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REDUCING PATHOGEN DISTRIBUTION FROM ANIMAL TRANSPORTATION

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Reducing Pathogen Distribution from Animal Transportation *(Proj#20140282)*

FINAL REPORT

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Reducing Pathogen Distribution from Animal Transportation (Proj#20140282)

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4. Abstract/Summary

In response to the need by the industry for a livestock vehicle that addresses both increased animal welfare and biosecurity during transport, a prototype air-filtered trailer was designed and assembled. Design parameters were determined from inputs gathered from a stakeholders' survey and the initial multiple design configuration options were narrowed down using computer simulation. The final design featured a transport trailer with two separate compartments: front compartment that houses generator set, a bank of 6 air filters, ventilation controller, supplemental heater, and two axial fans; and a livestock compartment with solid aluminum walls, two decks with hinged upper deck floor and roof that can be lifted open, and a hydraulic loading platform. Based on this design, a prototype trailer was assembled and evaluation of the effectiveness of the installed air filtration system (MERV-8 pre-filter and MERV-16 main filter) showed overall reduction of 96.9% in concentration of aerosolized model virus (bacteriophage Phi X174) inside the animal compartment relative to upstream of the filter. Moreover, two monitoring trips with pigs loaded in the prototype trailer showed that the mechanical ventilation system was able to maintain the desired thermal conditions within the animal compartment. Supplemental heating

unit helped to ensure that the temperature in the animal compartment did not go lower than 10°C during the trips under winter conditions. Events during the trip such as slowing down or full stops due to traffic stops affected environmental conditions inside the trailer, although the desired conditions were quickly restored once the trip resumed, particularly when the mechanical ventilation control system enabled compensation for relative humidity and carbon dioxide levels in the animal compartment in addition to the conventional temperature-based control. Cost analysis of the air-filtered trailer prototype which considered total equipment and installation cost as well as annual operational and filter maintenance costs, yielded a payback period of 2.10 years if a modest premium of $5 per pig is realized for transporting pigs using an air-filtered trailer. From this first effort on design and development of a major equipment such as this new transport trailer, various points for optimization of the prototype have been identified to facilitate continuing work to further improve the efficiency of the trailer and to bring the overall trailer design closer to commercialization. Finally, to fully gain the confidence of livestock producers to adopt and utilize this design, it is strongly recommended that the air-filtered trailer is ultimately tested against a disease challenge, wherein the performance of the trailer in protecting the animals being transported is assessed when the trailer is actually exposed to conditions known to certainly cause airborne transmission of disease.

5. Introduction

Aerosol transmission of swine disease pathogens has been documented in several studies. The study by Dee at al. (2009) investigated two of economically significant pathogens, namely porcine reproductive and respiratory syndrome virus (PRRSV) and *Mycoplasma hyopneumoniae* (*M hyo*), and reported that certain strains remained infectious over long-distance airborne transport up to 4.7 km for *M hyo* and 9.1 km for PRRSV (Otake et al., 2010). Similarly, swine influenza A virus (IAV) was found capable of being transmitted to other barns through the air exhausted from infected swine barns and transported downwind (Corzo et al., 2013). Diseases caused by these pathogens can impact the swine industry through actual loss in animal productivity, added costs of medication and eradication measures, and even potential loss of access to markets for pigs from a PRRS-positive herd. With respect to the economic impact of PRRSV infection, a study in Canada estimated economic losses to a breeding facility when affected by the virus to be from \$250 to \$460/sow/year for a chronic PRRS or new acute outbreak (Mussell, 2010 as cited by Pouliot et al., 2013). In the U.S., the annual impact of PRRS was estimated at \$664 million attributed to combined productivity losses in the breeding and grow-finish pig herds (Holtkamp et al., 2011). These led to various studies that explored effectiveness of installing air filtration systems in swine barns making use of mechanical and antimicrobial filters and eradication of loopholes in the disease prevention strategy particularly in the North American swine production system (Batista et al., 2008; Dee et al., 2010; Alonso et al., 2012; Dee et al, 2012; Alonso et al., 2013; Pouliot et al., 2013).

Pig production is a major industry in Canada (Dorjee et al., 2013) and its success over the years relied heavily on the availability of highly improved breeding stock. These breeding stock are typically raised by pig genetics companies in nucleus and multiplier farms located in production areas such as Saskatchewan where disease pressure is low and biosecurity perimeters are wide. However, being able to take advantage of this biosecurity benefits also requires that the breeding stock would need to be transported to clients in other pig production areas in the country. While in transit, these high-value genetic stocks are inevitably exposed to risk of airborne disease contamination. Several Canadian studies have provided evidence that introduction of infected animals, particularly gilts and sows into farms, was one of the common reasons for spread of PRRSV in the country (Kwong et al., 2013; Rosendal et al., 2014; Thakur et al., 2015). Thus, it is imperative that measures be developed to prevent infection of these animals during transport and consequently close the biosecurity gap through which potential infection can be introduced to the big commercial herds in other provinces. In addition, the livestock transport industry is also facing growing pressure to provide more herdsman-friendly and welfare-friendly vehicles (i.e., capable of providing stable, acceptable environmental conditions, reduced incidence of fatigued animals, among others) in response to growing public awareness of animal welfare issues. Hence, there is also a need to re-visit the design of livestock trailers currently in use in the industry to address these issues by incorporating new design features that improve worker safety and animal welfare.

The main goal of this research project was to develop a new and improved design for animal transport trailer that will mitigate the risk of airborne disease transmission during transport and to improve operational efficiencies. The specific objectives were to:

1. develop a new and improved design of swine transport trailer that will facilitate control of airborne pathogen contamination;
2. assemble a prototype of the developed animal transport trailer design;
3. evaluate the overall performance of the air-filtered trailer in preventing airborne pathogen transmission; and
4. characterize cost and technical feasibility of the new trailer design in commercial swine production.

6. Methodology

To achieve the above-mentioned objectives, this project was conducted in four phases. Using knowledge generated from the CAAP-funded project on developing an air filtration system for an animal transport trailer and the result from survey of relevant stakeholders in livestock transport, various trailer design configurations were evaluated using a computer simulation package to select the best design option. A prototype of the new trailer design was then assembled and testing and evaluation of its performance was carried-out. The following sections describe the activities undertaken in this project.

6.1. Phase 1 - Development of the animal transport trailer design

The goal of this phase was to select the best possible option for a swine transport trailer which will reduce or prevent the risk of airborne disease transmission and at the same time address issues commonly encountered on existing trailer designs such as animal welfare, ease of maintenance as well as trucker/worker well-being.

6.1.1. Development of initial trailer design

A survey questionnaire which gathered inputs on the observed strengths and deficiencies of the conventional commercial swine transport trailers was distributed to a number of relevant stakeholders including pig producers, swine veterinarians, livestock truckers, herdsmen involved in pig transport and researchers. Additionally, their desired features and preferences for an improved swine transport trailer were solicited. Responses gathered from the survey were summarized and formed the basis for the initial design of the new trailer.

6.1.2. Selection of best design option by computer simulation

Computer simulations were done using the commercially-available computational fluid dynamics (CFD) software ANSYS (ANSYS Student License, ANSYS Inc., Canonsburg, PA). CFD has gained popularity among users in different fields including agriculture to model airflow processes and achieve comprehensive evaluation and design of systems while considerably reducing the amount of physical experimentations (Norton et al., 2006).

Simulation of the base model and initial design of new trailer

To create a reference baseline case for latter comparisons with new trailer design, simulation was done on a conventional straight deck trailer (15.8 m L x 2.5 m W). It has two decks and five compartments in upper deck and six in the bottom deck. Figure 6.1 shows the geometry of the existing commercial livestock transport trailer which served as the base model. The initial design of the new trailer made use of the framework of the base model except that it included features such as being entirely closed with designated inlet openings at the front and outlet openings located at the rear of the trailer; another option considered was addition of an air filtration system (a bank of 9 filters, 3 ventilation fans, power generator and controller) located at the front end of the trailer. The remaining length was divided equally into 4 compartments for each deck. The computer model of the initial design of the prototype trailer is shown in Figure 6.2. Both geometries, as well as all subsequent models for various design configurations for the prototype trailer were generated using the Design Modeler module in ANSYS.

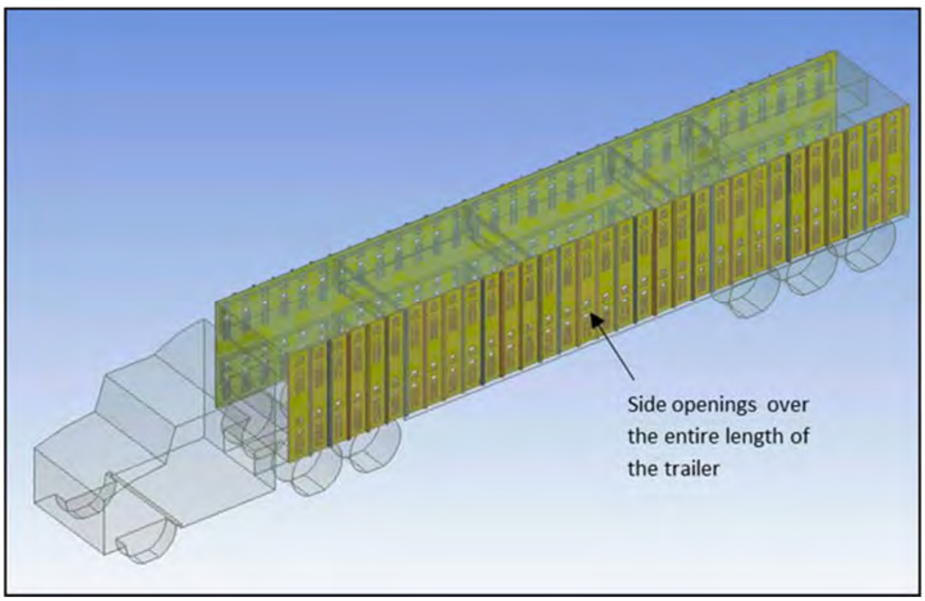


Figure 6.1. Screenshot of the base model of the trailer with basic physical configuration similar to a conventional straight deck livestock trailer.

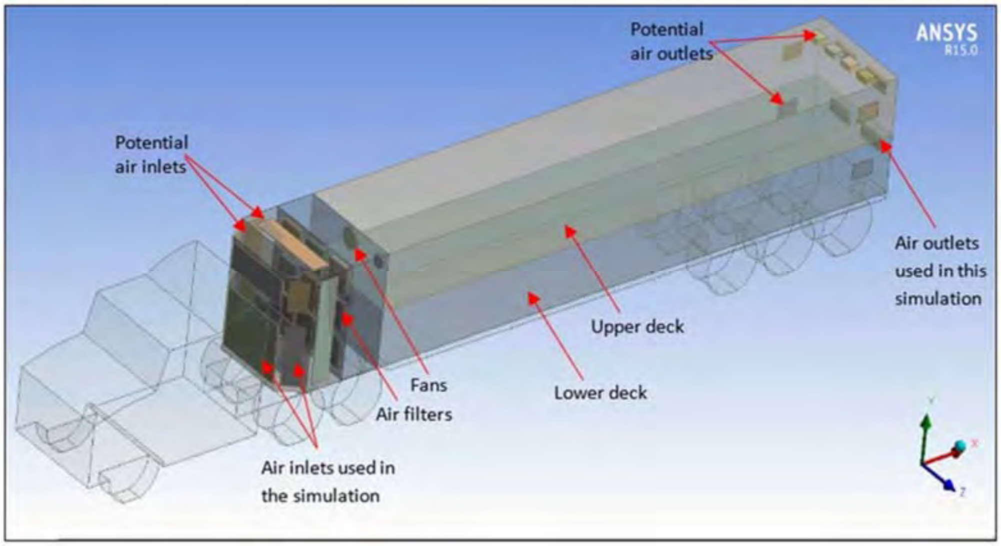


Figure 6.2. Screenshot of the model of the initial design of the new trailer equipped with air filtration system.

After refining the geometry model and mesh, simulations of airflow, temperature and moisture were carried out using the boundary conditions in Appendix Table 15.1. Each simulation run in ANSYS involves steps such as pre-processing (setting up of model geometry, specifying boundary conditions), iterations (solving the CFD equations until convergence was attained) and post-processing (extracting numerical predicted values, plotting graphical outcomes, analyzing and interpreting results). On average, each simulation run took about 5 to 7 days.

Computer simulation of the different design configurations of the filtered trailer

Findings from simulations of the initial designs of the new trailer showed relatively poor distribution of temperature and moisture inside the trailer. Thus, various design configurations for the ventilation system of the air-filtered trailer were created and further simulations were done. Six design options based on alternative locations and different number of air inlets and air outlets, which are the main drivers of air movement in mechanical ventilation systems, were evaluated. Appendix Table 15.2 provides description of the 6 design configurations. The geometry model used in the final simulations is shown in Figure 6.3. The potential inlet locations are on the sides and top of the front compartment while exhaust openings are on the sides and top of the back part of the trailer. Locating exhaust openings on the rear end (i.e., at tail-gate) of the trailer was eliminated as an option due to potential for backflow of unfiltered air through these openings when the trailer is moving. This was based on the findings from initial simulations. Each deck in the animal compartment has one 18-in diameter axial fan operated in positive pressure relative to the trailer and 4 compartments. Moreover, in the final simulations, a bank of 6 air filters was installed at the upstream side of the fans.

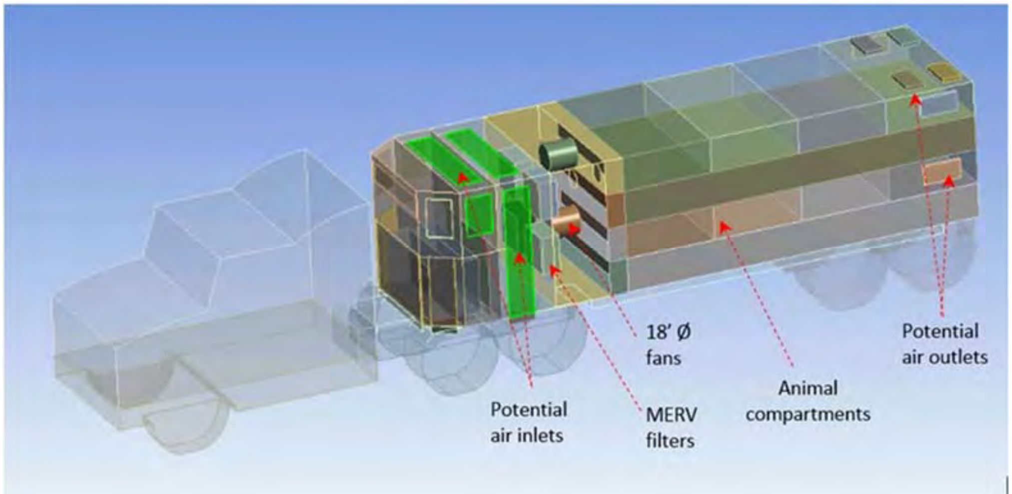


Figure 6.3. Screenshot of the model of the new trailer equipped with air filtration system.

Due to the significant amount of time needed to complete each simulation case (i.e., for each design configuration and boundary condition), all 6 design configurations were tested under summer conditions while only the top 3 designs were further evaluated under winter conditions.

Appendix Table 15.3 summarizes the boundary conditions used in the final simulations. Top designs were selected based on (1) ventilation effectiveness, and (2) the capability to meet the environmental requirement of pigs during transport. Heat removal effectiveness (HRE) was used to evaluate the ventilation effectiveness of each design option and is computed as follows (van Wagenberg and Smolders, 2002):

$$HRE = \frac{T_{outlet} - T_{inlet}}{T_p - T_{inlet}} \quad \text{(Equation 1)}$$

where *HRE* is the dimensionless heat removal effectiveness at point *p*; T_{inlet} is temperature of the inlet air, °C; T_{outlet} is temperature of the outlet air, °C; T_p is temperature at point *p* in the animal compartment, °C. The ability of each design configuration to meet allowable thermal condition for market pigs during transport was compared. Thermal comfort zone during transport was set to at least 10°C during winter (Brown et al., 2011) and below 27°C during summer (using the National Weather Service Heat Index calculator). Range and mean values for HRE, temperature, moisture level and air velocity at 8 monitoring points (4 for each deck) located 1 m above deck floors were used in the comparisons.

As mentioned, only the top 3 design configurations (S4T2-S4, S2T1-S4 and S2-S4) were subjected to simulation under winter conditions and the best performing design (S2-S4) was further subjected to sensitivity analysis under both summer (30°C, 25°C and 22°C) and winter (-25°C, -17°C and -10°C) conditions. Sensitivity analysis was aimed to predict thermal conditions inside the trailer under extreme and various weather conditions and to determine the range of weather conditions and loading capacity that will require either supplemental heating or cooling systems.

6.2. Phase 2 - Assembly and construction of a prototype

The best design configuration (i.e., S2–S4) for the air-filtered trailer selected from simulation results was implemented in the construction of the prototype trailer. Trailer components such as flatbed trailer, fans, ventilation system controller, generator set and air filters were purchased through local distributors while the main animal compartment was subcontracted to a commercial livestock trailer manufacturer. Retrofitting of a metal storage container into the front compartment was done at Prairie Swine Centre (PSC). Installation of both front compartment and animal compartment box to the flatbed trailer and subsequent welding jobs including installation of the air filter wall, ventilation fans, dampers for the exhaust openings and controller box of the hydraulic platform were done in farm equipment manufacturing and welding shop in Outlook, SK. Electrical connections to power the ventilation system was done by an electrical service company in Saskatoon, SK. Finally, programming of the ventilation controller and securing hydraulic and electrical connections for the hydraulic loading platform were done with help from an instrumentation technician from the College of Engineering, University of Saskatchewan. Figure 6.4 presents some photos during construction of the prototype.

Figure 6.4. Photos during assembly of the prototype air-filtered trailer. Shown in (A) and (B) is the retrofitting of the metal storage container into the front compartment, (C) the animal compartment box being unloaded in Outlook, SK, (D) inspection of the trailer for placement of air outlet vents on the animal compartment, (E) moving of the assembled trailer to the College of Engineering to install sensors and (F) wiring of the sensors in the animal compartment.

6.3. Phase 3 - Testing and evaluation of the prototype

The goal of this phase of the project was to assess the performance of the assembled air-filtered trailer in preventing airborne pathogen introduction to herd during transport. Additionally, the effectiveness of the trailer ventilation system for providing acceptable micro-climate to pigs during transport was evaluated.

6.3.1 Stationary test

In this test, a benign virus or bacteriophage phi X174 (ATCC 13706-B1) which was propagated in its host *Escherichia coli* (ATCC 13706) were used as surrogate of common viral swine pathogens. Phage phi X174 contains single-stranded DNA (ssDNA) as its genomic material, tailless, non- enveloped, and 25 - 27 nm in capsid size. The bacteriophage and its host were obtained from the American Type Culture Collection (www.atcc.org). Propagation of phage phi X174 at 37°C and storage of the phage stock (2.78 x 10^{10} ssDNA copies/ml) at -80°C were done at the Microbiology Laboratory of Western College of Veterinary Medicine, University of Saskatchewan.

On the day of testing, a nebulization solution composed of 1 mL phage lysate diluted in 39 mL distilled water was prepared. A cold fog mister (Hurricane ULV/mister, Curtis Dyna-Fog Ltd. Westfield, IN, USA) was then used to generate aerosol at an average liquid use rate of 37.5 mL/min. Aerosol produced was directed inside a 2' x 2' x 1.5' (length x width x depth) chamber made of cardboard lined with aluminum foil insulation which was installed upstream of the specific air filter set (composed of the pre-filter and main filter) being tested. The same material was used to create a duct that connects downstream of the air filter set to the bottom deck fan. Downstream of the fan (inside the animal compartment), a 2' x 2' x 4' chamber received the air flow from upstream of the set of air filters being tested. For each replicate of the test, the filter set was replaced with a new set. A smoke test was done prior to testing to locate any leaks in the testing setup; any leaks found were sealed using duct tape and foam weather-strip. For the entire duration of the test, the ventilation system was run at 10% of fan capacity with estimated ventilation flow rate of 2000 L/min for the bottom deck ventilation fan. Figure 6.5 and Figure 6.6 show the testing set-up.

