultimately be used as a gestation room if required.

4.1 Discussion

Even if the installation costs of filtration and ionization systems for a quarantine facility attached to the farrowing barn can be offset by savings as compared with a remote quarantine facility, the difference remains very small (a little more than $3,000). Considering that the situation varies between each farrowing barn (physical location, building plan, etc.), each quarantine facility project will be different. This implies that the net profit between additional costs and the savings for projects with and without filtration may sometimes be negative.

The main issue when deciding to filter the quarantine facility or not, whether it is attached to or remote from the farrowing barn, will not be the filtration cost but rather the risk of contamination by the PRRS virus that replacement gilts represent to the herd of sows from the farrowing barn. The higher the risk that gilts will excrete the virus in a quarantine facility[2] and that there will be airborne contamination in the farrowing barn, the more quarantine filtration will be appropriate. Therefore, air filtration might be appropriate for a quarantine facility remote from the farrowing barn, especially if it is poorly located with respect to prevailing winds. Knowing that the PRRSv can travel up to 9.2 km, one must question the need to filter the exhaust air of quarantine facilities located in the vicinity of farrowing barns, which would, from an economic perspective, lead to opt for attaching the quarantine facility to the farrowing barn. The filtration cost of the quarantine facility must then be compared with the costs of a PRRS outbreak in a farrowing barn. During a recent study conducted in 78 farrowing houses in Canada (Quebec, Ontario, Alberta), the median number of piglets weaned per sow for PRRS-free farrowing houses was 24.7 piglets vs. 23.8 piglets for PRRS-positive farrowing houses for the period of April 2010 to March 2012 (Klopfenstein *et al.*, 2013). However, for companies with serious health problems, median productivity was only 22.0 piglets per sow per year vs. 25.9 for well-performing companies.

Thus, the introduction of a health problem into the herd of sows can have serious consequences on herd productivity, with 1 to practically 4 weaned piglets less per year, according to the initial situation of the herd. Based on a price of $35 per piglet, this represents a loss of revenue of $35 to nearly $140 per sow, excluding the loss related to sow mortality, additional veterinary costs or a possible eradication.

[2] Either because gilts were carrying the virus upon their arrival in the quarantine facility or because they were contaminated during the quarantine period.

5. Recommendations

With the use of antimicrobial filters, the present project has demonstrated the importance of using an efficient prefilter so that antimicrobial filters remain effective in inactivating pathogens and considering that they are not easily maintained. The aspiration of particles using an aspirator does not allow removing all dust from antimicrobial filters. Water cleaning is required. However, the use of an ionization system should allow reducing the maintenance frequency by nearly half. In this project, the number of lines of the ionization system was doubled as compared with the manufacturer's recommendation. For the time being, as a precaution, we should continue in the same direction when this system is combined with an air filtration system installed at tPhe exhaust fans. However, the results achieved during this project do not allow establishing maintenance frequencies for filters and prefilters as there were little repetitions and no trials with the MERV 13 prefilters during the warm season, when airflow rates are higher. Nonetheless, based on the results obtained in the autumn, it seems that the MERV 13 prefilters can be used on more than one breeding batch when the filters and prefilters are no longer used following the quarantine period, due to the airflow deviation, but this remains to be validated in a subsequent project.

During the warm season, special attention will be required to pressures and the clogging rate, as the biocontainment concept tested generates a pressure drop at the fans of 0.45 in wg when the MERV 13 prefilters and antimicrobial filters are new and all fans are in operation. Therefore, there will be less leeway in the summer. The biocontainment system was designed for a pressure gradient of 0.50 in wg at the fans but these can tolerate up to 0.60 in wg. In the summer, the MERV 13 prefilters can clog up more quickly as there seems that the ionization system is less effective in reducing dust content in the air during such period. To minimize the handling of prefilters and filters in the presence of animals, an air bypass system could be put in place to stop filtering the air, but this only once the adequate health status of gilts has been confirmed.

