Mimicking indoor climate dynamics and ammonia emissions in a pig housing compartment using artificial pigs and an automatic urea spraying installation

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Abstract: The study aims to develop a test platform (TP) compartment that could mimic diurnal trends in indoor climate and NH_3 emission in a real pig compartment and to compare diurnal indoor climate and NH_3 production between two TP compartments and a real compartment. The objectives were achieved by using a real and TP compartment followed by a second test that used two TP compartments and another real compartment. The TP had two compartments equipped with mock-up pigs as heat source and automatic urea solution spraying installation to mimic pig urination at the pen floor. The study evaluated indoor climate and NH_3 production in a 4-day comparative test between a TP and a real compartment followed by a 3-day comparative test between two TP compartments and a real compartment where exhaust and slurry pit NH_3 concentrations, ventilation rate, indoor temperature and relative humidity were simultaneously measured. The TP reproduced comparable diurnal trends in the measured parameters in the real compartment. The TP compartment overestimated NH_3 emissions in the real compartment by 23% ($R^2 = 0.27$) in the first experiment. In the second experiment, the two TP compartments overestimated the NH_3 emissions in the real compartment by 38% ($R^2=0.36$) and 44% ($R^2=0.37$), respectively. The overestimated NH_3 emission in the TP was probably due to the differences in urea solution vs. pig urine chemistry and floor fouling characteristics. The two TP compartments when compared showed similar diurnal trends in NH_3 concentration and emission rate with hourly averages of 11.5±4.1 vs. 11.6±2.8 ppm and 13.2±3.0 vs. 12.1±2.9 g h^{-1}, respectively. The study shows the TP could simulate indoor climate dynamics and NH_3 emissions trends in a real compartment and therefore could be used to study NH_3 volatilization processes and emission reduction techniques on relative emission basis.

Keywords: ammonia, emission, modeling, pig housing, test platform, ventilation, Belgium

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1 Introduction

Ventilation and climate control strategies are among the techniques applied to reduce pollution from pig housing (Santonja et al., 2017). However, emission studies on existing/novel ventilation strategies often require tools that adequately investigate their performance before optimized and implemented in real houses (Zhang et al., 2008). Full-scale models are considered convenient in such studies because they offer relatively better control and eliminate disturbance in comparison to field studies and similarity criteria requirements in reduced-scale models are absent (Saha et al., 2011; Ye et al., 2011).

This study mimicked indoor climate and NH_3

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emissions in a real compartment using two test platform (TP) compartments, equipped with artificial pigs and an automatic urea spraying installation to mimic pig urination on fully slatted pen floors. This study is an improvement of the study of Ye et al. (2011), which did not mimic pen floor fouling and used floor heating. This study checked the usefulness of the TP by comparing it with an occupied compartment with real pigs for indoor climatic conditions and NH_3 emissions in a first experiment in 2016 and a second experiment in 2017. Another objective of the second experiment was to compare the NH_3 production and diurnal trends in indoor climate between the two TP compartments. The tests did not aim to reproduce the same climatic conditions and NH_3 emissions as the real compartment but to generate similar diurnal trends in indoor climatic conditions. By doing so, the effects of different climate control strategies, ventilation design configurations and manure management strategies could be subsequently tested to acquire knowledge on NH_3 transport behavior and identify low-emission reduction techniques in pig housing, without performing very expensive animal experiments.

2 Materials and methods

2.1 Experiments to compare TP performance with a real pig compartment

The investigation conducted two separate experiments. In the first experiment, compartments 14 and 16 (Figure 1(a)) were used as the TP and real pig compartments, respectively from 7-11 July 2016. The experiment compared NH_3 emission rate, indoor temperature, relative humidity (RH), slurry and slurry pit headspace temperature between the TP and real pig compartments. To produce a similar ventilation pattern in both compartments, approximately 4.8 kW was continuously produced by 32 mock-up pigs (4 mock-ups per pen) in the TP compartment to simulate sensible heat production by the 32 pigs of 79 to 84 kg in the real compartment (CIGR, 2002). The calculated energy balance in the real compartment during the experiment from ventilation and transmission heat loss (156 W pig^{-1}), produced similar total heat input in the TP compartment (150 W pig^{-1}). On the contrary, the sensible heat production (134 W pig^{-1}) calculated from the CIGR (2002) equations for the pigs in the real compartment underestimated the ventilation and transmission heat loss. The appendix shows details of the material description of the compartment, the mean environmental parameters used to calculate the ventilation and transmission heat loss, and the CIGR heat production equations.