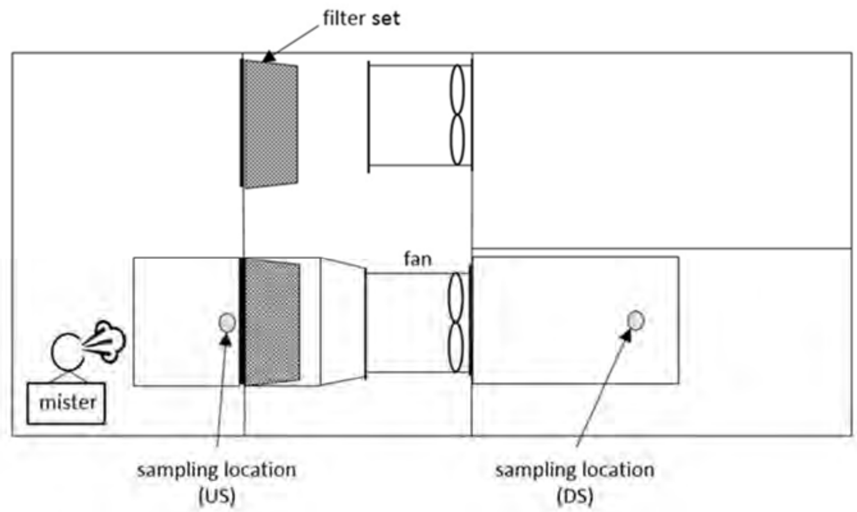


Figure 6.5. Diagram of the testing setup during the stationary test. US and DS stand for upstream and downstream, respectively.

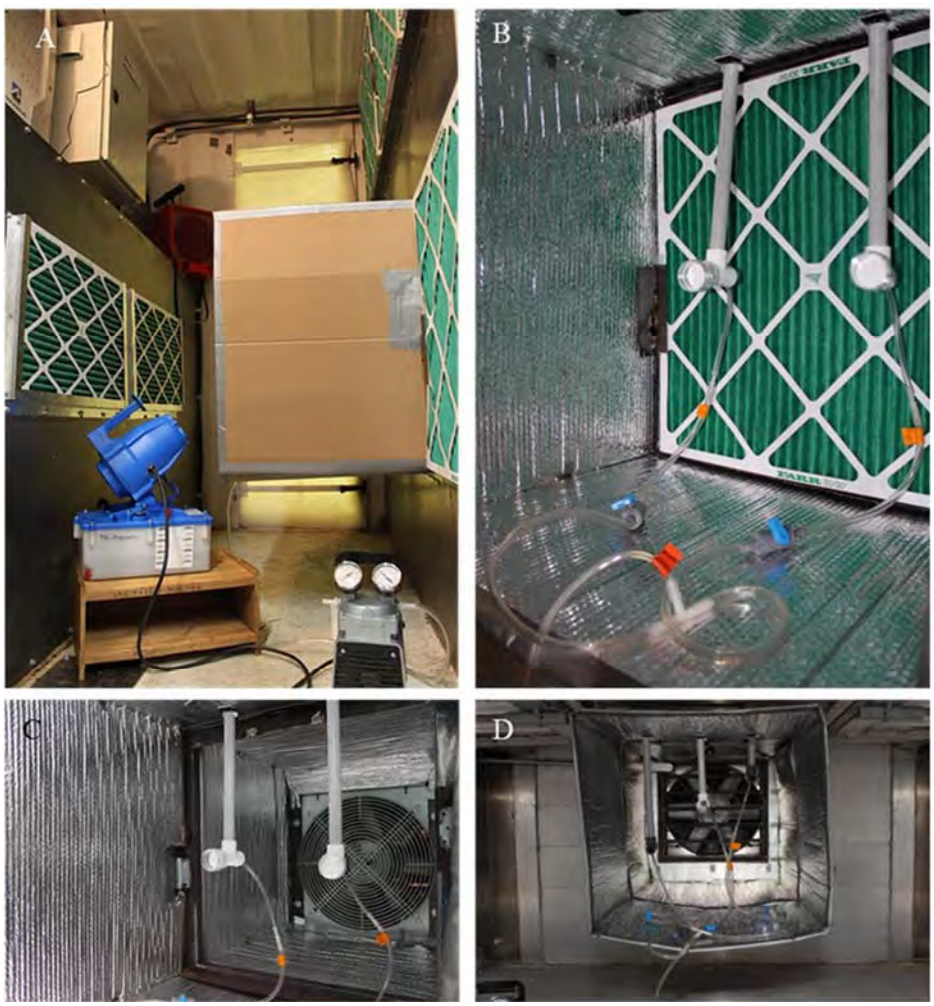


Figure 6.6. Photos of the testing setup. (A) shows exterior of the chamber upstream of the air filter and the nebulizer used. (B) is inside the upstream chamber with two cassette samplers and

air filter set. (C) shows the duct connecting downstream of the air filter set (removed in the photo) to the bottom deck fan. (D) shows the 4' depth chamber downstream in the animal compartment with three cassette samplers.

To monitor the airborne viral load at different points in the testing set-up, 37-mm diameter polycarbonate filters (PC) (SKC Inc., Eighty Four, PA) with a 0.4 µm porosity mounted on cellulose support pads placed in 37 mm clear styrene 3-piece cassettes (Sureseal, SKC Inc.) were used to capture aerosols upstream and downstream of the air filter-fan assembly. For every sample, two cassette samplers were placed in the upstream location and three samplers in the animal compartment 3' downstream from the ventilation fan grill. The aerosolization and sample collection duration was 10 minutes. Also, approximately 5-minute downtime in-between samples was provided for changing samplers and to allow the phage concentration in the upstream and downstream compartments to decline to background level prior to starting next sampling run. The filter cassettes were connected to Gast air sampling pumps (Gast Manufacturing, Benton Harbor, IM, USA), DOA-P704-AA for upstream samplers and DAA-V715A-EB for downstream samplers. Following isokinetic sampling principles, sampling flow rates for each cassette samplers were determined by conducting a velocity traverse at each sampling plane using a hot-wire anemometer prior to sampling. Average sampling flowrates for upstream samplers were 1.823 and 1.873 L/min while for downstream samplers 9.350, 5.148 and 3.520 L/min, respectively. PVC ball valves were used to adjust flow rate for each sampler and flow calibration was done using Bios DryCal® DC-Lite Model DCL-M (Bios International, Butler, NJ, USA).

A total of 4 replications each consisting of 6 sets of 10-min paired upstream-downstream samples were conducted. Thus, each replication took at least 60 minutes of phage aerosolization. Moreover, to validate integrity of the sampling method, 2 positive control (air filter set removed) and 2 negative control (distilled water was aerosolized with air filter set on) samples were collected.

Viral load captured on filter samplers were extracted in microfuge tubes and liquid were kept at 4°C until quantitative polymerase chain reaction (qPCR) analysis. Both viral particle extraction and qPCR were done in WCVM Microbiology Laboratory.

Finally, filtration efficiency in terms of viral load was estimated using Equation 2:

$$\eta_{i,filter} = \frac{L_u - L_d}{L_u} x\ 100 \qquad \text{(Equation 2)}$$

where $\eta_{i,filter}$ is the air filter efficiency (%) and L_u and L_d are the viral loads (ssDNA copies/L of air) upstream and downstream of the air filtration system, respectively. L_u and L_d were derived from:

$$L = \frac{C\ x\ v}{f\ x\ t} \qquad \text{(Equation 3)}$$

where C (ssDNA copies/mL) is the viral or phage concentration of the sample, v (mL) is the sample volume, f (L/min) is the sampling flow rate for each cassette sampler and t (min) is the sampling duration (Turgeon et al., 2014).

6.3.2 Road test

Two monitoring trips from Prairie Swine Centre in Saskatoon, SK to an abattoir in Moose Jaw, SK with the trailer loaded with market pigs were done under winter conditions (December 1 and 14, 2017). The average live weight of the market pigs, stocking density, time of start of loading, travel interruptions on the road and time until end of unloading in the abattoir were recorded.

The route (Appendix Figure 15.1) used during the monitoring trips was chosen to achieve travel time of not less than 5 hours, excluding time allotted for loading, wait time in the yard of the abattoir and unloading.

The mechanical ventilation system was turned on before start of loading and was kept operating until end of unloading. Real-time access to the Maximus System ventilation system controller was set up using a tablet, which was connected to the controller through Wi-Fi connection to monitor the operation of the fans and change the settings as needed during the trip.

Data collection and analysis

1. Temperature and humidity

Temperature and relative humidity in the bottom and top decks of the prototype trailer were logged every 30 seconds using OM-EL-USB-TP-LCD and OM EL-USB-2 data loggers (Omega Environmental, Laval, QC, Canada). The data loggers were spatially distributed at the top of each deck, approximately 1 m (40 in), above the trailer floor to avoid damage to sensors by animals. Additional protection was provided by data logger holders made of PVC pipes with holes for free air movement around the data loggers. Additionally, real-time thermal condition inside the trailer was monitored through thermistors and RH sensors connected to the Maximus System controller.

2. CO_2, air velocity and room static pressure

Concentration of carbon dioxide at 7 locations inside the trailer were measured every 30 seconds using SE-0018 sensors (CO2Meter.com, Ormond Beach, Florida). On the other hand, every 15 seconds measurement of air speed in 8 locations inside the trailer were made using D6F-W10A1 air speed sensors (Omron, Japan). The CO_2 and air velocity sensors were mounted on specially designed holders. All wiring to connect the sensors to the data acquisition system were run through metal conduit and routed through junction boxes for protection from damage. A pressure transducer (Setra 265, Setra, Boxborough, MA) was installed to measure static pressure inside the trailer every 30 seconds. Data for these three parameters were logged continuously using a 16-port CR1000 data logger (Campbell Scientific, Edmonton, AB).

3. NH_3 and H_2S

Hydrogen sulfide (H_2S) and ammonia (NH_3) level monitoring were done using Dräger Pac® 7000 (Draeger Safety Canada, Ltd, Mississauga, Ontario). Logging interval was 1 minute for both gas monitors. Figure 6.7 shows the sensors and data loggers installed in the trailer during the monitoring trips.

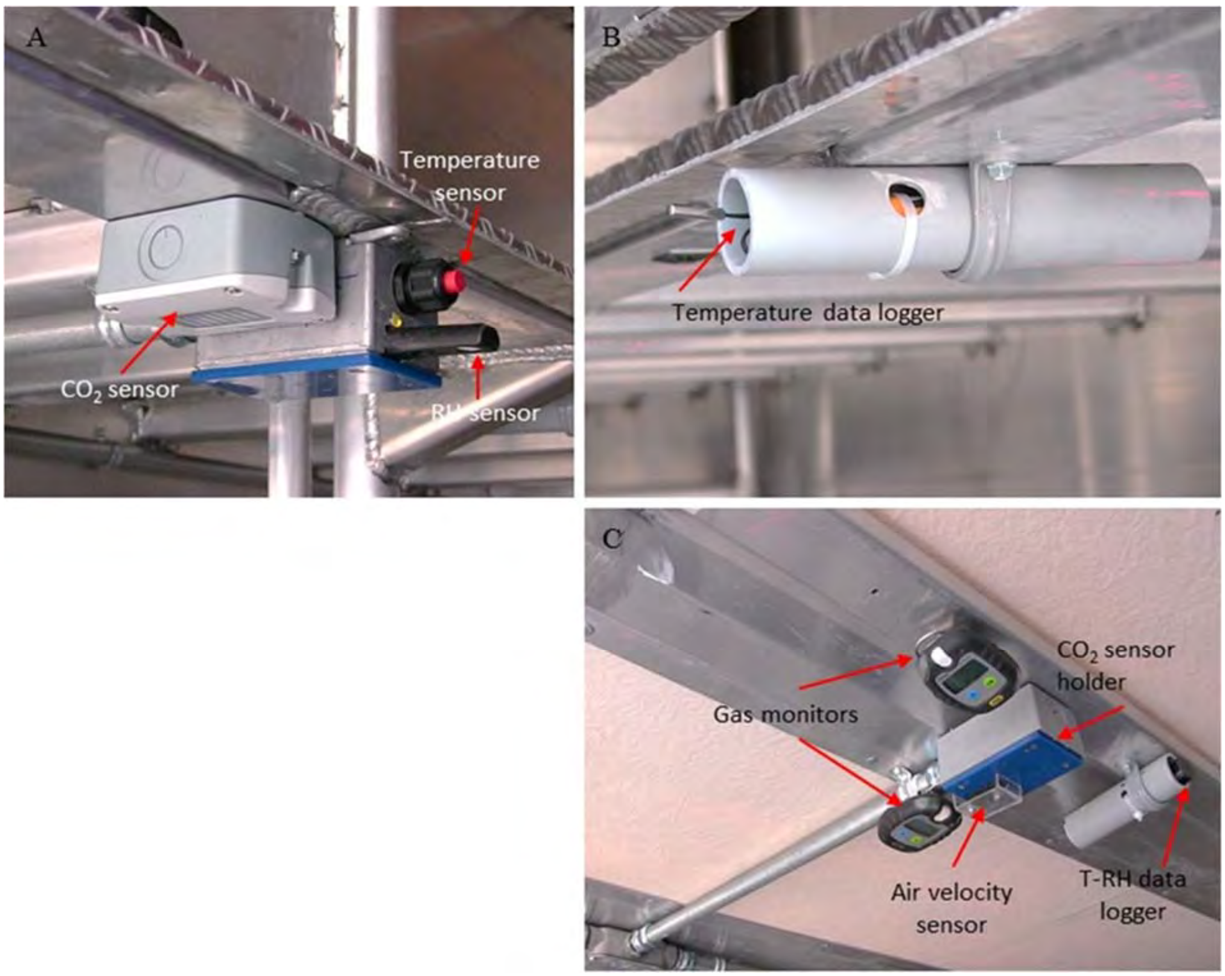


Figure 6.7. Sensors and standalone data loggers used during the monitoring trips. (A) CO_2, temperature and RH sensors installed at the bottom deck used as input to control the ventilation system. (B) Thermistor-type temperature data logger installed in a PVC pipe for protection. (C) Gas (NH_3 and H_2S) monitors, housing and holder for CO_2 and velocity sensors, and temperature-RH data logger.

The distribution of sensors and standalone data loggers inside the trailer is laid out in Figure 6.8. In subsequent sections, it is important to note that the interior of the livestock container was spatially divided into five main zones: Location 1 represents area close to the ventilation fans; Location 2 for center of the front compartment; Location 3 for center of the entire livestock container length; Location 4 for center of the rear compartment; and Location 5 for area close to the air outlets. This placement of measuring devices was used for both upper and bottom decks of the prototype trailer. Front, Middle and Rear and Left, Center and Right will be used in succeeding sections to refer to trailer locations, areas or portions as shown in the schematic diagram.

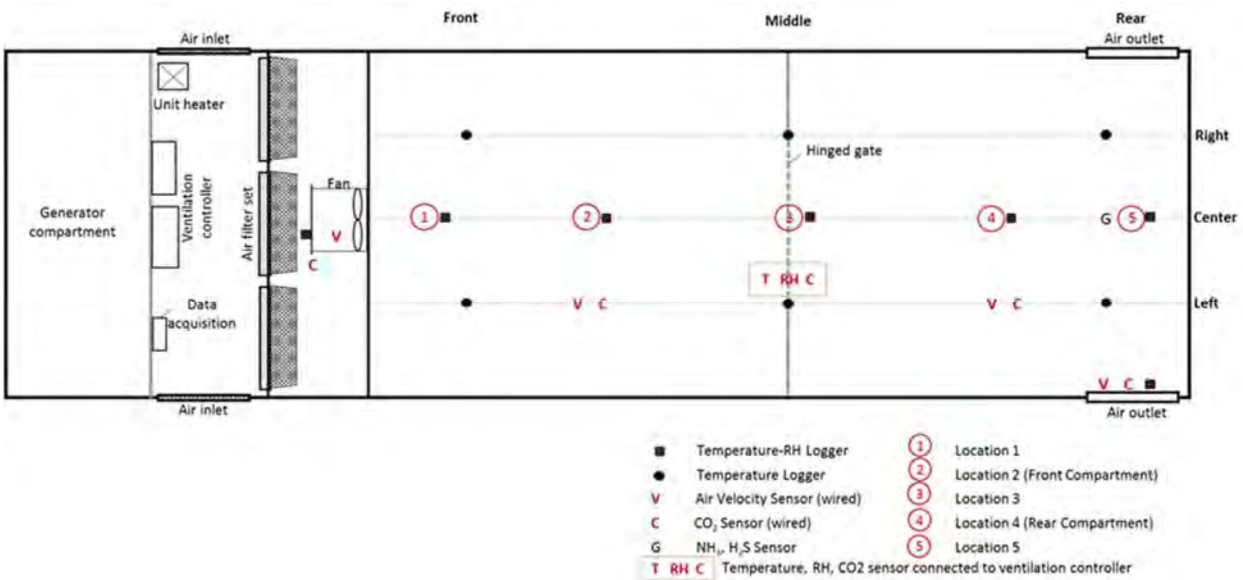


Figure 6.8. Schematic diagram of the trailer showing the spatial distribution of sensors and data loggers used to measure temperature, relative humidity, air velocity, CO_2 and other gases (NH_3 and H_2S) levels inside the trailer. Similar layout was followed for both top and bottom decks of the animal compartment.

4. Ventilation effectiveness

Ventilation effectiveness were assessed based on the heat removal effectiveness (HRE) and contaminant removal effectiveness (CRE) at the animal-occupied zone (AOZ) calculated using $HRE = T_{outlet} - T_{inlet}$⍰$T_p - Tinlet$ (Equation 1 for HRE. Similar method was used to determine CRE by replacing temperature values in $HRE = T_{outlet} - T_{inlet}$⍰$T_p - Tinlet$ (Equation 1 with CO_2 concentrations at different spatial locations.

5. Data quality assurance and analysis

A series of data filtering methods were done to remove data outliers and gross sensor errors. Filtering step #1 was removal of data outside the measuring range of the sensors and data loggers used. Step #2 involved computing for mean, minimum, maximum and standard deviation (SD) of data sets and retaining only data points in each data set that are within its 99.7% confidence interval, i.e. mean ± 3SD (Xiong, 2013).

Cleaned data sets for the different environmental parameters monitored were descriptively analyzed using means, standard deviations, and ranges. For comparison of mean differences of parameters used to describe the thermal and gas environment between the two monitoring trips, and between the top and bottom decks were analyzed using two-way independent student's t-test. On the other hand, paired samples t-test was used to compare within trailer deck conditions as well as in comparison of upstream and downstream bacterial phage concentrations for analysis of static test data. In the latter, log transformed values were used in the analysis to meet normality and homogeneity of variance requirements. Overall level of significance was defined by $p<0.05$. Processing of data and preparation of graphs were done using MS Excel while t-tests and test of correlation were run in SPSS (IBM SPSS Statistics, Version 24.0. Armonk, NY: IBM Corp.).

6.4. Phase 4 - Cost analysis and development of recommendations

Record on actual expenditures for this project were used in carrying out a cost analysis for an air-filtered trailer project. A 120-pig capacity trailer was analyzed (i.e. approximately double the size of the prototype trailer assembled). Estimation of annual operational costs were based on a 10-hr journey (pig transport) done at a maximum of 2 times per week. Various other assumptions particularly in carrying out payback period analysis are laid out in a subsequent section. Lastly, recommendations for redesign of the prototype and future work were developed.

7. Research Accomplishments and Discussion

7.1. Phase 1 - Development of the animal transport trailer design

7.1.1. Survey of stakeholders

Responses gathered from the stakeholder survey is summarized in Appendix Table 15.4. Among the issues raised on the existing commercial livestock trailers were potential for disease infection via air due to the open configuration of the trailer, difficulty in loading and cleaning, variable thermal conditions, among others. To address these concerns, the initial plan for the prototype trailer included design features such as incorporating mechanical ventilation and air filtration systems, reduced internal ramps and partitions, and having hinged floor panels to allow ease of loading/unloading pigs, and to facilitate cleaning.