According to the results obtained during the design validation of the ventilation system, the following are the main recommendations:

- The ventilation system must be designed based on housing pregnant sows, and not only gilts due to be covered (increased airflow), in order to provide more flexibility to this room;
- Install a third ventilation stage that allows reaching the conventional airflow for pregnant sows and keeping flexibility, at a reasonable cost, when the pressure drop across filters increases with clogging. The producer will then have the possibility to adjust the start-up temperature of this ventilation stage depending on the type of animal housed and the need to filter the air;
- Design the filtration system at the exhaust vent according to a low-flow ventilation strategy and oversize the power of fans in order to be able to increase the airflow rate if required. In the present case, the 20-inch fans were equipped with 0.5 HP motors instead of 0.3 HP and the impellers were selected accordingly, providing good results at a reasonable cost. It should be noted that for animals that have been confirmed to have an adequate health status, the filter and prefilter system can then be bypassed without filtering the air at the exhaust fans;
- Design the air filtration system at the air inlet based on a conventional ventilation rate;
- Use low-speed recirculation fans to let them start at a lower indoor temperature;

- Validate the interest of letting the third ventilation stage start before starting the air recirculation fans in order to reduce the temperature in the room, which may, however, increase the filter clogging speed;
- Validate the interest of delaying the use of recirculation fans in favour of starting the fans of stage-3 fans as compared with the efficiency of the ionization system in reducing the amount of dust contained in the air, thus reducing turbulence in the room.

One question remains: despite the high proportion of dust and bacteria removed from the air coming out of the room, does the biocontainment system sufficiently reduce the number of particles evacuated to avoid contaminating the farrowing section in case of airborne disease? In a subsequent project, it will be important to conduct trials by using bacterial viruses mimicking the PRRSv in order to validate excretion through the fans. In addition, it would be very relevant to evaluate the impact of the ionization system on virus survival in the air. To reduce costs without affecting the performance too much, it would also be appropriate to validate the interest of reducing the number of spiked lines in the ionization system. Finally, projects aimed at determining on which sizes of particles the PRRSv and other airborne pathogens travel will allow to better define the air filtration level to recommend depending on the risk.

With regards to biosecurity, it is important to comply with the daily protocol set up with the veterinarian and to always consider the gilts as being infectious until confirmation of their status is obtained. The biosecurity protocol in place during the trials is presented by way of example as Appendix A. Any company that wishes to install a biocontainment system in a quarantine facility attached to the farrowing barn should discuss with the treating veterinarian in order to set up an individual protocol and make sure that the latter is specifically adapted to the farm. It is also important to have an exit protocol for gilts should these be PRRS-positive, in order not to contaminate the sows of the farrowing barn. An evacuation procedure sample is provided in Appendix B.

6. Conclusion

This project made it possible to successfully test an innovative biocontainment system adapted to a porcine quarantine facility to reduce the risk of airborne virus spread in case of contamination by pathogens. The biocontainment system tested does not generate large savings as regards installation costs in comparison with a quarantine facility built very close to the farrowing barn (less than 500 m), except if the air coming out of quarantine facilities built in close proximity to the farrowing barns must also be filtered.

The ionization system was in line with the expectations set out at project start-up. However, the StuffNix® prefilter did not achieve expected results and had to be replaced with prefilters (MERV-13, folded), which proved more effective in retaining dust and bacteria from the quarantine area. This in order not to overload the antimicrobial filters and to maximize the antimicrobial action of said filters. The MERV 13 prefilters were used only during the trials conducted in the autumn, when the ventilation rate was lower. Other trials will need to be done in the summer. Also, with a view to reducing costs without affecting the performance too much, it would be appropriate to validate the interest of reducing the number of spiked lines in the ionization system. It would also be beneficial to experiment other types of prefilters to achieve the best possible combination in terms of efficiency and cost. Solutions for bypassing the air and stopping filtering it following confirmation of the health status of gilts should also be developed and tested. Trials with biological agents simulating viruses will need to be carried out to evaluate the efficiency of the concept in preventing virus release at the exhaust fans in the case of an outbreak, this to determine if the air filtration level is appropriate and establish whether improvements are required. In this project, the efficiency of the system was evaluated based on dust and bacteria.