The second experiment used compartments 13 and 14 simultaneously as the TP compartments and compartment 7 as the real pig compartment (Figure 1(a)) from 19-21 June 2017. The experiment compared NH_3 concentration and emission, indoor temperature and ventilation rate between the two TP compartments and the real compartment. In each TP, 16 mock-up pigs were placed (2 mock-ups per pen), continuously producing approximately 2.3 kW throughout the experiment, simulating sensible heat production by 32 growing pigs at approximately 50 kg (CIGR, 2002). The calculated total sensible heat production in the real pig compartment from 48 pigs at 25 kg according to the CIGR (2002) heat production equations was 2.6 kW.

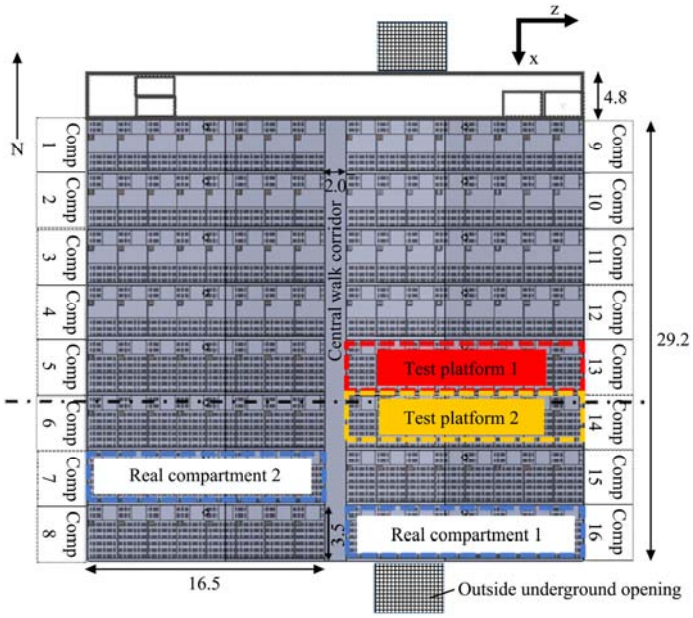
2.2 Test platform layout

The TP was developed in the fattening pig house at the Flanders Research Institute for Agriculture, Fisheries and Food (ILVO), Merelbeke, Belgium. Figure 1 presents the ILVO experimental facility. The pig house consists of 16 separate, Underfloor Air Distribution (UFAD), mechanically ventilated fattening pig compartments. The TP compartments were developed in the two fully slatted pig compartments (13 and 14) which were each divided into eight pens and equipped with the mock-up pigs as heat source and an automatic spraying installation to mimic pig urination/NH_3 production by applying urea solution.

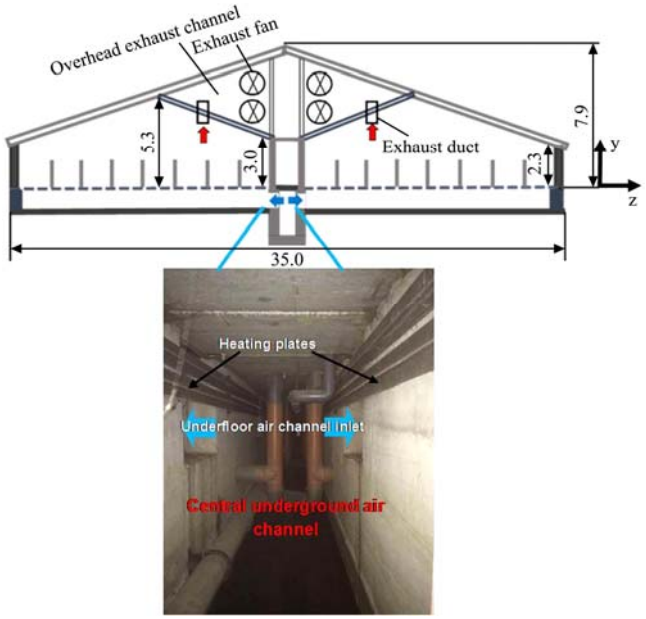
2.2.1 Heat production system by mock-up pigs