7.1.2. Simulation of different design options

Existing commercial livestock trailer vs initial prototype trailer design

Initial simulation of the existing commercial livestock trailer confirmed the potential for entry of pathogen-laden air into the trailer during travel. As shown in Figure 7.1, when the trailer was running at 96 kph with assumed zero wind during summer, natural air movement caused ambient air to enter the trailer through the side openings of the compartments in the middle part of the trailer (in red color) and then exited through the side openings at the front and rear portions of the trailer (in blue color). Although variations in temperature and moisture levels across trailer interior were relatively smaller at 20°C outdoor air temperature, the temperatures in almost all compartments were above 20°C (Figure 7.2). Compartments 1, 4, 5 and 6 showed temperatures as high as 25°C which is the upper limit of the thermal comfort zone for 120-kg pigs. Compartments were designated labels of 1 to 5 or 6 from front to rear end of the trailer for both top and bottom decks. This trend in temperature is due to movement of air through the trailer during travel. The simulation showed that following the pressure gradients within the trailer during travel, air enters through the side openings at the middle portion of the trailer body, then picks up heat as it moves forward or towards the rear before it exits. Conversely, winter simulation at -17°C showed more variable temperatures and moisture inside the trailer (data not shown).

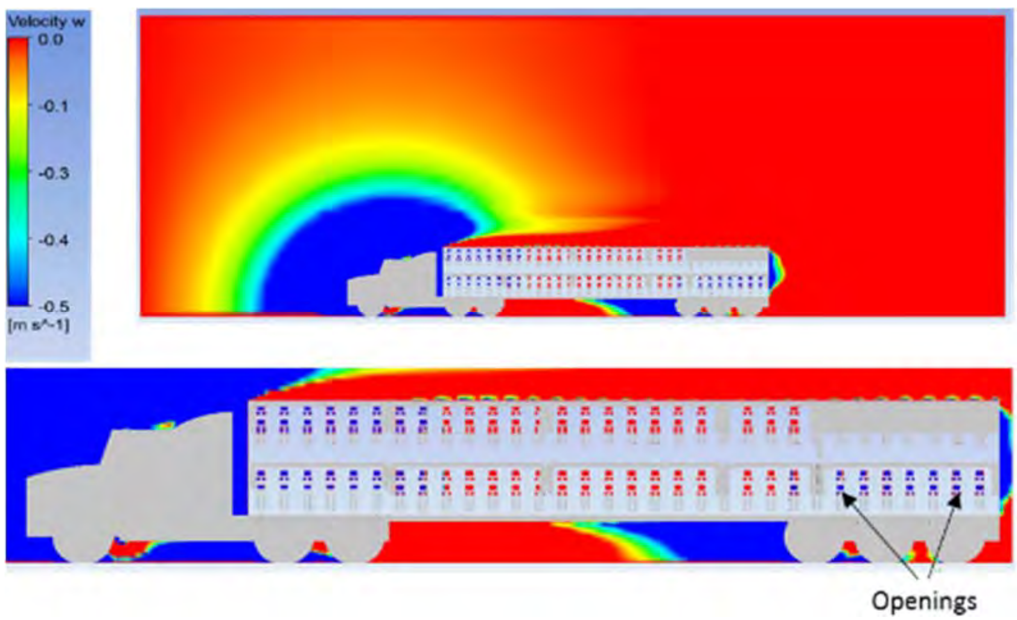


Figure 7.1. Air velocity profile of a transport trailer (side view) with no air filtration system moving at a speed of 96 kph.

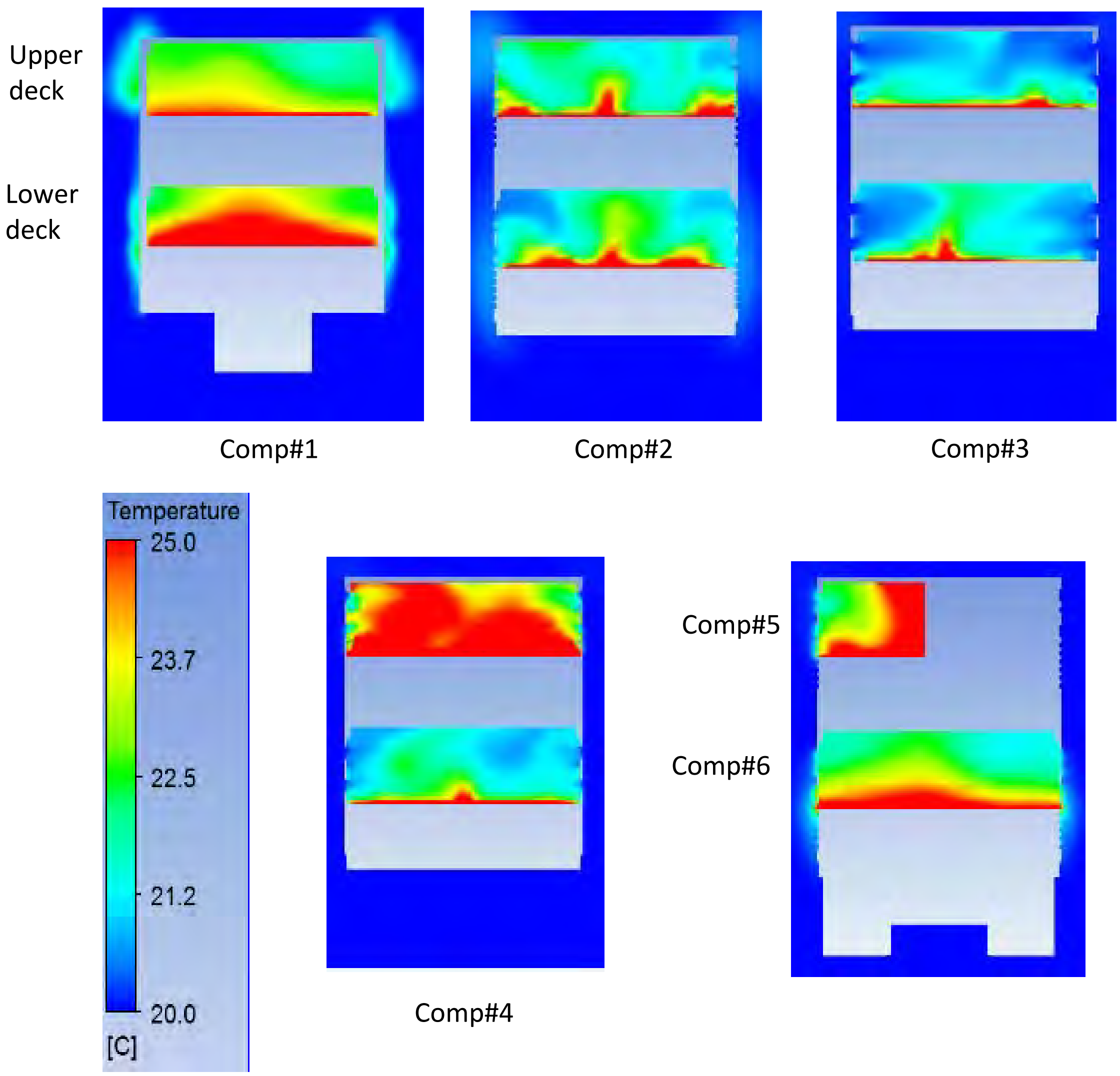
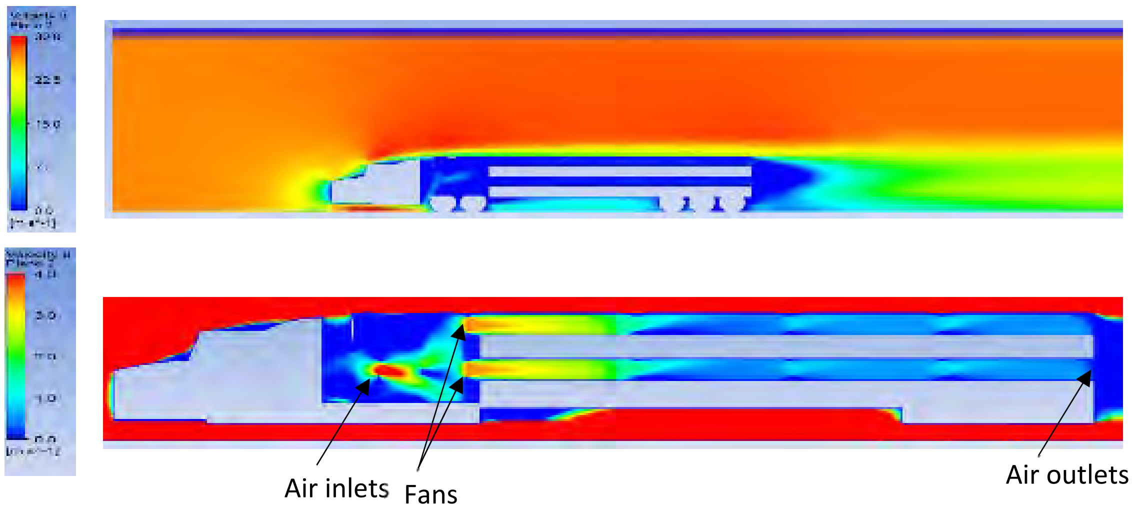
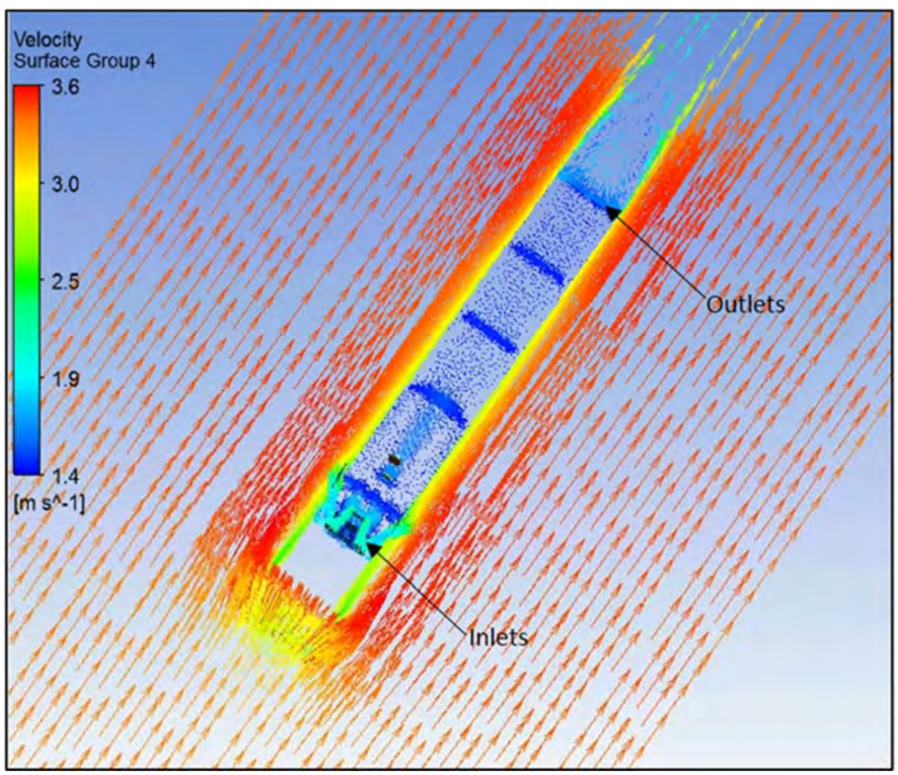


Figure 7.2. Contours of air temperature in each compartment of a conventional transport trailer (end view) on a hot summer day. For each compartment, the view shown is for a cross-sectional plane cutting through the middle of each compartment.

On the other hand, simulations on the initial design of the prototype air filtered trailer showed that air enters the animal compartment through the inlet openings found in front of the trailer only. Air was forced through the bank of air filters by the action of the fans. Contrary to the general air movement on the conventional livestock trailer, air in the animal compartment for the air-filtered trailer moves from front and exits through exhaust openings at the rear. Consequently, temperature and moisture levels increased as it moved from front to rear (tabular data previously reported). Moreover, a region of low pressure and swirling vortices was observed on the tail-gate end of the trailer when it is traveling forward (Figure 7.3). This implied avoiding this region as potential location for air outlets due to possibility of unfiltered air coming into the trailer through these openings and negating the function of the air filtration system. The observed downside of the initial design was the relatively poor distribution of ventilation air inside the trailer.



A (side view, median longitudinal plane)



B (top view)

Figure 7.3. Velocity contour (A) and velocity vector (B) of a new design of transport trailer fitted with air filtration system moving at a speed of 96 kph.

Selection of the best design configuration for the air filtered trailer

Summer conditions

Summary of results from the summer simulations (at 20°C outside air temperature) done on each of the 6 design configurations for the air-filtered trailer is shown in Table 7.1. Five of the six design options showed comparable range and mean values for HRE, temperature, moisture and air velocity at designated monitoring points. On the contrary, S2T1-T4 resulted to low ventilation effectiveness (mean HRE = 0.784), extreme temperature and moisture levels and relatively weak air movement. This set of results implied that locating air outlets at the top of the trailer is not effective in removing heat. Thus, the top 3 designs selected for further analysis (winter simulations) included only those that have side openings for air outlets: S4T2-S4, S2T1-S4 and S2-S4. Also, these 3 design configurations had the highest values for HRE.

Table 7.1. Simulated mean (range) values of heat removal effectiveness (HRE), temperature, moisture and velocity of the different design configurations during summer period, n=8.

Design code	HRE	Temperature, °C	Moisture, g/m^3	Velocity, m/s
S4T2-S4T4	1.852 (1.129 - 3.419)	22.6 (21.1 - 24.1)	14.18 (13.93 - 14.47)	3.13 (1.48 - 4.49)
S4T2-S4	2.202 (1.173 - 4.661)	22.7 (20.9 - 24.2)	14.20 (13.92 - 14.50)	3.33 (1.52 - 4.88)
S2T1-S4T4	2.046 (1.128 - 3.722)	22.6 (21.1 - 24.1)	14.20 (13.94 - 14.51)	3.27 (1.51 - 4.78)
S2T1-T4	0.784 (0.30 - 1.494)	79.2 (23.5 - 150.2)	18.68 (14.16 - 24.66)	0.26 (0.07 - 0.82)
S2T1-S4	2.223 (1.10 - 5.168)	22.7 (20.9 - 24.2)	14.18 (13.91 - 14.47)	3.20 (1.48 - 4.64)
S2-S4	2.368 (1.206 - 5.481)	22.7 (20.8 - 24.2)	14.18 (13.91 - 14.47)	3.19 (1.44 - 4.74)

Winter conditions

Table 7.2 shows results of the winter simulations (-17°C outside air temperature) for the top 3 design configurations from summer simulations. Similar to summer simulations, the three design options showed comparable mean values for the HRE, temperature, moisture level and air velocity. However, apart from having the highest mean HRE value, S2-S4 yielded least variation in temperature (2.6 – 9.4°C) compared to the other two options. Furthermore, for the designs with more inlet openings, lower temperatures were obtained at the front of the animal compartment compared to the S2-S4 design (Figure 7.4), indicating the possibility of chilling of pigs located in this section of the trailer.

Table 7.2. Simulated mean (range) values of HRE, temperature, moisture and velocity of the different design configurations during winter period, n=8.

Design code	HRE	Temperature, °C	Moisture, g/m^3	Velocity, m/s
S2-S4	0.969 (0.792 - 1.280)	6.3 (2.6 - 9.4)	1.97 (1.34 - 2.61)	0.73 (0.12 - 2.51)
S2T1-S4	0.950 (0.756 - 1.539)	6.1 (-2.0 - 9.2)	1.97 (1.34 - 2.58)	0.79 (0.20 - 2.47)
S4T2-S4	0.939 (0.726 - 1.337)	6.4 (0.6 - 11.4)	1.90 (1.33 - 2.49)	0.72 (0.07 - 2.52)

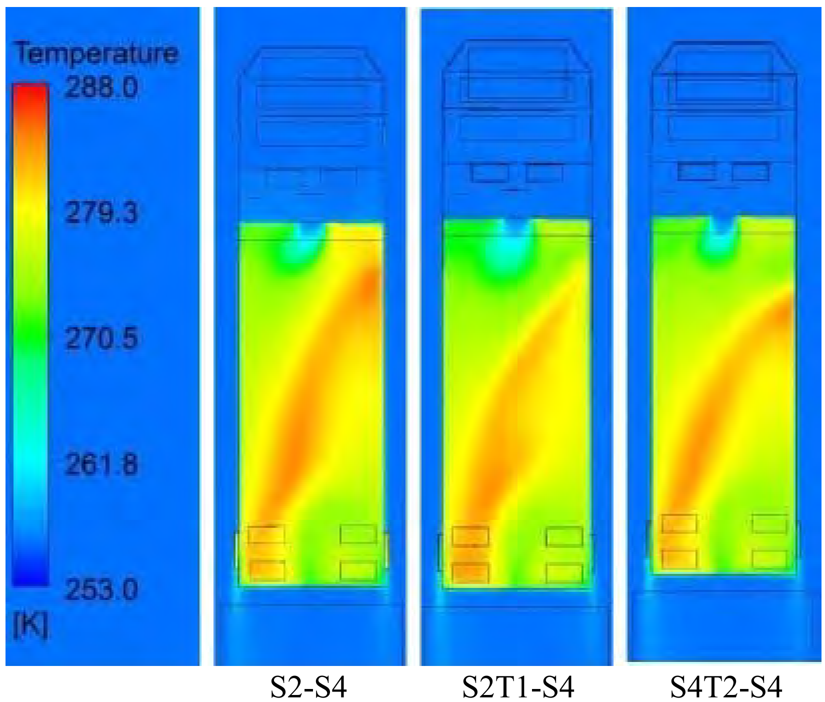


Figure 7.4. Contours of simulated temperature (K) inside the animal compartment (top view) of the three different trailer design configurations in winter.

Taking into account both summer and winter simulation results, S2-S4 (i.e., one inlet opening on each side at the front area of the trailer and two air outlets on each side near the back of the trailer) was selected as best design option for subsequent sensitivity analysis.

Sensitivity analysis

Additional simulation runs on the selected design options were conducted at different ambient temperatures to determine their impact on expected conditions inside the trailer during travel. Air temperature inside the animal compartment at outside air temperatures of 30°C, 25°C and 22°C reached as high as 35°C, 30°C and 27°C, respectively. Simulations further showed that at 22°C outside temperature, the expected temperatures in the animal occupied zone (AOZ) were within the recommended temperature requirement for market pigs during transport (not exceeding 27°C). Sensitivity analysis for summer conditions also showed that the ventilation fans created a stream of colder air along the center of trailer (Figure 7.5). Moreover, for all levels of outside air temperature investigated, a 3 to 5°C temperature rise was consistently observed inside the animal compartment. Thus, based on the computer simulation results, addition of a misting system was considered for the air-filtered trailer to cool down inside conditions when outside temperature rises above 22°C.