By way of conclusion, the present project helped demonstrate that it is possible to filter the air at the exhaust fans of a building used as a quarantine area, and this at an interesting cost and level of efficiency, without causing major clogging problems in the air filtration system. Considering it was a pilot project, other trials will be required in the future to continue to validate and improve the concept.

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Appendix A

Biosecurity Protocol of Quarantine Facility Until Introduction of Gilts into the Herd

Quarantine Facility Attached to the Main Building and With Air Filtration at the Exhaust Fans

February 3, 2013

Site Manager Responsibilities

- Explain biosecurity protocols to other employees and occasional visitors;
- Make sure that biosecurity protocols are applied at all times;
- Report any health or building problem that affects the application of biosecurity measures to the site manager as soon as the problem arises;
- Report any refusal to comply with the biosecurity protocol to the site supervisor as soon as this situation occurs;
- Prohibit access to the building to anyone failing to comply with the protocol;
- Do not let any animal into the building or do not let any truck come into contact with a loading dock if the biosecurity protocol is not followed;
- Monitor the pressure gage each day and inform the veterinary or site supervisor if the negative pressure exceeds 0.6 inch wg.

Signage

- Put in place posters that clearly indicate that the building is a quarantine area and no admission is permitted without an authorization and explanation of required procedures;
- Make sure that the telephone number of the person to be contacted in case of need is provided.

Introduction of Animals

- Quarantine area previously disinfected and cleaned with particular emphasis on cleaning the loading dock thoroughly.
- Block up the door that communicates with the gestation room. Do not open access points, since there is an air filtration system.
- Access must be locked.
- Door sealed with a temporary weatherstrip sealer or other material that will keep the opening airtight.
- Anyone unloading the animals:
  - Goes through the Danish entrance of the quarantine area and complies with all entry steps as described below in the section “Personnel and visitors”;
  - Enters the trailer by going through the inside of the quarantine area;
  - Unloads the animals;
  - Goes through the Danish entrance of the quarantine area and complies with all exit steps as described below in the section “Personnel and visitors”;
  - Does not go back into the farrowing barn after the unloading is completed.

Personnel and Visitors

- Enter the room housing the animals only at the end of the day.
- Always access the quarantine area through the outside.
- Do not wear farm boots or clothes for going back and forth between the main building and the quarantine area.
- Wear civilian or dedicated clothes and boots to go from the main building to the quarantine area or vice versa.
- Avoid keeping the two Danish entrance doors open at the same time since this would allow non-filtered air to enter the quarantine area.
- Use the Danish corridor of the quarantine area to enter the section housing the gilts.
- Take off civilian clothes, coats and boots.
- Carefully observe contaminated and clean areas.
- Wash hands. Special attention must be paid to have clean hands. Use a hand brush if required.
- Put on a dedicated coverall and quarantine boots.
- Observe the onset of clinical signs: cough, pumping, glanders, fever, sows that stop eating, diarrhea, etc. Inform the veterinarian as soon as abnormal signs are observed.
- Use the Danish corridor of the quarantine area to go out.
- Take off the dedicated coverall and quarantine boots.
- Carefully observe contaminated and clean areas.
- Wash hands. Special attention must be paid to have clean hands. Use a hand brush if required.
- Put on civilian clothes, coats and boots.
- After having been in contact with quarantine animals, refrain from going back into the main building.