The mock-up pigs were developed from 1.0 mm thick galvanized steel, shaped into semi-cylinders with a diameter of 0.3 m, length of 1.8 m and painted matte black (Figure 2(b)). Both ends of the mock-up pigs were enclosed with steel plates and 18 mm thick plywood insulated them against the floor. Each semi-cylinder represented two headless 50 kg real pigs in sternum lying position. The total exposed surface area of each mock-up pig (semi-cylinder) was approximately 1.0 m^2 as derived from Baxter (1984). The mock-up pigs were heated with electrical heating cables (Danfoss B.V., Rotterdam, the

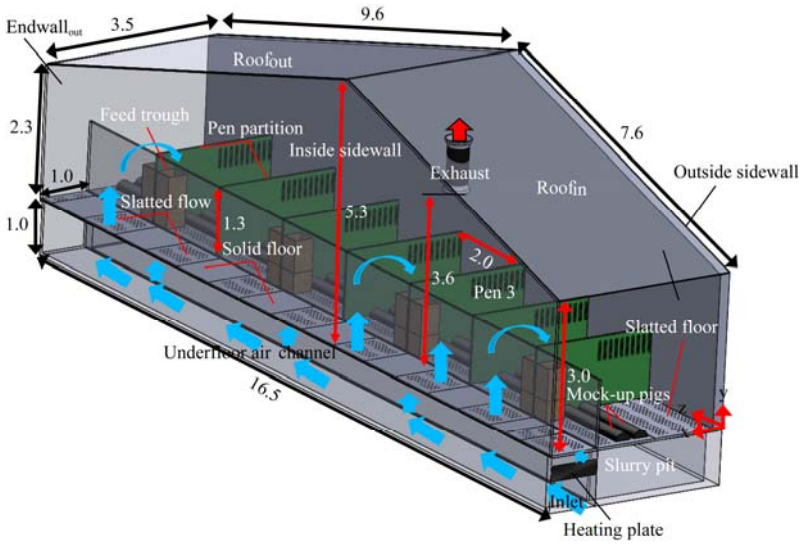
Netherlands). To produce uniform surface temperature, the electrical heating cables were tightly fastened to the internal shell of the metal cases using plastic tie fasteners. A 40 m long, ~300 W electrical heating cable heated two semi-cylinders. Previously, Puma et al. (1999) used cylindrical tubes equipped with light bulb heaters to represent 13-35 kg nursery pigs, while Hoff et al. (2000) used semi-cylindrical tubes equipped with cone resistance heaters to simulate the sensible heat from 45 kg pigs in a laboratory scale pig house.



(a) Plan view of the experimental fattening pig house



(b) cross sectional view of the fattening pig house



(c) dimensions and schematic airflow pattern in a compartment (Comp), dimensions in meters

Figure 1 The ILVO experimental facility

(a) Real pigs

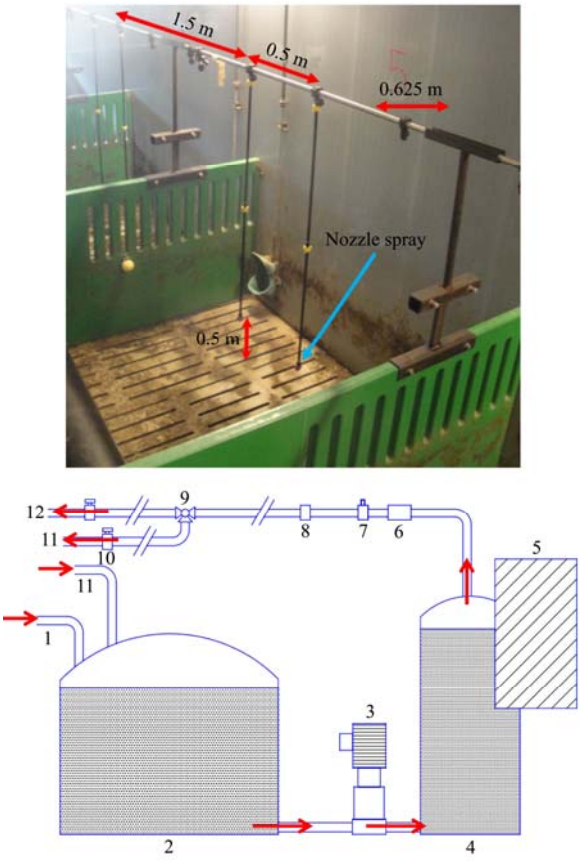
(b) mock-up pigs in the real and TP compartments