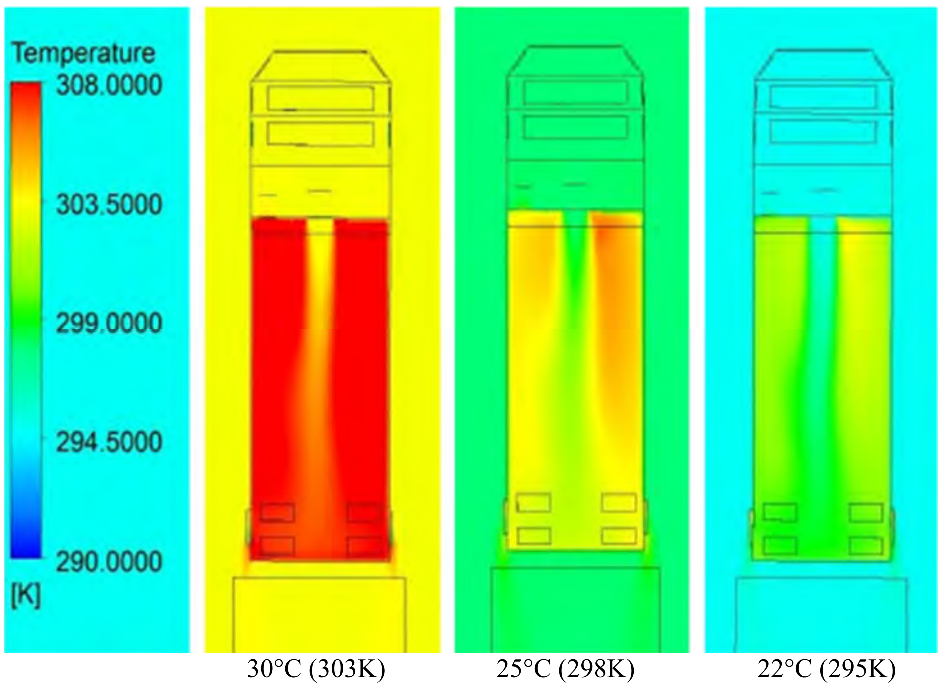


Figure 7.5. Variations in expected air temperature inside the trailer for simulations when outside temperature was 30°C, 25°C and 22°C.

Sensitivity analysis for winter conditions showed that at -25°C, the expected temperatures inside the animal compartment were below 0°C. Predicted temperatures at 8 designated monitoring points inside the trailer (4 on each deck) ranged from -8°C to -1°C. At outside temperature of -17°C, inside temperature slightly increased to as high as 8°C, but with some areas still below 0°C. On the other hand, simulation at -10°C outside temperature yielded predicted temperatures at the 8 monitoring points ranging from 10°C to 17°C, although at points close to the fans temperature could still drop below 10°C. Simulations at cold temperature conditions also showed that the central parts of the animal compartment were warmer compared to the areas at the periphery, which was expected because these areas were close to the cold outer walls of the animal compartment (Figure 7.6). Based on these simulation results, the installation of a 5-kW supplemental heater into the trailer was considered for operation when outside temperature falls below -10°C.

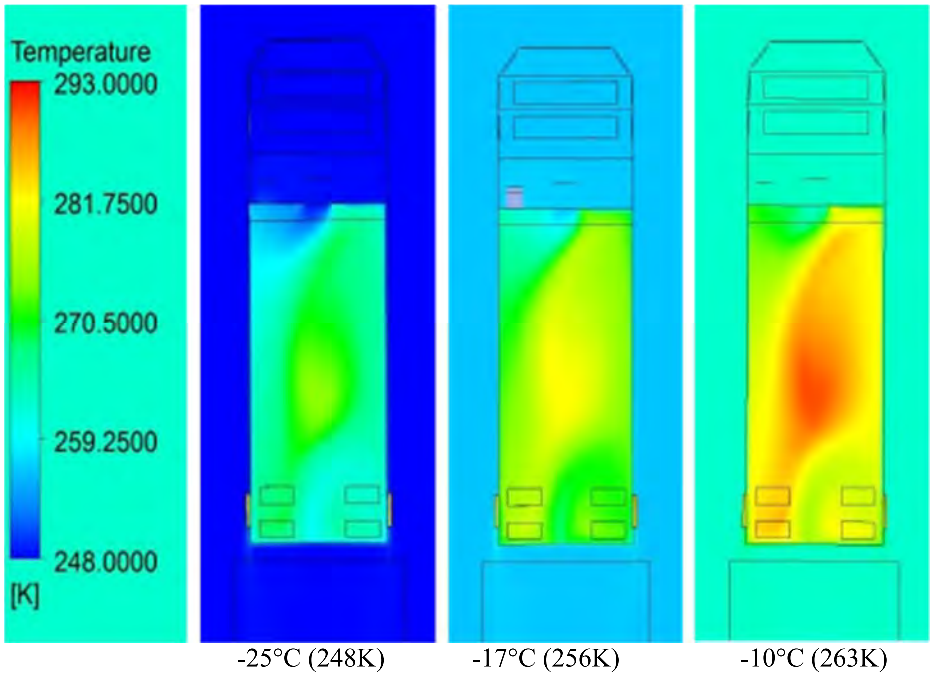


Figure 7.6. Variations in expected air temperature inside the trailer for simulations when outside temperature was -25°C, -17°C and -10°C.

7.2. Phase 2 – Assembly of prototype air-filtered trailer

The prototype trailer was made up of two main compartments -- the front compartment and the animal compartment, installed on top of a flatbed trailer. The two compartments are described in more detail in the following sections.

7.2.1. Front compartment

The front compartment holds components of the trailer air filtration and ventilation systems. It was made out of a metal 10' x 8' x 7.5' (l x w x h) storage container. A 10-kW, single-phase generator set (PowerLine^{TM} Model KS1000-T4, Frontier Power Products, AB, Canada) was installed at the front of the compartment. The air inlets were two 2' x 6.25' (w x h) openings on both sides of the compartment and covered with steel mesh and detachable pre-filters. Air inlet on the driver side also served as access door to the front compartment. The air filter wall, sealed on all sides, is composed of a bank of 6 filter sets, each composed of a 24 x 24 x 1 MERV 8 pre-filter and 24 x 24 x 12 MERV 16 main filter (Camfil, AB, Canada). Two 18-inch diameter, 2 HP, 3-phase axial fans (Sukup, Sheffield, IA USA) were installed at the downstream side of the filters to pull fresh air through the bank of air filter sets and onto the animal compartment. The flow rates for each fan was controlled using a commercially-available centralized ventilation control system, Maximus System (Maximus Systems, Saint-Bruno-de-Montarville, QC, Canada) which also came with 2 variable frequency drives, VFD (Leeson SM2 Series Flux Vector, Regal Beloit Canada, ON, Canada) to operate each of the fans. Schematic diagram of the front compartment is shown in Figure 7.7.

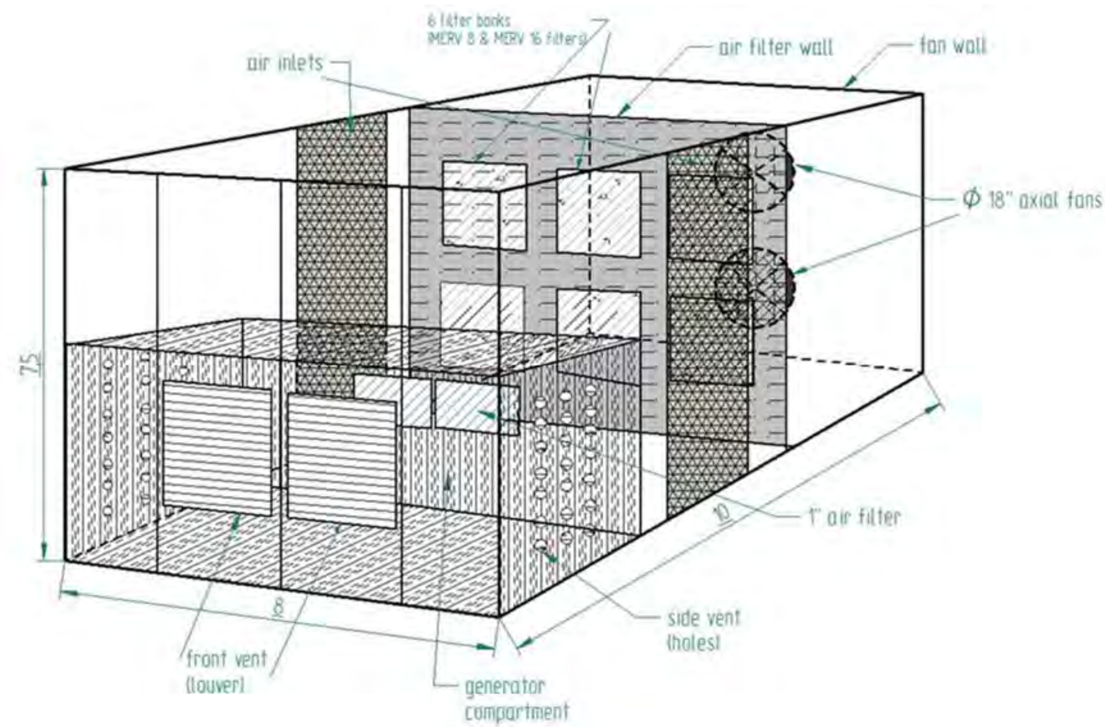


Figure 7.7. Schematic diagram for the set-up of the components of the air filtration systems on the trailer front compartment.

7.2.2. Animal compartment

The animal compartment is a 20’ x 7.25’ x 7’ (l x w x h) box of aluminium 5754 H111 construction (Figure 7.8). It has solid walls, in contrast to conventional livestock trailers where side vents are present throughout the entire length of the trailer. It has two straight decks each divided by a gate into two compartments (referred to as front and rear compartments in later sections). Both bottom and upper decks are 3’5” in height. The middle portion of the floor of the upper deck is hinged and can be lifted up to allow easier loading, unloading or other activities (i.e., trailer cleaning, washing, inspection, etc.) in the bottom deck. Similarly, the middle portion of the trailer roof is hinged for the same purpose in the upper deck. Additionally, pneumatic cylinders are installed on these hinged panels of floor and roof for easier lifting and closing of these movable parts.

Figure 7.8. Photos of the animal compartment showing (A) its lower and upper decks, (B) hinged roof, (C) gate that partitions each deck into two compartments, (D) air exhaust damper, (E) hydraulic loading platform, (F) hydraulic system showing motor, pump, controller and power supply, and (G) exterior of the assembled compartment.

The ventilation fans were installed in the front compartment such that the ventilation air is supplied at the center of the front end wall of each deck in the animal compartment. A steel guard frame was installed at the ventilation opening for each deck to prevent injury to animals from the fan blades. On the other hand, the exhaust air openings were located on both sides at rear part each deck. To prevent the potential of unfiltered air entering the animal compartment through these openings, 2.5' x 1' (w x h) backdraft dampers (Kehfab, Steinbach, MB) were installed on the exhaust openings; additionally, a deflector frame was installed on the outside of each exhaust opening to shield the backdraft dampers (Figure 7.8D).

To address animal handling and welfare issues arising from use of ramps in the conventional livestock trailer, a 1000-kg capacity hydraulic loading platform was added in the prototype trailer. The system is comprised of a hydraulic motor and pump, powered by two 12-V DC automotive batteries, and controlled by a push-button type remote controller shown in Figure 7.8F.

7.3. Phase 3 - Testing and evaluation of the prototype

7.3.1. Stationary test

The aim of the stationary tests was to determine the effectiveness of the air-filtered trailer in minimizing potential exposure of livestock to pathogens during transport. For this purpose, a static test without pigs inside the trailer was done using aerosolized bacteriophage PhiX174 as surrogate to common swine pathogens. Temperature and relative humidity during the test were 19.7 ± 1.6°C and 59.4 ± 12.1% for the upstream chamber and 23.9 ± 0.7°C and 38.4 ± 9.8% for the downstream chamber. The relatively cooler thermal condition in the upstream was attributed to the cooling effect of mist during aerosolization. Average phage concentration in the nebulization solution was 3.0×10^8 ssDNA copies/ml as determined by qPCR.

Figure 7.9 shows the average concentration (in genome copies/m^3 of air) of Phi X174 in the air measured upstream and downstream of the air filter set consisting of a MERV 8 pre-filter MERV 16 main filter. Significant ($p < 0.001$, $n = 24$) reduction in bacteriophage concentration was observed between upstream and downstream of the air filter sets tested, with mean bacteriophage concentrations of 1.8×10^8 (95% CI: 1.2×10^8 - 2.3×10^8) genome copies per m^3 of air and 3.8×10^6 (95% CI: $2.8 \times 10^6 – 4.8 \times 10^6$) genome copies per m^3 of air, respectively. Overall, the air filtration system installed in the trailer yielded an approximately 96.9% reduction in the concentration of bacterial virus Phi X174 measured in the animal compartment of the trailer relative to upstream concentration. Moreover, there was strong positive correlation ($r = 0.445$, $p < 0.05$, $n = 24$) between bacterial virus concentration upstream and downstream of the air filter; which means that the level of downstream concentration fluctuates with that of the upstream concentration.

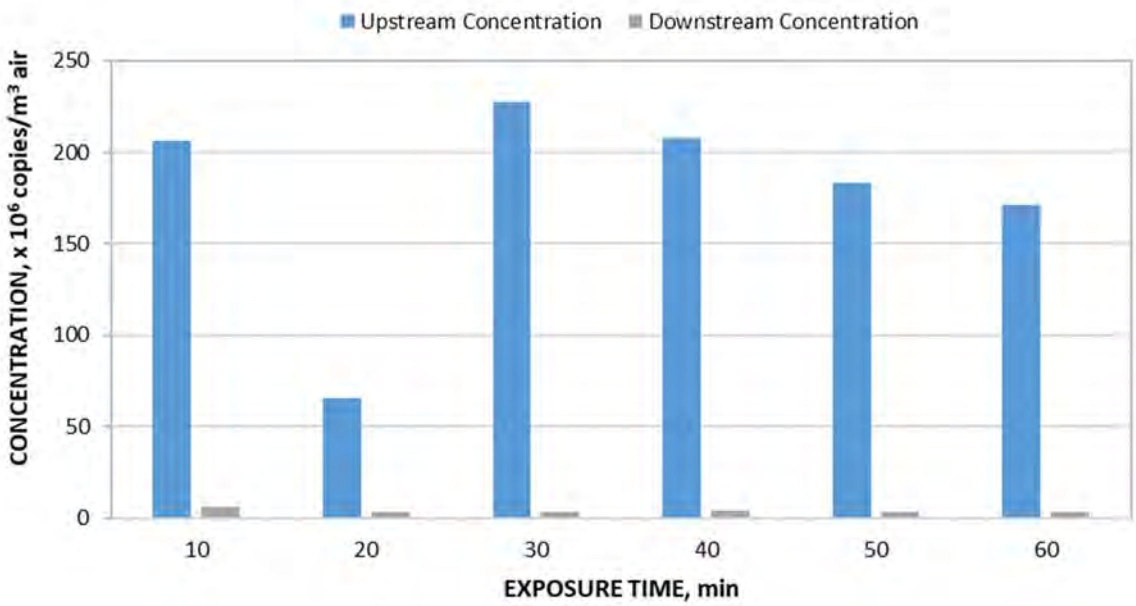


Figure 7.9. Total bacteriophage Phi X174 (in genome copies/m^3 of air) detected by qPCR. Each bar represents average concentration of the surrogate virus in the air sampled using 37-mm cassettes loaded with polycarbonate filters from four replicate trials.

To test the integrity of the sampling method and set-up, smoke test coupled by two 10-minute each of positive and negative control tests were conducted. Smoke test was done to ensure there was no leak around the air filter sets and the testing chambers (from upstream of the filter set to downstream of the fan). No significant difference ($p = 0.341$) between the upstream and downstream phage concentrations was found from the positive tests conducted. The positive control test confirmed that no false negative results were obtained in the four trials conducted, i.e., no viral genome detected or below qPCR detection limit, as a consequence of factors other than the relative effectiveness of the air filtration system installed. On the other hand, the negative control tests yielded no Phi X174 genome detected at both upstream and downstream sampling locations. This means that the positive results obtained, i.e., all quantifiable genome counts, were primarily due to actual concentration of the aerosolized test virus captured in the sampling device and not due to unknown contaminations.

Due to limited duration of exposure to aerosol challenge (approximately 60 minutes) per filter set, no effect of loading can be tested. Furthermore, it is important to note that the air filter sets were tested under extreme condition, i.e., at very high bacterial virus concentration (1.8×10^8 genome copies per m^3 of air). In a study conducted by Corzo et al. (2013) for instance, measured concentration of influenza A virus varied in different locations: 3.20×10^5 RNA copies/m^3 air inside the barn, 1.79×10^4 RNA copies/m^3 air external exhaust fans, and 4.65×10^3 RNA copies/m^3 air at distances 1.5 at 2.1 km away from the infected area. Thus, the tested filters may show greater potential in control of pathogen exposure during transport under conditions normally expected in the field.

7.3.2. Road test

Details of the trailer loading for monitoring trips

Table 7.3 summarizes the details of the monitoring trips, including dates, number of pigs transported, and corresponding space allowances used including the time for each event category throughout each trip.

A total of 60 market-sized pigs with average weight of 125.5 ± 6.2 kg (115 – 140 kg) were loaded into the four compartments of the prototype trailer at 15 pigs/compartment. For the second trip, similar group size was used with an average weight of 122.8 ± 6.4 kg (114 – 140 kg). A total of 61 pigs were loaded for the 2nd trip. Space allowance of 0.40 m^2/115 kg pig as recommended by Correa (2011) as cited by Schwartzkopf-Genswein et al. (2012) for winter transport of pigs, was adapted for both trips.

Duration of different events throughout the two journeys were synonymous except that waiting period at the plant took longer during the first trip than the second trip. Moreover, journey started earlier during the first trip (loading at 4:15 am) while second journey started at around 5:15 am on December 14.

Table 7.3. Summary of details on the loads of pigs and the event and timelines for the two monitoring trips.

	Monitoring Trip #1	Monitoring Trip #2
Date of trip	December 1, 2017	December 14, 2017
Number of pigs transported	60	61
Average weight of pigs, kg	125.5	122.8
Space allowance, m^2/115 kg pig	0.40	0.40
Event / duration (hr, min)		
Loading	1 hr (4:15 am – 5:15 am)	55 min (5:12 am – 6:07 am)
Waiting for departure	1 hr (5:16 am – 6:15 am)	1 hr, 12 min (6:08 am – 7:20 am)
Main travel	4 hr, 14 min (6:16 am – 10:30 am)	4 hr, 20 min (7:21 am – 11:40 am)
Arrival and waiting at the plant	2 hr (10:31 am – 12:30 pm)	1 hr, 18 min (11:41 am – 12:59 pm)
Unloading	1 hr, 5 min (12:31 pm – 1:35 pm)	1 hr (1:00 pm – 2:00 pm)
Total trip time (hr, min)	9 hr, 19 min	8 hr, 45 min

During the December 1 trip, one pig at the rear compartment of the top deck was found dead upon arrival at the plant, while on the December 14 trip, one pig from the same compartment was found non-ambulatory during unloading and had to be euthanized in the plant. The actual cause of the dead or down-on-arrival (DOD) pigs could not be directly ascertained, but subsequent discussion with the plant personnel and the barn manager indicated that those pigs most likely had pre-existing health conditions and should have been held back at the barn for appropriate care before being loaded with the next batch of market pigs.

Ventilation system

The active ventilation system for the air-filtered trailer prototype was programmed as shown in Table 7.4. Ventilation flow rate was primarily controlled based on the temperature measured by a temperature sensor installed at the center of each deck. Minimum ventilation was set at 10% of fan capacity. When temperatures in the compartment exceeds 16.5°C, the ventilation system ramped up from its minimum setting to a maximum of 100% fan capacity within a range of total temperature increase of 7.5°C above the set-point of 16.5°C. During the 2nd monitoring trip, RH and CO_2 compensation as stated in Table 7.4 were also applied. This flexibility in ventilation control was one feature of the installed ventilation system controller system.

Table 7.4. Ventilation system control program settings for the prototype air-filtered trailer during the monitoring trips.