Particular Problem of Personnel Going Back and Forth Between the Main Building and the Quarantine Area on the Same Day

- Avoid going back into the main building after you have been in contact with potentially contagious animals of the quarantine area.
- Ways to reduce the need to go there at the beginning of the day:
  - Install windows between the gestation section and the quarantine section for observing the inside of the quarantine area. This will help make sure that there is no water damage or other situation requiring urgent action.
  - Install a thermometer facing the gestation section and the probe in the quarantine area to detect ventilation problems that would not be visible.
- In case of a fortuitous event where someone is forced to go back into the main building after having been in contact with quarantine animals:
  - Comply with all quarantine entry or exit protocols.
  - Strictly observe the principle of the Danish entrance when entering the main building by taking a shower instead of just washing your hands.
  - If it was impossible to take a shower or strictly observe the principle of the Danish entrance, take a shower elsewhere and change clothes before going back into the farm.

Introduction of Material

- Before the animals are entered, make sure to have available in the quarantine area the drugs, syringes, needles, lasso or any other equipment that will be needed during the batch.
- Disinfect everything that will be introduced into the quarantine area before the animals are entered.
- Only new material can be introduced into the quarantine area.
- If material needs to be introduced during a batch:
  - Space must be available to receive and disinfect it. The specific receiving room consists of three areas: a “contaminated” area where the delivery person can walk, a raised area for placing the material and an area where the farm personnel can walk to fetch the material.
  - The material receiving room will be kept at 21°C or above at all times.
  - If in boxes or bags, these must not leave the room. Only the content of boxes or bags can enter the farm. Once the material is taken out of the box, it must be disinfected before entering the farm.
  - If, for some reason, it is impossible to take out only the contents of boxes, a disinfectant will need to be applied on the boxes in the receiving room and a 24-h contact period will be required before entering the boxes into the quarantine area.
- New paper: place it in a dedicated plastic container in the material receiving room. Leave it there for 24 h before entering it into the farm.
- If seed is to be introduced, the seed delivery person has access to the Thermofix through the material delivery room or directly through the outside, without entering the quarantine area.
- Feed delivery orders will be dropped in a letter box outside the building.

Dead Gilts

- Take out the dead gilts through a door with direct access to the outside by leaving the ventilation on. This way, the air will not go out of the quarantine area without being filtered, which is more critical than filtering the incoming air.
- There is a washable cement surface outside next to the door.
- Wash and disinfect this surface if the season allows it after removing the dead body.
- The person who takes out the dead stock must remain in the building at all times.
- Another person may help from the outside, remaining outside of the building at all times.
- Put the carcasses in a closed container.
- Move the container away from the building during storage.
- Take the container out of the site so that it can be emptied by the knacker.

Pest Control

- Controlled by an exterminator;
- External maintenance of the building;
- No material or wastes around the building.

Employees' Food

- No food can be brought into the quarantine area.

Major Work or Renovations

- Reduce the frequency of breakages through inspections, preventive maintenance and repair work in between quarantine batches.
- A specific protocol will be required on a case-to-case basis if animals still in quarantine are in the quarantine room.

Exit of Animals

- Once the quarantine animals are confirmed to be disease-free, they can be brought into the main building.
- To this end, the doors that had been sealed at the beginning of the quarantine period can be opened to let the animals go through them.

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Appendix B

Procedures to be Implemented if PRRS-Contaminated Animals are to be Taken Out of a Quarantine Facility With Air Filtered at the Exhaust Fans

The purpose of this document is to reduce the risk that animals identified as PRRS virus carriers in a quarantine facility attached to a farrowing barn, of which the air is filtered at the exhaust fans, contaminate animals of the herd upon their withdrawal from quarantine.