	Set-point Temperature, °C	Ramping Temperature, °C	Minimum Ventilation, % Fan Capacity
Temperature	16.5	7.5	10%

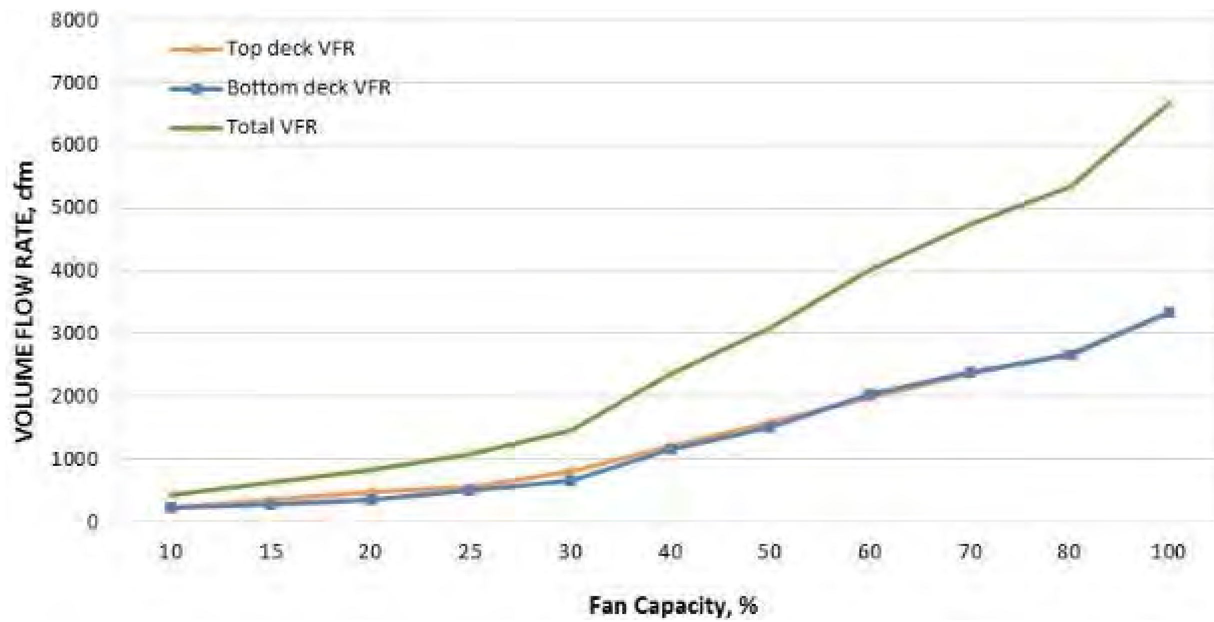
*RH compensation - 20% ramping up in ventilation from minimum of 10% as RH rises above 70% to 80%.
*CO_2 compensation - 20% ramping up in ventilation from minimum of 10% as CO2 rises above 2500 ppm to 5000 ppm.

*RH and CO_2 compensations were only applied during the December 14 monitoring trip.

Minimum and maximum ventilation for the trailer were determined based on a total of 60 market pigs loaded in the trailer at an average of 130 kg/pig. Minimum ventilation of ~ 500 cfm (for the entire trailer) was dictated by moisture control at outdoor temperature as low as -35°C. Maximum ventilation, on the other hand, was computed using the recommendation from Mitchell and Kettlewell (2008) for estimation of ventilation flow rate for livestock in transit ($VFR = TMHP$ $C_p\ x\ \Delta T$ (Equation 4):

$$VFR = \frac{TMHP}{C_p\ x\ \Delta T} \qquad \text{(Equation 4)}$$

where *VFR* is the ventilation flow rate in m^3/s, *TMHP* is total metabolic heat production in J/s, C_p is specific heat capacity of air (1226 L/m^3/°C) and ΔT is acceptable temperature rise in °C. The computed maximum ventilation was ~ 5600 cfm for a design outdoor temperature of 25°C. Initial calibration of the installed ventilation fans (data not shown) indicated that the maximum flow rate could reach as high as ~ 9200 cfm for the entire trailer. Thus, frequency was reduced for both variable frequency drives of the ventilation controller to 39 Hz from a full capacity of 60 Hz.



Appendix Figure 15. 2 provides the calibration of the two fans at the settings applied during the two monitoring trips. As shown, minimum ventilation at 10% of fan capacity was ~ 440 cfm while maximum ventilation at 100% fan capacity was ~ 6700 cfm, although the latter was not reached during the two trips.

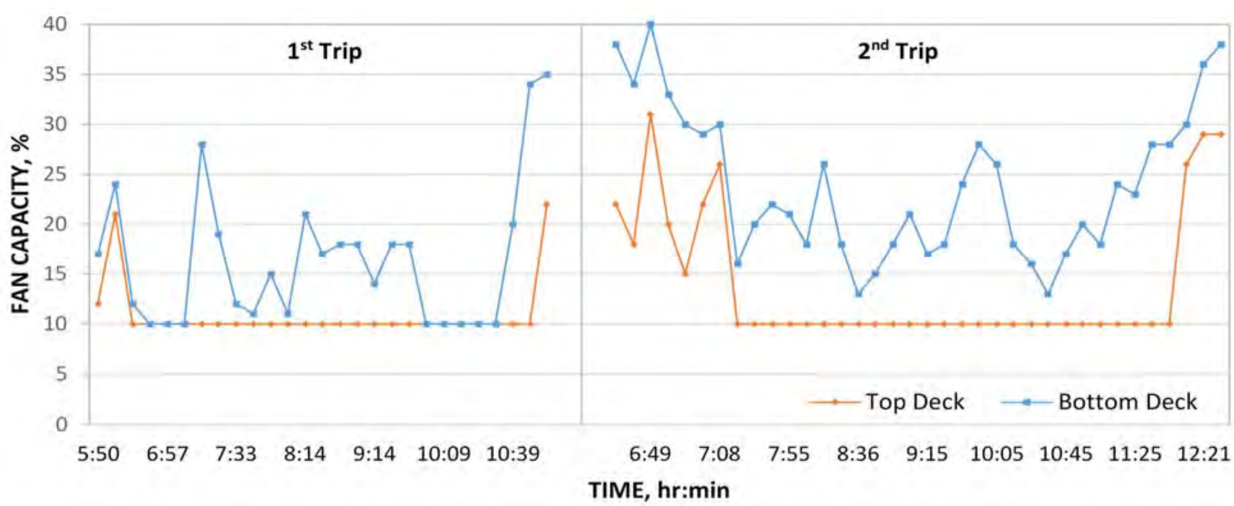


Figure 7.10. Actual ventilation schedule for the two monitoring trips.

Figure 7.10 shows the actual ventilation schedule manually recorded during the two road tests. Due to the generally low temperature (below set-point temperature of 16.5°C) at the top deck for both trips, ventilation flow rate was at the minimum (10% of fan capacity) for most of trips. Ventilation ranged between 10% - 22% and 10% - 35% for the top and bottom decks, respectively, during the 1st trip. Corresponding values for the 2nd trip were 10% - 31% and 13% - 40%. Considering only ventilation flow rates during the main travel (stable) portion of the two trips, average ventilation flow rates for the top and bottom decks were 10 ± 0.0% (~ 220 cfm) and 14 ± 4.9% (300 cfm) for the 1st trip and 10 ± 0.0% (~ 220 cfm) and 20 ± 4.5% (~ 415 cfm) for the 2nd trip.

Environmental conditions in the trailer during the monitoring trips

<u>Temperature</u>

Figure 7.11 shows the temporal variation in temperature throughout the course of monitoring trips 1 and 2. The trend in temperature for the two decks (top and bottom) were similar for both trips. Temperature for the bottom deck continually rose from the start of loading until it peaked during the early period of the travel. Top deck temperature on the other hand, had an initial increase in temperature for approximately 30 minutes from start of loading, dropped for a short period and increased until peak during early period of the travel. This observation in the top deck temperature was due to the hinged floor being open while loading pigs in the bottom deck compartments, which was then closed after filling each bottom compartments to capacity. Temperature from start of loading to early period of the trips ranged within -7°C to 22°C and -0.5°C to 23°C for the first and second monitoring trips, respectively. Although ambient temperature was similar for both monitoring trips, minimum interior temperature recorded for the second trip was generally higher compared to the first one. This is attributed to the use of a unit heater during the December 14 trip. Temperature for both decks then started to stabilize during the main travel period (combined average for both decks of 10.2 ± 3.4°C for the first trip and 12.8 ± 3.9°C for second trip), except for some minor peaks, such as during slow down upon entering the town center together with a short stop from 7:10 am to 7:20 am for the December 1 trip and during a stop to adjust unit heater in the front compartment around 9:30 am until 9:36 am during the December 14 trip. Compared to temperature during the main travel period, the temperature during the waiting period at the abattoir was generally higher (18.1 ± 2.2°C and 16.7 ± 3.9°C for trips 1 and 2, respectively). At the start of unloading, temperature dropped first in the upper deck followed by drop in temperature in the lower deck, mainly because the roof was flipped open to start unloading from the top deck first.

For the entire transport period, the inlet temperature for monitoring trips 1 and 2 ranged from -6.5°C to 11.5°C and 0.5°C to 22°C, respectively. The significantly lower ($p<0.05$) inlet temperature for the first trip (1.5 ± 4.5°C) can be attributed to use of unit heater during the second trip (7.5 ± 4.6°C). Correspondingly, the average outlet temperatures were -7°C to 22.5°C and -1°C to 21.5°C, respectively, for the two trips.

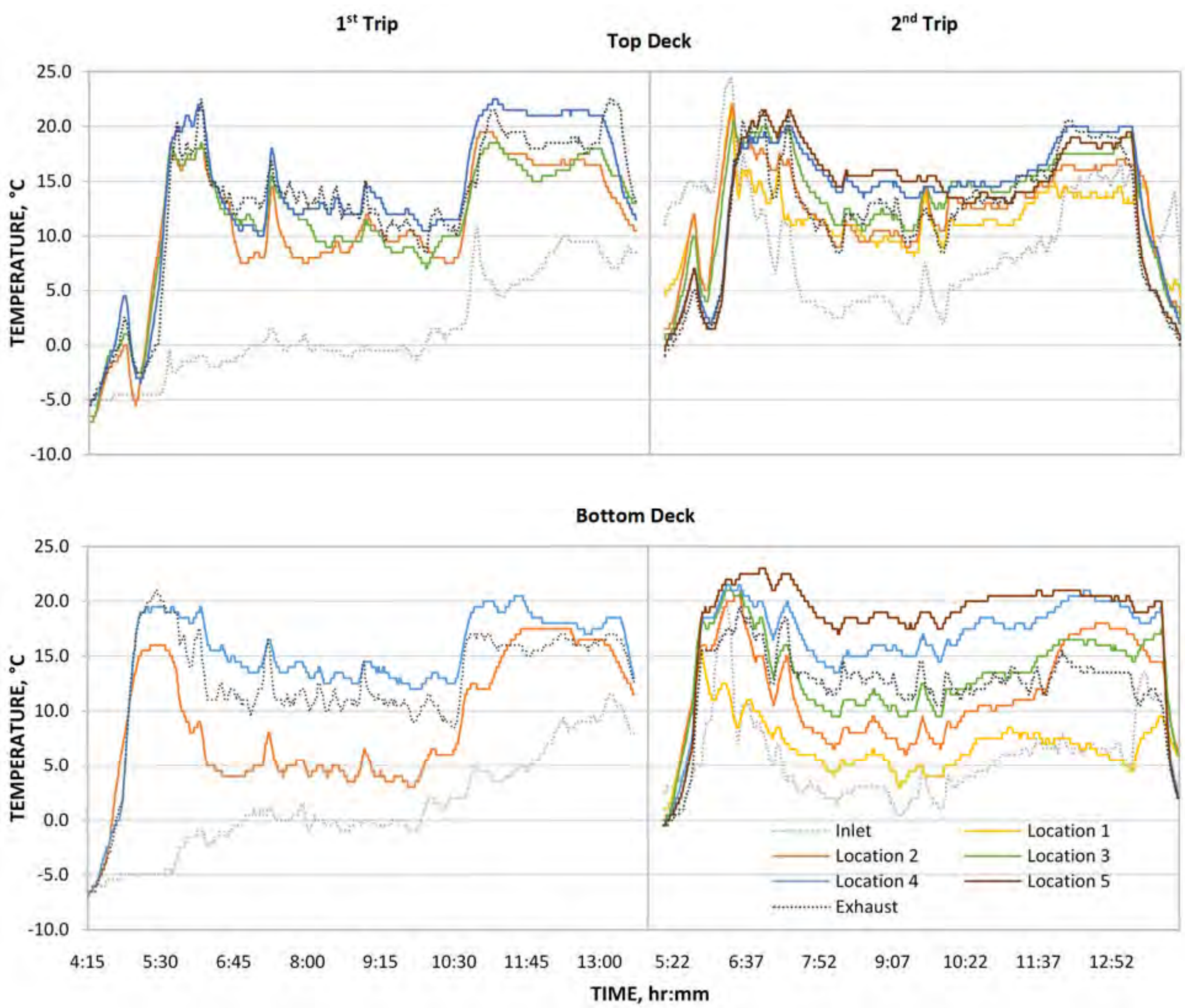
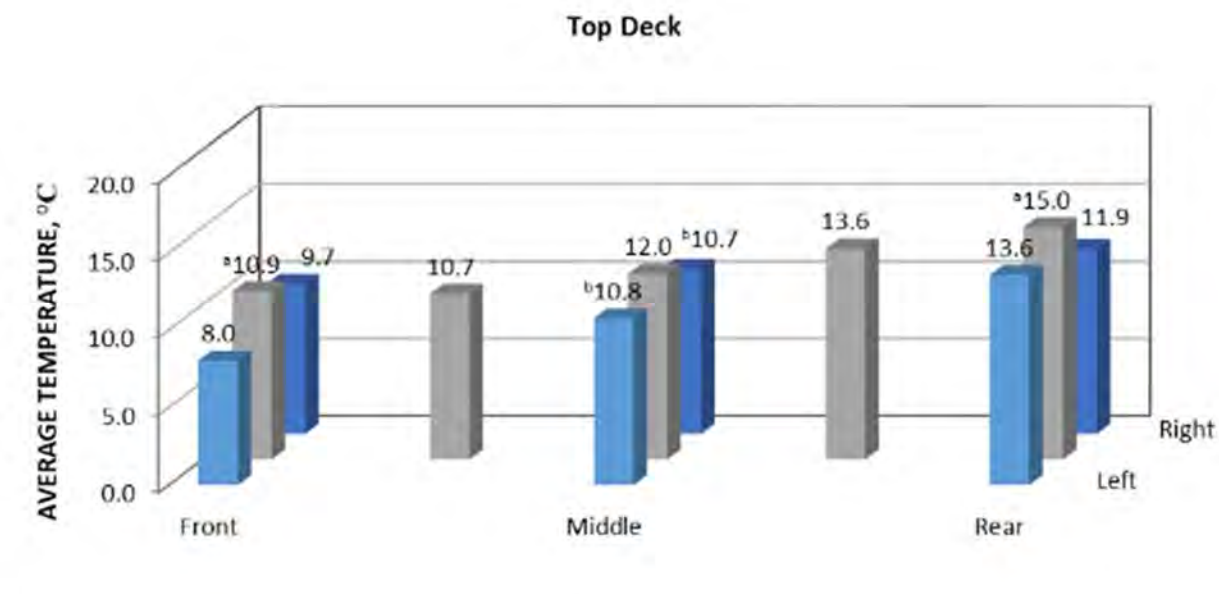


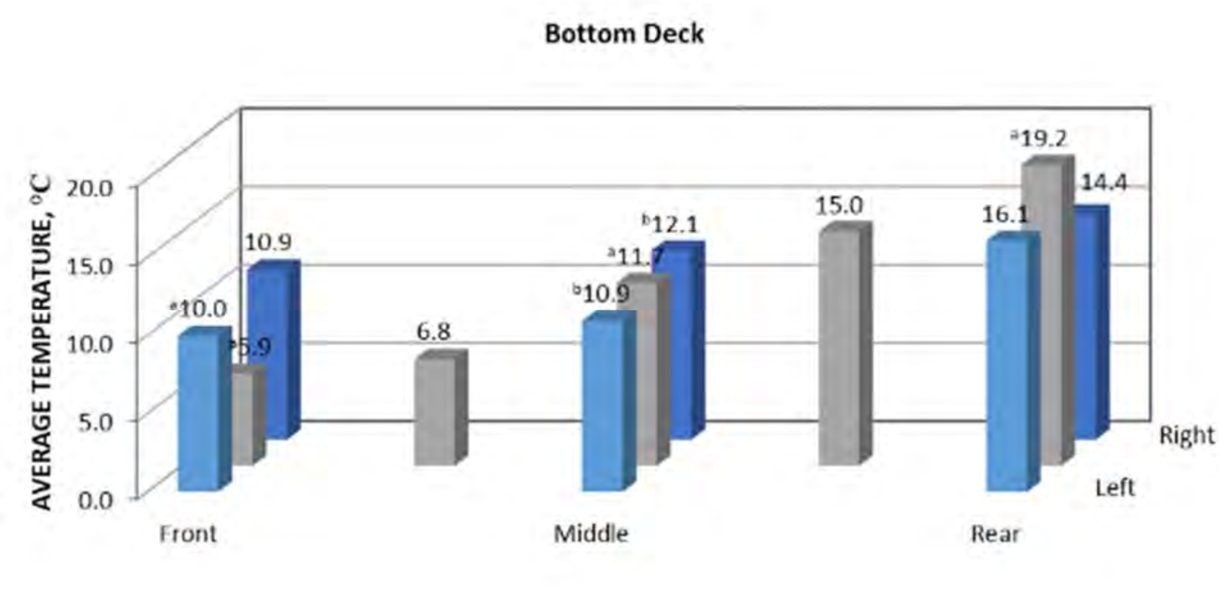
Figure 7.11. Variation in inlet, exhaust and internal trailer temperature measured in different locations approximately 1 m (~ 40 in) above the floor along the center of the trailer top and bottom decks during the two monitoring trips. The time series represent temperature levels from start of loading in the farm to end of unloading in the plant.

Figure 7.12 shows distribution of average temperature inside the trailer at several locations during the most stable period of the two trips (i.e., the main travel period). These periods were defined after the trailer has travelled for ~1 hour and by visual inspection of the time series shown in Figure 7.111. A series of data filtering techniques were also applied before analysis was done.

Generally, temperature inside the animal compartment of the prototype trailer increased from front to rear. Moreover, a paired t-test at 95% confidence interval of the temperature at the center of the trailer vs the average of corresponding temperatures at the periphery (left and right side of the trailer) showed significantly higher (*$p<0.05$*) temperature for the central part of the trailer. This is in agreement with the prediction using computer simulations during the design phase of the project. Sensitivity analysis using the S2-S4 design configuration under winter conditions yielded higher temperatures at the center compared to the sides of the trailer in close proximity to the cold trailer walls (Figure 7.6).



(A)



(B)

Figure 7.12. Average air temperature during the main travel period of the two monitoring trips at in different locations approximately 1 m (~ 40 in) above the floor of the (A) top deck and (B) bottom deck of the animal compartment. Means marked with [b] which were measured at 0.7 m (~

30 in) above the deck floors to represent pig-level temperature. Data labels marked with [a] and [b] represent means derived from monitoring trip # 2 only.

Also, Figure 7.12 shows that mean temperature at the center of Location 1 of the bottom deck (5.9 ± 1.4°C) was lower compared to temperature at corresponding location in the top deck (10.9 ± 1.2°C). It is important to note that averages for the said locations were based on data gathered from the second monitoring trip only (superscript a) when the unit heater was operated at the front compartment. Thus, it is presumed that the unit heater which was installed at the top-right corner of the front compartment (refer to Figure 6.8) was able to pre-heat inlet air for the top deck only. Average bottom deck inlet temperature of 3.4 ± 1.7°C was significantly lower ($p<0.05$) than upper deck inlet temperature of 5.1 ± 2.1°C during monitoring trip 2. Table 7.5 summarizes inlet and outlet temperatures during the main travel (stable) period of the two monitoring trips.

Table 7.5. Inlet and exhaust temperatures (mean ± SD) in °C in the top and bottom decks of the prototype trailer during the main travel (stable) period of the two monitoring trips.

Trip	Bottom Deck		Top Deck	
	Inlet	Exhaust	Inlet	Exhaust
1	0.0 ± 0.9	10.9 ± 1.0	-0.3 ± 0.9	12.6 ± 1.6
2	3.4 ± 1.7	12.6 ± 0.9	5.1 ± 2.1	12.4 ± 1.9

Additionally, variability of temperatures across different locations inside the animal compartment at a specific time reached as high as 12°C (5.0 ± 3.0°C) during the 1st trip and was maximum at 9.0°C (4.3 ± 2.2°C) during the 2nd trip. These high temporal differences in temperature were observed between the front and rear compartments of both bottom and top decks.