Decision Process

- It is of the utmost importance to involve the treating physician and, if required, an external consulting veterinarian.
- Laboratory results:
  - Make sure that there has been no contamination of samples during sampling or transportation;
  - Make sure that there has been no misinterpretation of results;
  - If needed, perform new laboratory tests on the same or new samples.
- Choose the location where contaminated animals will be transferred to.
  - Make sure that there is no withdrawal time to observe prior to shipping the animals to the slaughterhouse if this option is selected;
  - One may consider euthanizing animals that show obvious or severe signs of PRRS prior to the loading. These animals are very likely to be rejected at the slaughterhouse and to be more contagious, thus increasing the risk of contaminating the main building during the loading.
- Cease transferring the manure from the scupper of the quarantine facility to the pit and determine the best method for eliminating the PRRS virus from the manure present in the scupper and possibly the pit. Different options are offered to the producer:
  - Manure can be pumped to a tank and taken away from the site after the animals have been taken out of the quarantine facility;
  - Manure can be left in the scupper until the PRRS virus is no longer infectious. The required time will depend on environmental conditions, especially the temperature;
  - The manure from the scupper can be processed with chemical substances like quicklime to inactivate the virus. This product is extremely corrosive and can be used only if there is a V-shaped scraper system without causing major damage to equipment.

Choice of the Loading Day

- Choose a sunny day to benefit from the impact of UV radiation, which contributes to inactivate viruses in the air.
- Avoid days when the winds blow from the quarantine facility to the main building.

Equipment

- The loading dock of the quarantine facility is the furthest possible from the air inlets of the main building.
- Choose a trailer that is equipped with a cushion in order to increase the airtightness between the trailer and the dock.
- The use of an airtight trailer with filtration of the outgoing air, if existing, should be privileged.

Loading

- Close the trailer openings as much as possible while letting the gilts breathe comfortably. This will permit creating a negative pressure in the trailer once it comes into contact with the dock.
- Open the trailer door to load the animals.
- Back the trailer against the loading dock. Do not open the dock door at this time.
- The persons who are about to load the gilts must all use the Danish corridor of the quarantine facility to access both the section that accommodates the gilts and the trailer.
  - Take off civilian clothes, coats and boots;
  - Carefully observe contaminated and clean areas;
  - Wash hands;
  - Put on a dedicated coverall and quarantine boots.
- To create a negative pressure in the trailer and thus reduce the transport of gilts' viral particles from the trailer to the main building:
  - Keep the trailer openings closed as much as possible;
  - Manually increase the airflow rate of the fans of the quarantine facility so they operate at full capacity;
  - Manually close the air vents of the quarantine facility until they are nearly completely closed;
  - Open the door of the loading dock.
- Load the animals.
- Once the loading is completed, close the trailer door.
- The truck operator drives the truck at least 2 km away from the main building as quickly as possible after the door was opened. He then stops to open the trailer openings in order to prevent the animals from overheating.
- A person remains in the quarantine facility to close the dock door then set the ventilation back to automatic mode. It is important to leave the air filtration in operation as long as the quarantine building has not been decontaminated.
- Use the Danish corridor of the quarantine facility to go out:
  - Take off the dedicated coverall and quarantine boots;
  - Carefully observe contaminated and clean areas;
  - Wash hands. Special attention must be paid to have clean hands. Use a hand brush if required;
  - Put on civilian clothes, coats and boots.
- After being in contact with the quarantine animals, do not go back into the main building on the same day.

Decontamination of the Quarantine Facility

- Leave the filters in place both at the air inlet and at the exhaust fans.
- Clean the room with soap. Clean all surfaces, including ceilings. Also clean the equipment and material that can be washed.
- Disinfect surfaces with a disinfectant recognized to be efficient against the PRRS virus.
- 24 hours after the disinfection, prefilters can be removed and replaced with new ones, and the antimicrobial filters of fans can be cleaned thoroughly as per manufacturer's recommendations and left to dry.
- Take out clothes and wash them in a secure location where they are not likely to contaminate animals.
- Replace any equipment or material of little value.
- Replace all drugs, vaccines, syringes and needles.
- Clean again the surfaces that have been soiled when removing the prefilters and filters.
- Disinfect again with the same disinfectant.
- Allow to sit for at least 24 hours or until surfaces are dry.

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