Relative humidity

Relative humidity as depicted in the time series shown in Figure 7.13 showed generally high levels within the first to 1.5 hours from the start of loading. Interior RH levels eventually decreased and stabilized during the main travel periods of both 1st and 2nd trip. Average RH inside the trailer during the travel period of the 1st trip was 51.9 ± 5.6% and 60.5 ± 7.5% for the bottom and top deck, respectively. Corresponding values for the 2nd trip were 48.9 ± 5.0% and 62.7 ± 7.5%. After a brief increase in RH upon entering the town center where the abattoir was located, RH levels dropped during the waiting period at the plant. A slight increase then followed while preparing for unloading. Also worth noting is the interaction between temperature and RH during the stationary period at the plant. While temperature was high during this period (Figure 7.11), RH on the other hand dropped. This could be partly due to higher ventilation rates at higher temperatures inside the trailer which could have effectively lowered moisture level during the waiting period at the plant.

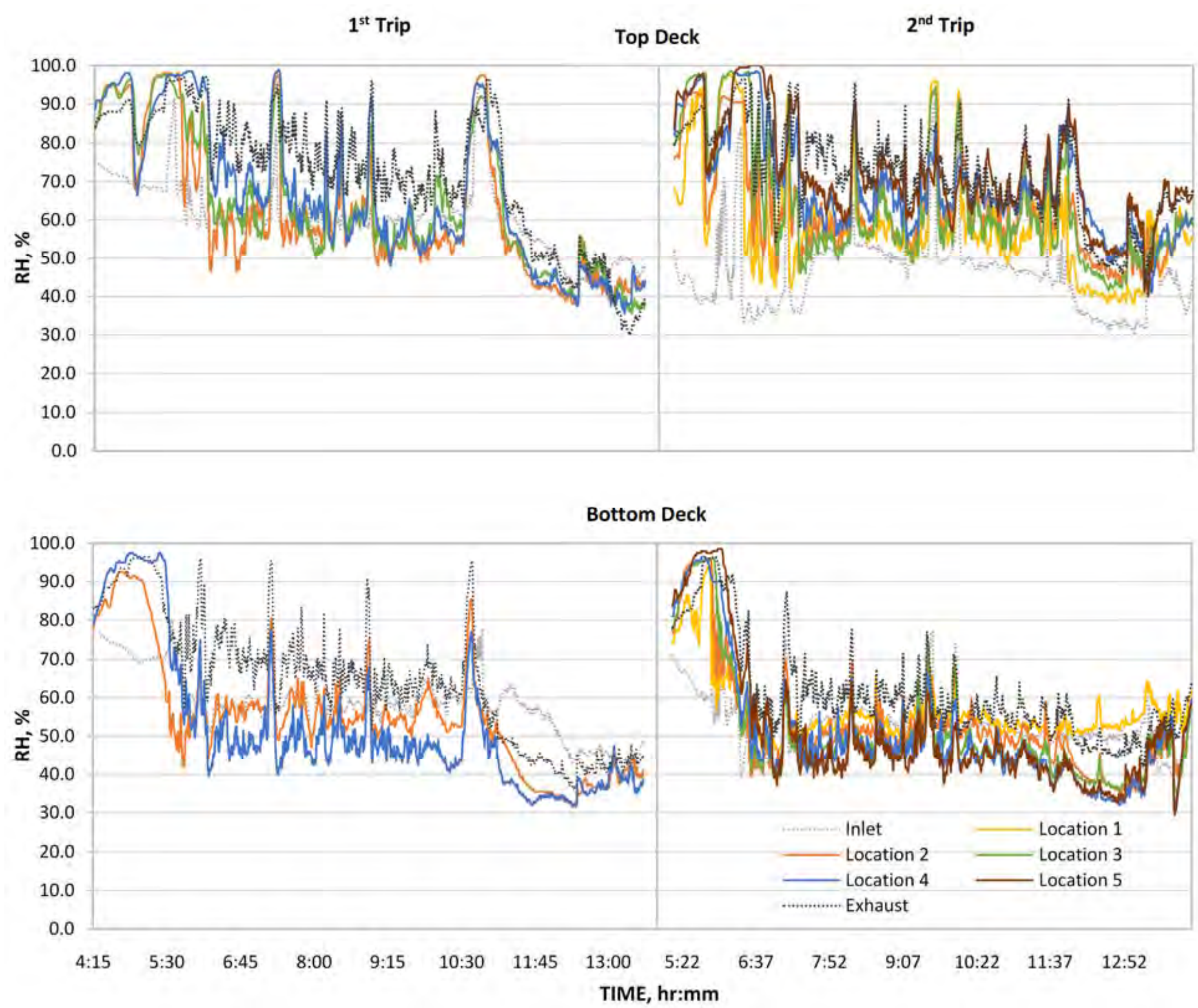


Figure 7.13. Variation in inlet, exhaust and internal trailer relative humidity measured at different locations along the center of the trailer top and bottom decks during the two monitoring trips. The time series represent RH conditions from start of loading in the farm to end of unloading in the plant.

Figure 7.14 shows the average RH along five monitoring locations in the top and bottom decks of the trailer during the main travel (stable) period. RH level increased from front to rear in the top deck. On the contrary, RH decreased from front to rear in the bottom deck. While the trend in the top deck is expected due to the front to rear movement of ventilation air, the decline in RH in the bottom deck needs further investigation.

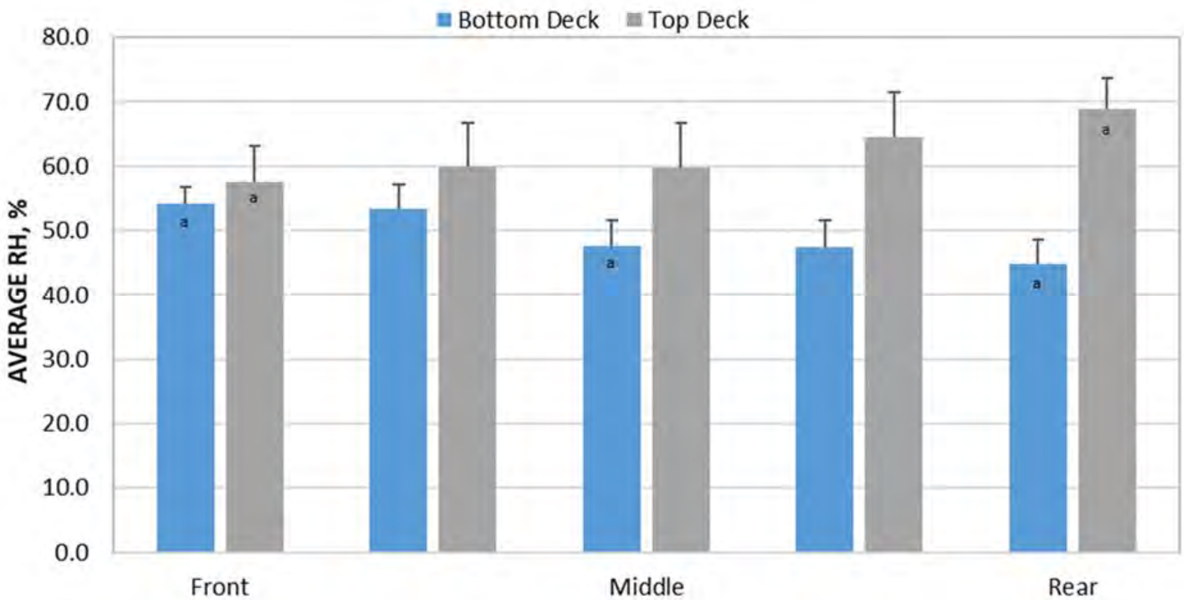


Figure 7.14. Average relative humidity during main travel (stable) period of the two monitoring trips) measured at different locations along the center of the trailer top and bottom decks. Columns marked with [a] represent means derived from monitoring trip # 2 only. Error bars correspond to standard deviations of the measurements.

<u>Carbon dioxide</u>

Carbon dioxide (CO_2) level was used as an indicator of overall air quality inside the trailer during the two monitoring trips. CO_2 concentration (Figure 7.15) inside the loaded trailer followed the general trend exhibited by temperature and RH throughout the monitoring trips. Generally, with higher physical activities such as when pigs are moved into or out of the compartments as well as during slow downs and other transit interruptions including traffic stops and longer stationary periods that tend to agitate the pigs, increase and peaks in temperature, RH and CO_2 were observed. The levels for these parameters then stabilized during transit, usually a few hours after loading and several minutes after short travel interruptions.

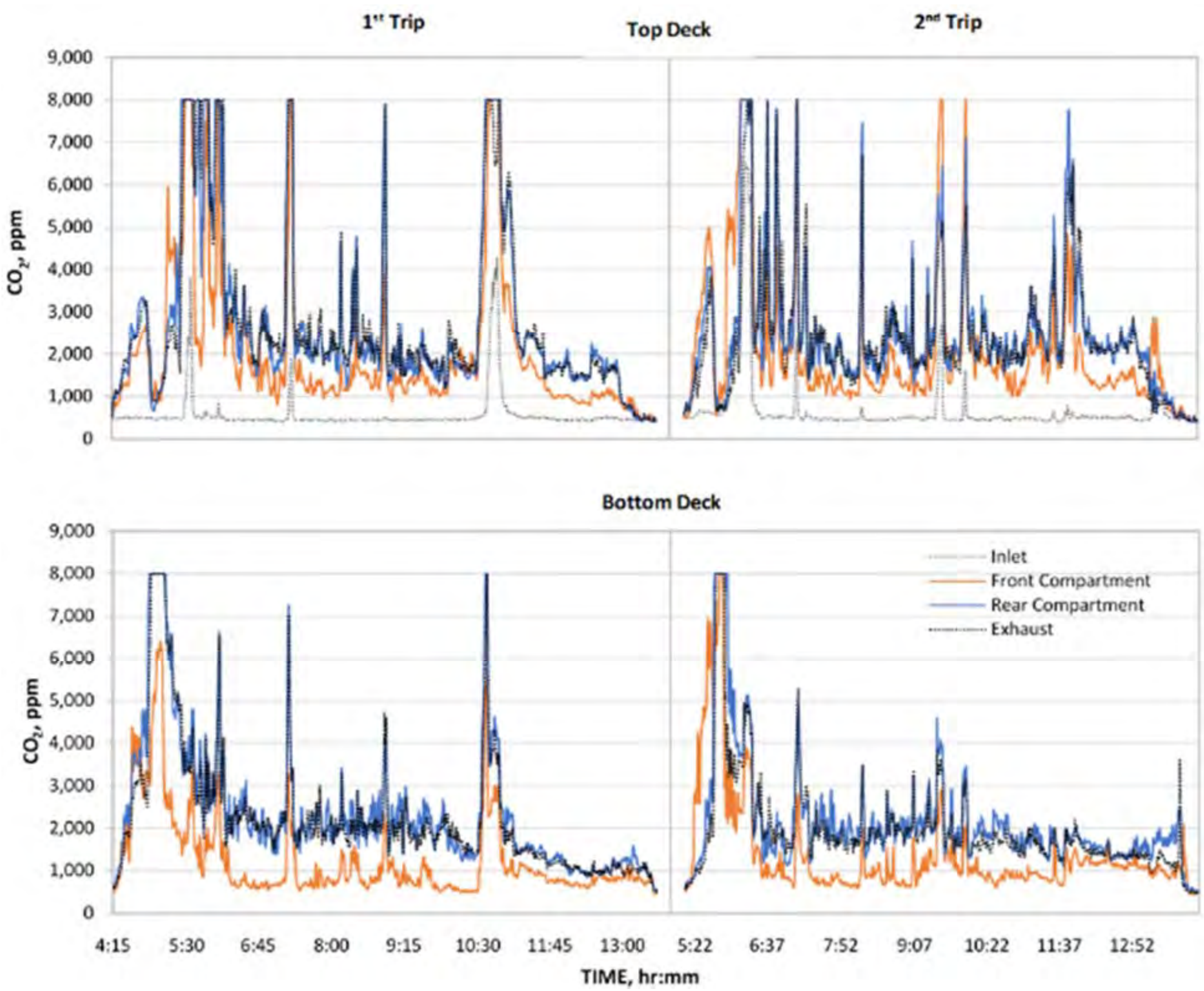


Figure 7.15. Variation in inlet, exhaust and interior CO_2 levels for both the trailer top and bottom decks during the two monitoring trips. The time series represent CO_2 levels from start of loading in the farm to end of unloading in the plant.

During the main travel (stable) period of the trips, average CO_2 concentrations at the bottom deck were 850 ± 277 ppm and 1999 ± 422 ppm for front and rear compartments, respectively. Corresponding values for the top deck were 1533 ±_427 ppm and 2125 ± 518 ppm. Moreover, inlet CO_2 level for the two trips was 462 ± 55 ppm while outlet CO_2 levels were 1888 ± 322 ppm and 2209 ± 508 for the bottom and top decks, respectively. Figure 7.16 graphically summarizes these results. These values are comparable to CO_2 levels observed inside pig barns during cold weather conditions when ventilation rates are low. Finally, the consistently higher CO_2 concentration at the rear portion of the trailer as well as in the outlet suggests that the ventilation system under the given weather and its operating condition was able to remove stale air from inside the trailer.

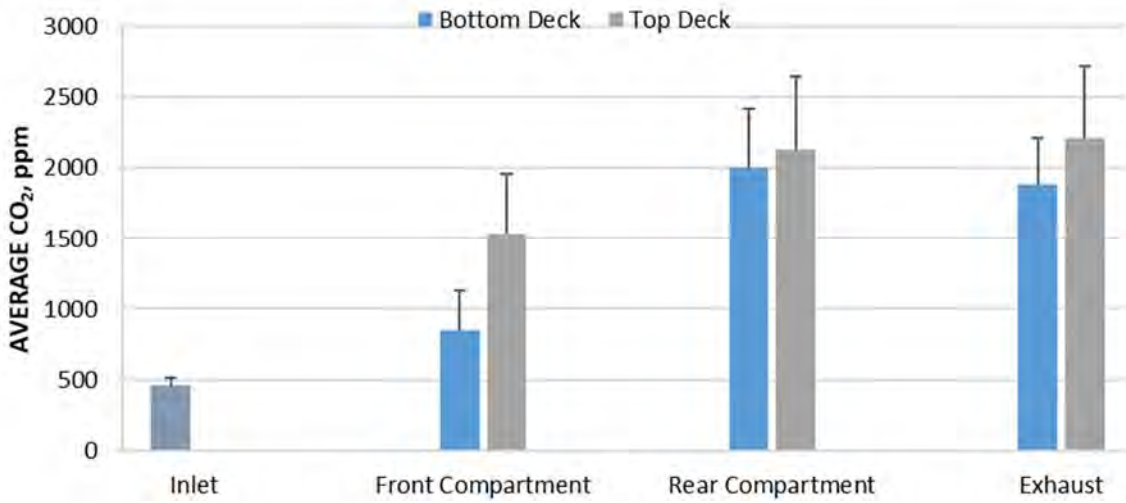


Figure 7.16. Average inlet, exhaust and interior CO_2 levels during main travel (stable) period of the two monitoring trips for both the trailer top and bottom decks. Error bars correspond to standard deviations of the measurements.

<u>Air velocity</u>

Air movement inside the prototype trailer was primarily driven by mechanical ventilation provided by the axial fans that blows air into the animal compartment at the front end. Thus, as shown in Figure 7.17, rear compartment (top and bottom decks) air velocities were fairly stable throughout transit while front compartment air velocities for both top and bottom decks showed peak values probably during periods when ventilation rate increased as driven by increase in temperature, RH or CO_2 inside the animal compartment.

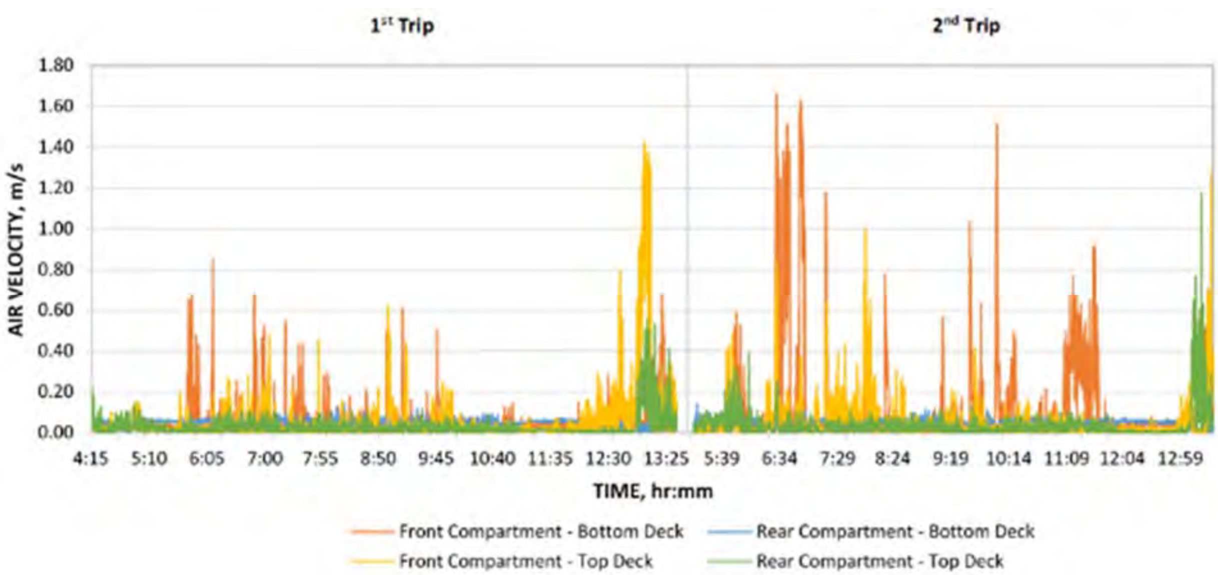


Figure 7.17. Variation in air velocity inside the trailer measured at the center of the front and rear compartments of the trailer top and bottom decks during the two monitoring trips. The time series represent air velocities from start of loading at the farm to end of unloading in the plant.

Figure 7.18 shows the average air velocity during the main travel period of the two trips. As shown, the average velocity at the front compartments were higher and showed greater variability compared to the rear compartment air velocities. The range and mean (mean ± SD) velocities for the four different sensor locations in the animal compartment are as follows: 0 – 0.61 m/s (0.06 ± 0.10 m/s) and 0 – 0.11 m/s (0.04 ± 0.02 m/s) for front and rear compartments of the bottom deck; and 0 – 0.28 m/s (0.04 ± 0.05 m/s) and 0 – 0.09 m/s (0.02 ± 0.02 m/s) for front and rear compartments of the top deck, respectively. In addition, inlet velocities measured by sensors located inside the housing of the ventilation fans gave the following values: 0.07 – 5.21 m/s (2.95 ± 0.76 m/s) for the bottom deck and 0 – 4.55 m/s (1.48 ± 0.93 m/s) for the top deck. These values were computed after relevant data filtering described in the methodologies was applied.

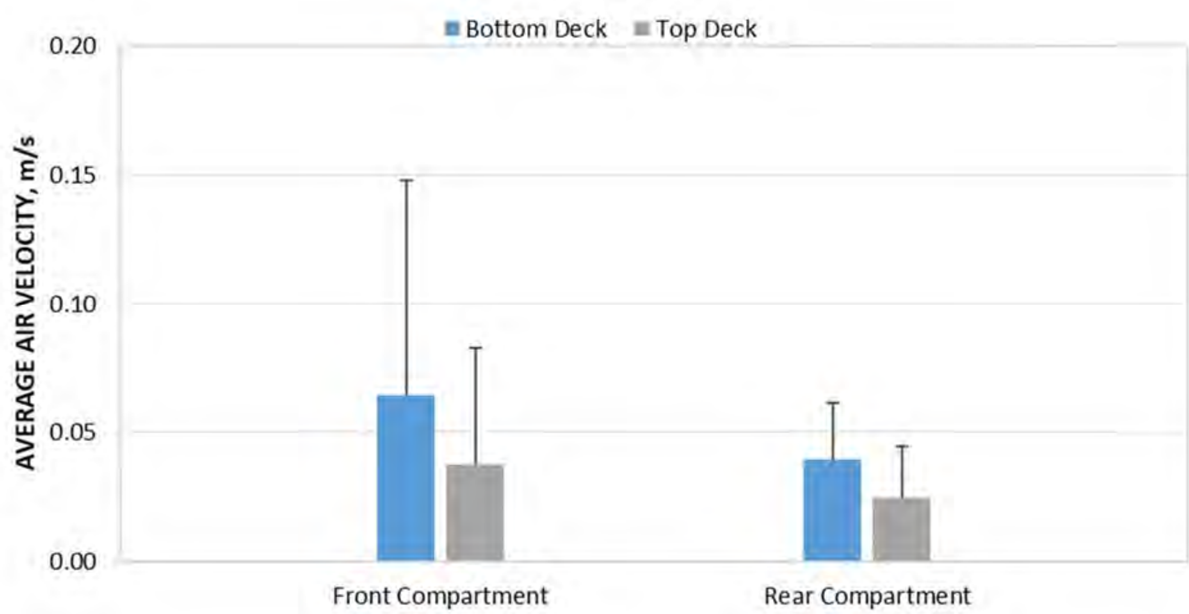


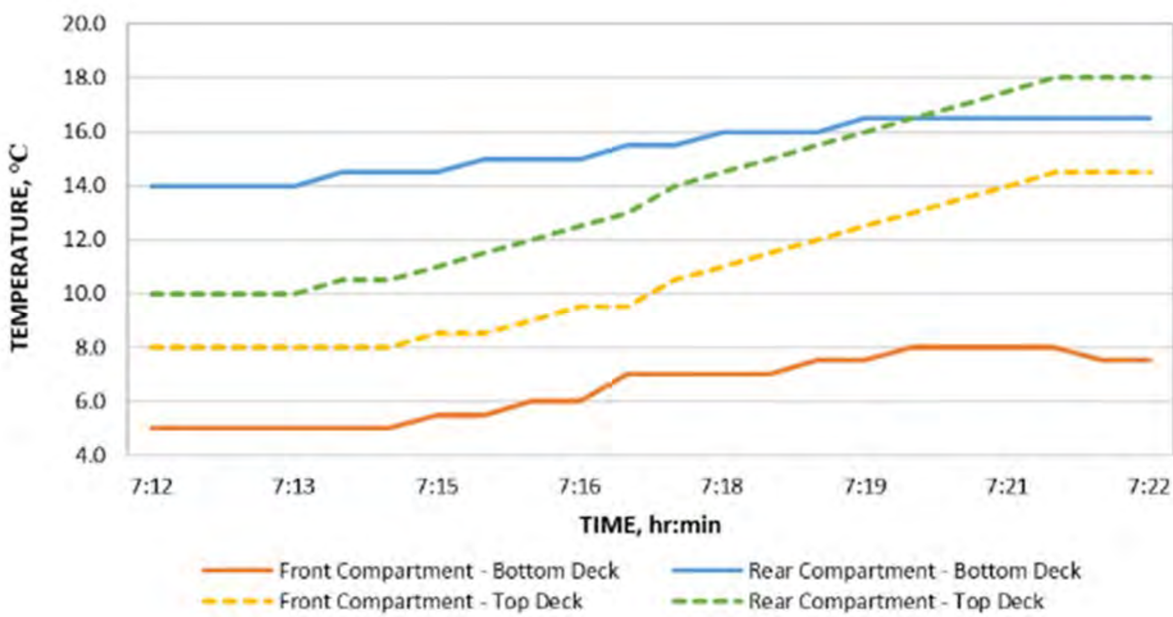
Figure 7.18. Average interior air velocity during main travel period for both the trailer top and bottom decks during the two monitoring trips. Error bars correspond to standard deviations of the measurements.

<u>Effect of travel interruptions on trailer thermal condition and air quality</u>

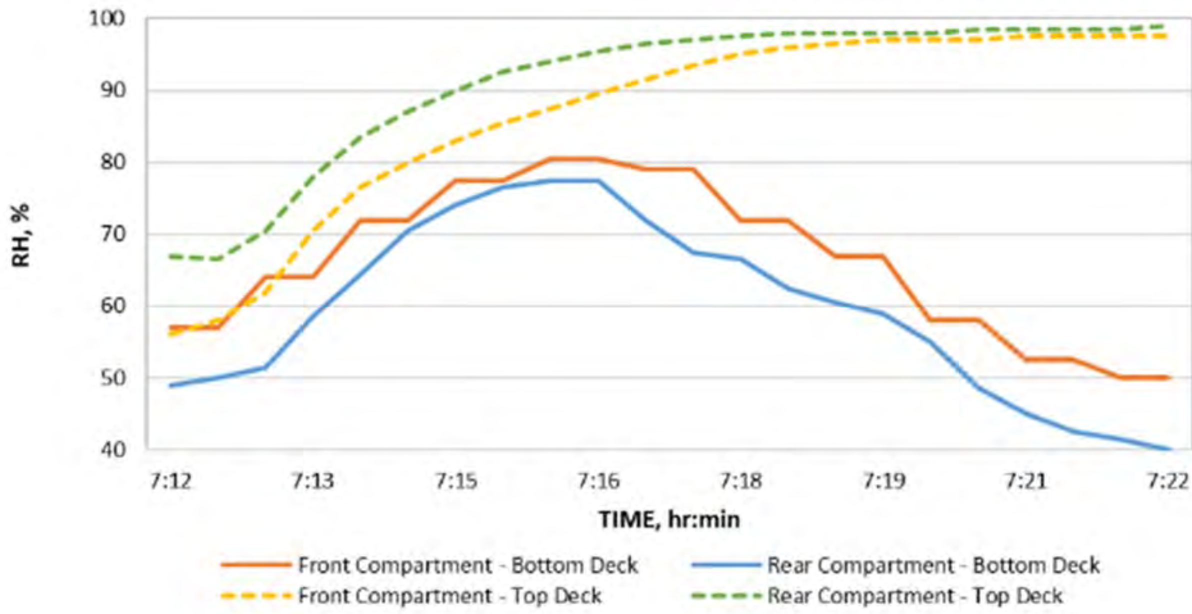
The impact of travel interruptions such as slowing down at town centers and short stoppage on the thermal condition and air quality inside the trailer with pigs during the December 1 trip is summarized in Figure 7.19. The event explored through the graphs was within the main travel (stable) period of the 1st trip when the trailer approached a town along the route (7:12 am) and subsequently went for a short stop (7:17 - 7:22 am).

An average temperature increase of 0.5°C/min with a 2.5 – 3°C temperature increase within a 5-minute period was observed in the bottom deck compartments. A more rapid temperature rise (~1°C/min) occurred at the top deck compartments with 6.5 - 8°C increase within ~7 minutes. While temperature gradually increased from the beginning of the travel interruption until the trip resumed, change on RH and CO_2 levels, on the other hand, peaked early during stoppage. At approximately 5 minutes when travel resumed, bottom deck RH and CO_2 levels started to drop until it reached their corresponding stable levels. Top deck RH and CO_2 levels on the contrary took longer to return to their stable levels. The shorter period it took for bottom deck RH and CO_2 levels to stabilize compared to the upper deck levels is primarily attributed to higher ventilation rate at the bottom deck because of the consistently higher temperature at the rear compartment of the bottom deck where sensors (T, RH, CO_2) used in controlling the ventilation system were installed.

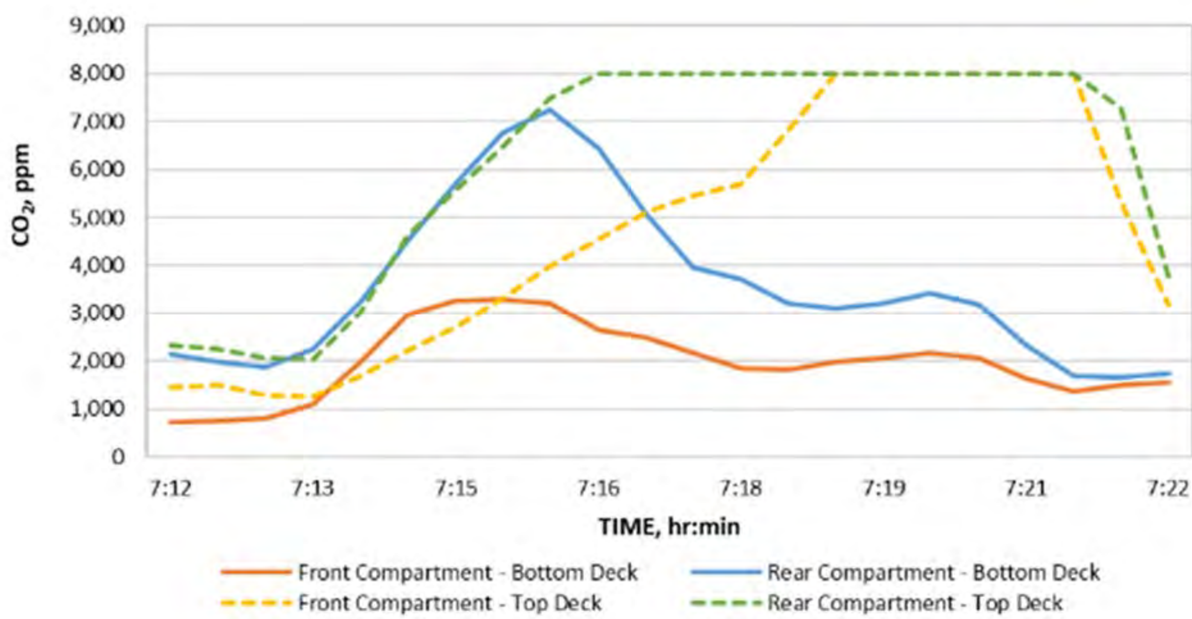
Although travel interruptions showed favorable increase in temperature inside the animal compartment during mild winter condition, these may cause potentially extremely high temperatures during trips in warm summer days. It is also worth noting that during the December 1 monitoring trip, no unit heater was installed yet in the trailer.



(A)



(B)



(C)

Figure 7.19. Change in (A) temperature, (B) RH and (C) CO_2 levels before and during a short stoppage (9:30 am to 9:38 am) on the December 1, 2017 monitoring trip. Parameters were measured at the center of the front and rear compartments of the trailer top and bottom decks.

Ventilation effectiveness

The calculated HRE values at different locations in the animal compartment varied due to the heterogeneity in the thermal conditions, with observed decrease from front to rear of the trailer. The average HRE computed for the bottom and top decks were 1.00 ± 0.38 and 1.17 ± 0.33, respectively. HRE values obtained for the front end of the container (1L, 1C and 1R) were not included in the computation of the average HRE due to presumed direct impact of inlet air on the temperature measured at these monitoring locations. Local HREs are as shown in Table 7.6.

Table 7.6. Heat removal effectiveness (HRE) at different locations in the top and bottom decks of the animal compartment during the two monitoring trips.

Trailer Location		Bottom Deck HRE	Top Deck HRE
Front	1L	3.69†	2.47
	1C	4.95†	1.59†
	1R	2.58	1.71
Middle	2C	1.70	1.35
	3L	1.38†	1.41†
	3C	1.02†	1.12
	3R	1.11†	1.81†
	4C	0.75	0.88
Rear	5L	0.71	0.89
	5C	0.57†	0.88†
	5R	0.79	1.04
Average*		1.00	1.17
SD*		0.38	0.33

† represents HRE values computed from ~ 718 (data from monitoring trip # 2 only) time-specific HRE computations for each location while remaining mean values are averages for ~ 1557 time-specific HRE values
*Average HRE for the ventilation system computed from HRE values for the middle and rear portions of the trailer only. L, C and R in trailer locations stand for left, center and right, respectively.

During heating periods when ventilation flow rates are at the minimum, the primary task of the ventilation system is to effectively remove contaminants and moisture inside an enclosed housing or livestock trailer during transport. In Table 7.7, CRE values for the front compartment of each deck were higher as expected. CRE value of 4.07 for the bottom deck front compartment can be explained by its proximity to the ventilation fans that supplied fresh air as well as to the relatively higher ventilation rates at the bottom deck compared to the top deck. The latter potentially displaced significant amount of CO_2 generated by the animals at the front compartment of the bottom deck that led to CO_2 levels very close to that of the inlet values. Slight short circuiting, i.e., CRE < 1 indicated by higher concentration of CO_2 inside the animal compartment than at the exhaust point, were observed at rear compartments more frequently for the bottom deck.

Table 7.7. Average contaminant removal effectiveness (CRE) at the center of the front and rear compartments of the top and bottom decks of the animal compartment during the two monitoring trips.

Trailer Location	Bottom Deck CRE	Top Deck CRE
Front Compartment*	4.07	1.81
Rear Compartment*	0.95	1.05

* Mean CRE values for each of the four trailer compartments are averages for ~ 1415 readings measured during the two monitoring trips.

7.4. Phase 4 – Economic analysis and recommendations for re-design and optimization

7.4.1. Cost analysis

The cost analysis focused on the incremental costs associated with the assembly and operation of an air-filtered swine transport trailer. Table 7.8 summarizes primary cost elements in the assembly of a full-scale 120-pig (market pigs or gilts) capacity air-filtered trailer. Actual costs incurred in the construction of the 20-ft prototype air filtered trailer were used as reference in the estimation of cost for the full-scale air-filtered trailer. In addition, annual operational costs were estimated based on a 10-hr journey (pig transport) done at a maximum of 2 times per week.

Major incremental expenses for using an air-filtered livestock vehicle over an ordinary commercial trailer are related to purchase of generator set ($15,000), ventilation control system and fans ($11,400) and installation labor cost ($11,500). Initial cost for filters and pre-filters ($1,600) covers expense for an air filtration system with a banks of 6 filter sets (each set comprised of a MERV 16 main filter and MERV 8 pre-filter). Space heater cost is for 2 units of 6kW capacity heaters while other material cost in assembly includes hardware supplies.

Estimated cost for purchase of a 40-ft aluminum solid-wall livestock container with similar features as the prototype trailer is shown in Table 7.8. Also included are costs for addition of a hydraulic loading platform as well as having a separate compartment for the generator and control system of the fans and housing for air filters, and actual cost a flatbed trailer on which both the livestock container and control compartment are installed. Thus, subsequent analysis including estimation of total annual costs and payback periods are based on assembly of a full and operational air-filtered swine trailer with added features such as hydraulic loading platform and hinged floors and roofs and solid aluminum walls. It is important to note that retrofitting of an existing commercial livestock trailer, i.e., closing and sealing of all openings and installation of air filtration and ventilation system components as required is another potential option. However, this option was not explored in this study. The estimated total equipment and installation cost for the full-scale 120-pig capacity air-filtered trailer is $109,900, with operational cost estimated to be $9,520 per year. The latter includes cost for diesel fuel as well as hydraulic oil for the hydraulic platform and data subscription for mobile monitoring and control of the ventilation system.

Table 7.8. Costs analysis for the assembly and operation of full-scale 120-head air-filtered trailer.

Type of Expense	**Estimated Cost**
Equipment cost	
Filters and pre-filters	$1,600
Ventilation fans	$3400
Generator set	$15,000
Ventilation system controller	$8,000
Space heater	$500
Other material cost in assembly	$3,600
Total equipment cost	***$43,600***
Total installation cost	***$11,500***
Other capital cost	
Animal container body	$43,300
Hydraulic platform and accessories	$11,300
Control compartment	$2,500
Flatbed trailer	$9,200
Total of other capital costs	***$66,300***
Total equipment and installation cost	**$109,900**
Operational cost	
Fuel for genset*, $/yr	$8,320
Others (hydraulic oil, data plan), $/yr	$1,200
Total operational cost, $/yr	**$9,520**

All costs are in CAD dollar.
*Diesel fuel cost estimated at $1.120/L. Consumption based on a 5-month heating period (i.e. space heaters are utilized) and 7-month cooling period (i.e. no heater used, but no supplemental cooling system assumed in analysis) in a year.

Table 7.9 provides an estimate of the replacement cost for the filters, with replacement required for the main filters every 3 years and every 6 months for the pre-filters. This assumption was based on replacement plan applied in actual air-filtered swine barns (Alonso et al., 2013; Reicks and Polson, 2011). A conservative 10-year useful life (Batista et al., 2008) was used in the analysis for the air filters in a livestock trailer due to anticipated less moisture and dust exposure compared to barns, as well as the significant downtimes (i.e., system not in use) during periods when no pigs are inside the trailer or the trailer is not travelling. Neglecting labour cost for filter replacement and maintenance (e.g., washing of filters if required), the annual cost for replacement of filters distributed over an assumed 10-year lifespan is $600.

Table 7.9. Calculation of filter replacement cost.

	Estimated Cost
Assumed lifespan, yr	10
Replacements per lifespan	3
Number of filters	6
Filter cost, $	$2,000
Total replacement cost per lifespan, $	$6,000
Total replacement cost per year, $/yr	***$600***

In this cost analysis, a simple payback period was calculated based on the anticipated premium on the price of each pig transported in an air-filtered trailer. Figure 7.20 shows sensitivity of the payback period to the level of added premium ranging from $2 - $10 realized for every genetic stock transported in the 120-pig capacity air-filtered trailer. The range of premium values was based on a $1 - $10 incremental premium for every weaned pig that is PRRSV-negative reported in the financial impact study of air filtration in swine barns conducted by Alonso et al. (2013). Payback period computations were based on the assumption that cash inflows are solely from premiums received for every pig delivered using the air-filtered trailer. Taking for example a premium of $5/pig delivered, assuming 2 journeys per week (104 journeys in a year) at 120 pigs per journey, would translate to an annual net cash inflow of approximately $52,280 after subtracting annual operational and air filter replacement costs. Thus, at $5/pig premium, the payback period is 2.10 years, while more conservative premium estimates of $3/pig and $4/pig will yield payback periods of 4.02 and 2.76 years, respectively.

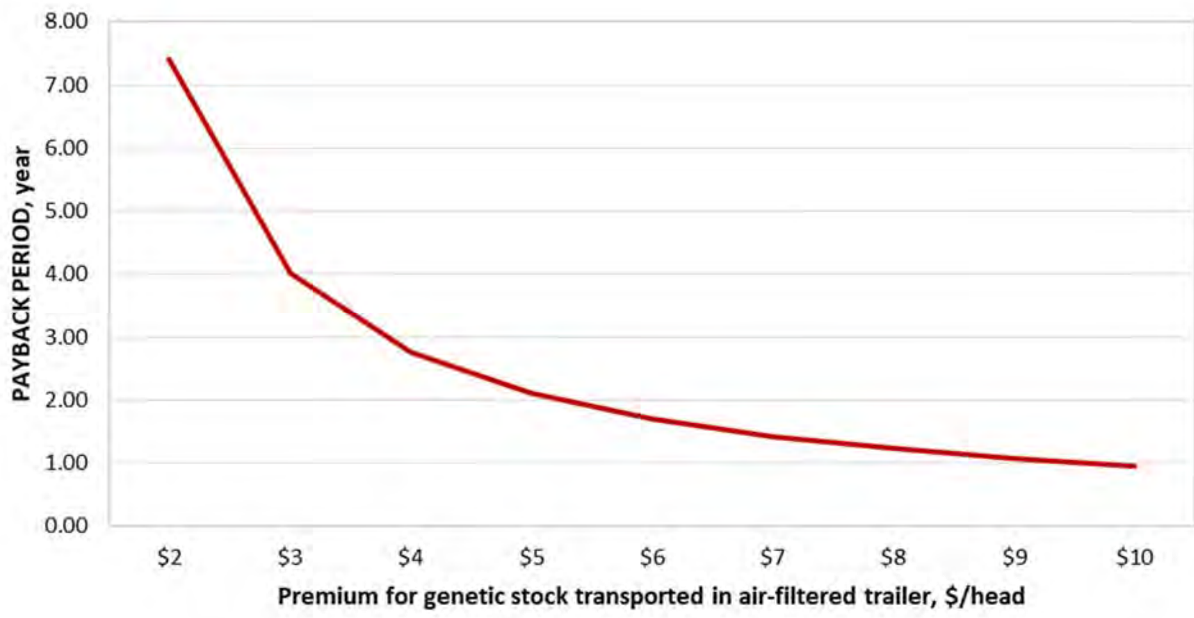


Figure 7.20. Sensitivity analysis of air-filtered trailer investment payback period considering a range of premiums (in $/head) for every genetic stock transported using the air-filtered trailer.

7.4.2. Recommendations for design optimization

Based on the results and observations obtained in the evaluation of the prototype air-filtered trailer, the following recommendations for optimizing its potential in providing improved overall transport condition and biosecurity during transport were formulated:

1. Trailer compartments. The hinged upper deck floor and roof were very effective features in improving working condition for herdsperson during loading, unloading and other activities inside the trailer (such as cleaning and disinfection) by minimizing need for bending. Areas for improvement includes using a lower flatbed trailer platform on which the animal and control compartments were assembled. The current prototype is almost 5' high from the ground to the level of the bottom deck; this prevents the hydraulic platform from reaching all the way to the ground and makes it more challenging to go up and down to the front compartment to operate the generator and other related tasks. Furthermore, reduced space may be needed for the front compartment (genset, fans, air filters, controller housing) by using the space more efficiently, thereby maximizing trailer space for the animal compartment. Also, for assembling a new prototype of this design, retrofitting existing commercial livestock trailers into an air-filtered trailer may be considered to potentially reduce capital costs.

2. Loading platform. Safety in using the hydraulic loading platform for loading and unloading pigs can be further improved by increasing the height of its guardrails by at least one foot, to

prevent animals from potentially jumping out of the platform and as an added support to the herdsperson when moving animals in the platform. Also, the slip resistance of the loading platform floor can be improved by modifying floor corrugations or using rubber mat with non-slip top. However, cleanability should not be compromised in the modified flooring.

3. Cleanability. The prototype trailer's solid aluminum walls, upper deck floor and roof that can be lifted open and the minimal corners within the compartments made scraping of bedding material and trailer washing easier. Since wired sensors are located inside the animal compartment, moisture-proof housing that can withstand washing should be added. For the front compartment, louver-type dampers for the air inlets that can be quickly adjusted to desired opening depending on travel conditions (fully open during warm days, or partially closed during winter travel) must be installed. Additionally, these inlet dampers must be easily closed tightly prior to washing to protect the electronics and air filters inside the front compartment.

4. Ventilation system. Ventilation control systems that enable real-time monitoring of environmental parameters inside the trailer such as the ones used in the prototype trailer are very useful for the trucker to keep track of the condition of the animals while in the track cab during travel. Additionally, the trucker should be able to make adjustments as needed without having to stop to go into the front compartment. An appropriately-sized and properly located supplemental heater must be provided to cope with outside air temperature below -10°C and to ensure both upper and lower decks benefit from pre-warmed inlet air. Additionally, a misting system must also be considered for use during travel in warm conditions. Furthermore, use of air distribution ducts may be explored to address the observed variability in thermal condition between the front and rear sections of the livestock compartment.

5. Air filtration system. Although the installed air filter sets showed promising performance in the stationary test (based on overall % reduction in bacterial phage concentration), other types of filters may be evaluated for improved effectiveness in preventing pathogen transmission (e.g., antimicrobial filter materials) as well as for financial and operational considerations (e.g., replacement frequency, maintenance).

6. Others. Additional air openings at strategic locations around the livestock compartment must be installed to serve as alternate means for emergency ventilation in case of generator or controller malfunction; these openings can also serve as viewing ports for inspection of the animals (i.e., at border crossings) without having to open the entire compartment. Installing floor drains, which must be sealed and air-tight during travel, can also help facilitate the removal of bedding material and the washing and disinfection process after each trip. For long-distance transport of breeding stock, the installation of drinkers for the animals must be considered. Lighting fixtures in the animal compartment should also be installed, not only

for the benefit of the animals, but also for the herdsperson and trucker during night-time loading or unloading of the trailer, and for the inspection of the animals during the trip.

8. Conclusions and Recommendations

The following conclusions are made based on observations from the work done in this project:

1. Computer simulation was an efficient tool for preliminary assessment of the various potential configurations for a new trailer design that will facilitate control of pathogen contamination of animals during transport, ultimately narrowing down the choice to a mechanically ventilated air-filtered trailer with the major ventilation system components located in a separate compartment at the front part of the trailer. Unique features such as a hydraulic loading platform as well as animal compartment with solid walls and deck and roof that can be lifted were incorporated in the assembled prototype to address other issues on existing livestock vehicles identified during a stakeholders' survey.

2. Evaluation of the assembled prototype air-filtered trailer showed great potential in preventing airborne entry of pathogens to the livestock container, with the concentration of aerosolized bacteriophage inside the animal compartment reduced by 96.9% compared to initial levels upstream of the filtration system.

3. Monitoring of the trailer thermal condition during actual trips with the prototype trailer loaded with pigs under winter condition showed the need for supplemental heating to avoid temperatures in the animal compartment lower than 10°C.

4. Moisture (RH) level and air quality (CO_2) inside the trailer during the monitoring trips were maintained at levels comparable to conditions found inside swine barns. In addition to conventional temperature-based ventilation control, additional controller feature that compensates for RH and CO_2 levels inside the trailer to manage the operation of the ventilation system, enabled faster recovery to desired conditions when internal trailer conditions are perturbed due to travel interruptions.

5. Cost analysis showed an estimated payback period of about 2.10 years for the investment on this new trailer design if a premium of $5 per head is realized, particularly for high-value genetic stock animals transported under the enhanced biosecurity protection provided by an air-filtered trailer.

Based on observations made in this study, the following are recommended for further consideration:

1. The prototype air-filtered trailer needs to be tested for colder winter and also summer conditions that prevail in Canada.

2. Improvement in overall trailer environmental condition (i.e., reducing thermal and air quality variability) may be further investigated by applying smart technologies to optimize sensors (i.e., types and locations) and utilize control algorithms that respond more quickly to deviations from desired set points. Using air distribution ducts or other options for air dispersion in livestock vehicles with active ventilation system must be considered to equalize conditions among the different compartments of the trailer.

3. Finally, the trailer has to be challenged under conditions that are known to lead to disease transmission to pigs under transport. As indicated by pig producers familiar with this project, the ultimate test of the performance of the air filtered trailer will be determined only after subjecting it to a disease challenge test.

9. Success stories/practical implications for producers or industry

A fully operational prototype air-filtered trailed was successfully designed and assembled in this project. Evaluation and testing of the prototype trailer showed that it can provide better protection of animals against airborne transmissible diseases during transport, while maintaining conditions in the trailer necessary for the welfare and health of the animals. The outcomes from this work will help address one component of preventing spread of airborne transmissible diseases within the Canadian swine herds, as it is anticipated that more barns with air filtration system will be in place in Quebec and Ontario, thus a transport trailer with air filtration system will be a necessity to complete the biosecurity coverage for transported breeding stock originating from Saskatchewan. Additionally, unique and innovative features (such as hydraulic loading platform, hinged floor and roof sections) were incorporated into the trailer design to address the major issues identified by stakeholders in the current livestock trailers used in the industry. Overall, the outcomes from this study can also be potentially applied to poultry and other livestock species, thereby contributing to overall sustainability and profitability of Canadian agriculture and agri-food sector.

10. Patents/IP generated/commercialized products

A new design for an air-filtered livestock transport trailer was developed in this project. The possibility of a patent for the trailer design is being explored with the Innovation Enterprise office at the University of Saskatchewan, but ultimately, the goal is to secure partners (i.e., trailer manufacturers, truckers, livestock producers) to be able to facilitate adoption and commercialization of this new trailer design.

11. List technology transfer activities

Below is the bibliographic citation for the papers and presentations related to this project presented at various industry and scientific meetings and conferences:

- Alvarado, A., B. Predicala, J. Cabahug and S. Kirychuk. 2017. Design and evaluation pf a prototype mechanically ventilated swine transport trailer with air filtration system. Presentation made during the 2017 CSBE/SCGAB Annual General Meeting and Technical Conference. Winnipeg, MN.
- CANFARMSAFE. 2016. Importance of controlling airborne pathogens in transport trailers [Bulletin]. Retrieved from http://www.agrivita.ca/documents/CFS010.pdf.
- Predicala, B. 2016. Using technology to improve swine transport. Presentation made to the Swine Innovator's Club meeting. Banff, Alberta. 12 January 2016.
- CANFARMSAFE. 2015. Preventing airborne transmission of diseases in swine: development of an air filtration system for animal transport vehicles [Bulletin]. Retrieved from http://www.agrivita.ca/articles/15-03-003.php.
- Predicala, B. 2015. PSC Engineering Research Program Update. Presentation made to the PSC Board of Directors: Annual Research Forum. Saskatoon, SK. 28 October 2015.
- Predicala, B. 2015. Animal housing environments: reducing pathogen distribution from animal transportation. Presentation made to Canadian Agrisafety Applied Research Program Annual Collaborative Meeting. Saskatoon, SK. 08 October 2015.
- Predicala, B. 2015. Engineering Research at PSC: Program Update. Presentation made to the Alberta Pork Board of Directors. Edmonton, AB. 23 April 2015.
- Predicala, B. 2015. Engineering Research at PSC: Program Update. Presentation made to the Saskatchewan Pork Board of Directors. Saskatoon, SK. 24 February 2015.

12. List any industry contributions or support received

The Saskatchewan Pork Development Board, through its staff and member-producers, provided in-kind contributions to the stakeholders' survey to gather critical information for developing the new trailer design. Additionally, Sask Pork provided cash contributions through their support to the Prairie Swine Centre research program, in conducting this research project.

In-kind contribution was also received from the University of Saskatchewan for the access to the Hardy Lab at the College of Engineering during the installation of sensors and the static tests, as well as laboratory equipment such as flow meters, calibrators, and nebulizers from the CCHSA lab, and the microbiology lab at the Western College of Veterinary Medicine for the analysis of samples from the aerosol tests.

13. Is there a need to conduct follow up research?

Significant outcomes were achieved in this project, but because this is the first effort to design and develop a new major platform for transporting livestock, subsequent work is still very much needed to further improve the current prototype and bring it to a stage wherein it would be feasible for appropriate partners to readily adopt and commercialize the product. To avoid wasting the investment already made on the development and assembly and initial testing of the current prototype, recommendations for follow up research are indicated in Section 8, which includes areas for design optimization and improvement. In particular, a disease challenge test is highly recommended in order to prove the trailer effectiveness in protecting animals against disease infection during transport, thereby gaining the confidence of the target users (e.g., pig producers), ultimately facilitating adoption and subsequent commercialization of this new trailer design.

14. Acknowledgements

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15. Appendices

Tables

Appendix Table 15.1. Boundary conditions used in the initial CFD simulations.

Parameters		Winter	Summer
Trailer speed		96 kph (26.8 m/s)	
Inlet			
	temperature, °C	-17	20
	moisture concentration, kg/m^3	0.000283	0.0138
Outlet*			
	ventilation rate, m^3/s	0.415**	4.6***
Pigs			
	heat generation, W	231.35	234.61
	moisture production, mg/s	37.1	50.72

*applicable only to the new trailer design
**minimum ventilation of 5.5 cfm per pig adapted from commercial transport trailers
**summer ventilation of 60 m^3/hr/kN payload as per EU Regulation 1/2005

Appendix Table 15.2. Trailer design configurations investigated in the final simulation work.

Design Code	Air inlet location*		Exhaust location**	
	Side	Top	Side	Top
S4T2-S4T4	4 (2 on each)	2	4 (1 /deck/side)	4
S4T2-S4	4 (2 on each)	2	4 (1 /deck/side)	none
S4T2-T4	4 (2 on each)	2	none	4
S2T1-S4T4	2 (1 on each)	1	4 (1 /deck/side)	4
S2T1-S4	2 (1 on each)	1	4 (1 /deck/side)	none
S2-S4	2 (1 on each)	none	4 (1 /deck/side)	none

*Air inlet openings were located at the front part of the trailer
**Air outlets were located at the rear part of the trailer

Appendix Table 15.3. Boundary conditions used in the final CFD simulations.

Parameters		Summer	Winter
Trailer speed		96 kph (26.8 m/s)	
Inlet			
	temperature, °C	20	-17
	moisture concentration, kg/m^3	0.0138	0.000283
Outlet			
	ventilation rate (per deck), m^3/s	5.26*	0.55**
Pigs			
	heat generation, W	199.45	218.28
	moisture production, mg/s	43.21	35.01

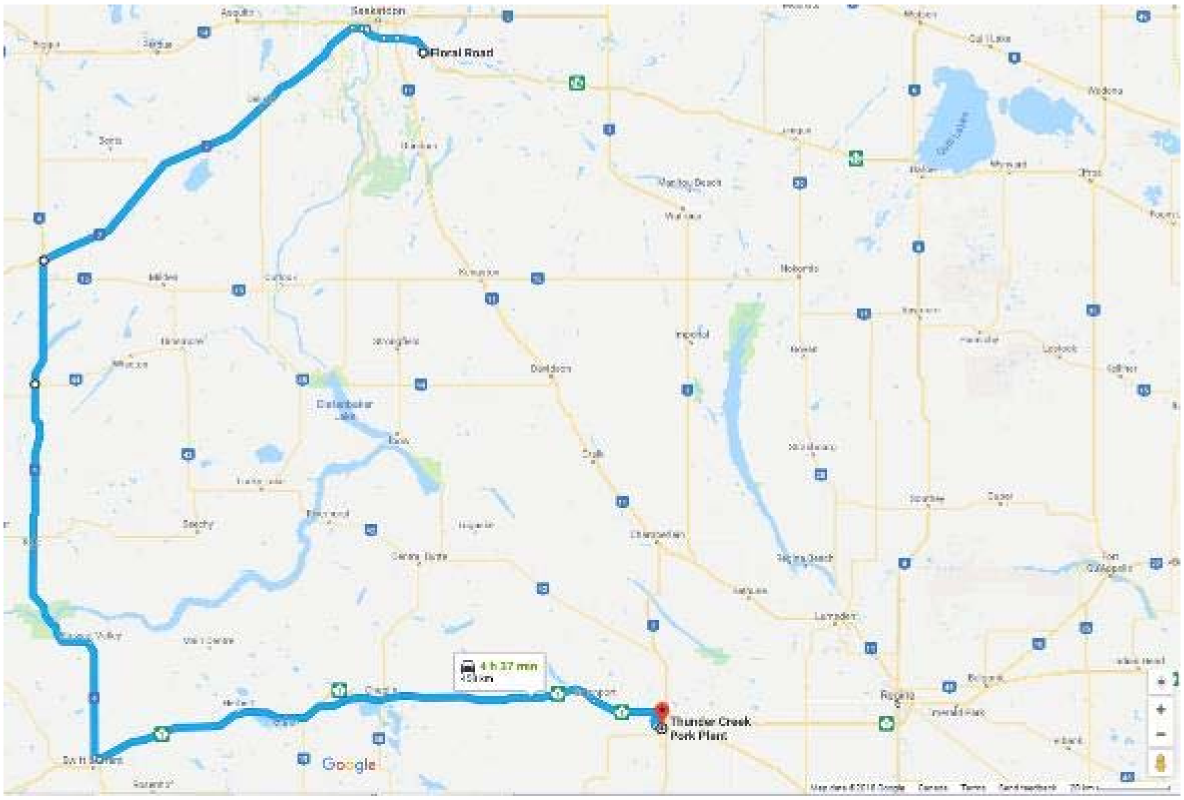
*summer ventilation of 60 m^3/hr/kN payload as per EU Regulation 1/2005
**minimum ventilation of 5.5 cfm per pig adapted from commercial transport trailers

Appendix Table 15.4. Summary of responses from the stakeholder survey.

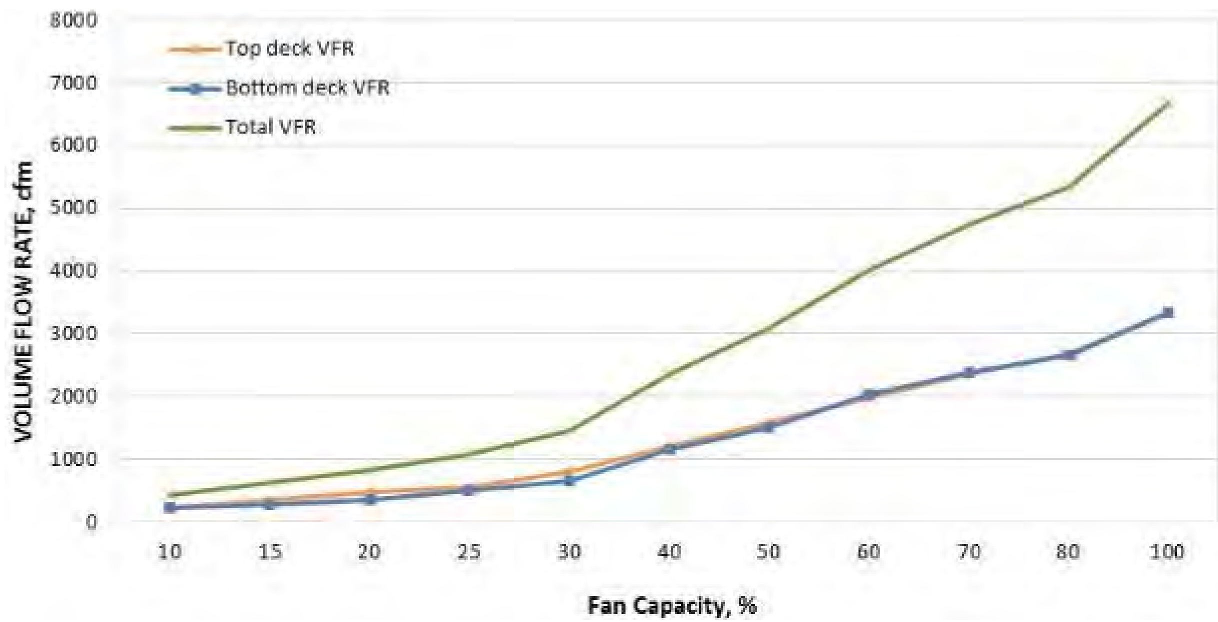
Trailer properties	**Current strengths of existing trailers**	**Deficiencies in existing trailers**	**Desired features in a new trailer design**
Efficiencies (capacity, etc.)	High capacity, light weight, removal of "pot belly"	Difficulty in moving animals through ramps, uneven axle loading leading to variable loading density, differing temperature zones within trailer	Moveable hydraulic decks and ramps, even axle weight distribution
Operation and maintenance	Low maintenance, well-built and familiar technology and standard parts	Lack of appropriate cooling in summer and heating in winter	Integrated ventilation and climate control and water cooling, better insulation
Welfare		Stressful to animals and hard on workers (too much bending) during moving, lack of water availability during long rides	Advanced monitoring equipment of pig comfort, improved working conditions in trailer
Biosecurity		Disease transfer risk through air - too many openings and no filters	Air filter system as part of disease prevention plan
Cleaning/disinfection		Hard to clean, wash and disinfect, no proper drainage	Mechanical cleaning/washing, improved and faster cleaning and disinfection - no planks, less corners,
Cost	Cost efficient		
Other			Usability for all stages of

			production

Figures



Appendix Figure 15.1. Screenshot of the route used during the monitoring trips. Source: https://goo.gl/maps/2PLYvTw12AJ2



Appendix Figure 15. 2. Equivalent volume flow rates in cfm of the top and bottom deck fans at different % fan capacities. Figure represents ventilation flow rates after variable frequency drives (VFDs) of the ventilation system controller were adjusted to 39 Hz.

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