Figure 2 The pig arrangement

2.2.2 Urea application system by nozzle spray installation

The TP artificially mimicked pen fouling using an automatic nozzle spray installation developed at ILVO (Figure 3). The study prepared 0.2 mol L^{-1} urea solution, which is within the range (0.1-0.6 mol L^{-1}) of real pig urine urea concentration (Canh et al., 1997). For simplicity, other chemical constituents present in real pig urine were not added to the urea solution. To prepare the urea solution of 0.2 mol L^{-1}, the required weight of 99% pure urea granules (Aveve N.V., Leuven, Belgium) were first manually weighed and poured into a 500 L mixing/storage tank after which the control box was programmed to automatically add the required volume of tap water to the tank. The mixture was mechanically stirred until all the urea granules were dissolved. A 1.1 kW centrifugal pump (Grundfos, Bjerringbro, Denmark) recirculated the solution from the mixing tank via a 2.4 kW, 200 L boiler to heat the solution to 37°C. When a three-way valve was switched on, the solution flowed via a 20-mm diameter pipe and was injected via flat jet spray nozzles (Tee jet technologies, Wheaton, IL, USA) in the TP compartment. The TP spray nozzles were arranged along the length of the pen area (Figure 3). Two spray nozzles were arranged per pen at 0.5 m spacing and a height of 0.5 m from the spray nozzle orifice to the floor.

The wetted floor area in the TP compartment was estimated by measuring the width and length of the wetted floor in each pen floor after the first and last spray regimes in the experiment and taking the average of both measurements. The fouled pen floor area in the real pig compartment was not quantitatively measured but visually inspected. The spray installation automatically applied 12 L urea solution in the TP compartment at 0.99 L min^{-1} in every three hours throughout the day and night at a pressure of 300 kPa and recirculation in the spray tank resumed after each spray regime. Approximately 96 L day^{-1} urea solution was sprayed in the TP. This is equivalent to 3 L pig urination per day, which is within the reported range of fattening pig (50 to 110 kg) urine excretion of 3-6 L day^{-1} (Canh et al., 1997). The pH of the prepared urea solution in the first experiment was measured using a compact pH 3310 meter (WTW, GmbH, Weilheim, Germany) each day. The second experiment urea solution pH was measured using a HACH pHC101 meter (HACH LANGE, GMBH, Düsseldorf, Germany).



1. Tap water 2. Mixing tank 3. Centrifugal pump 4. Boiler 5. Control box 6. Pressure sensor 7. Flow meter 8. Temperature sensor 9. 3-way valve 10. Valve 11. Recirculation tube 12. To spray nozzle.

Figure 3 Nozzle spray installation

2.2.3 Pit slurry and pen fouling

The TP compartment in the first investigation initially housed 25 to 60 kg pigs to foul the pen floors. The pigs were removed to an adjacent empty compartment before the experiment. The fouled floors were expected to contain enough urease enzyme to produce NH_3 during the urea spraying (Braam et al., 1997). There was neither fecal deposition nor the use of artificial urease enzyme during the investigation. The TP compartment was left empty for 86 days before the start of the experiment and pigs occupied the real compartment from 20/04/2016 until 07/07/2016 when the experiment started. Both the real and TP compartment slurry pits contained ~0.14 m slurry depth after emptying and refilling them with slurry from a slurry storage tank before the experiment started. The slurry storage tank contained a mixture of slurry from the fattening, farrowing, weaner and sow pig units.

Slurry samples were randomly collected every day from five locations in the slurry pit to a depth of 50 mm and stored at –18°C for total ammoniacal nitrogen (TAN) and pH analysis. A C3010 Multi-parameter analyzer (Consort bvba, Turnhout, Belgium) measured slurry pH and the slurry TAN concentration was analyzed with a Kjeltec 8400 analyzer (FOSS, Hilleroed, Denmark) using the BAM procedure (BAM/deel 3/05, 2015). The liquid slurry in the real compartment during the experiment had average TAN concentration of 1.76±0.17 mg g^{-1} and pH of 7.10±0.10 and the TP compartment had an average TAN concentration of 1.74±0.14 mg g^{-1} and pH of 7.23± 0.07.

Real pigs in the second experiment occupied the compartment five days before the start of the experiment. Before occupying the real compartment, the pen floors were soaked with KENO™SAN (CID LINES N.V., Ieper, Belgium), cleaned with high-pressure hose and disinfected with VIROCID® (CID LINES N.V., Ieper, Belgium). The slurry pit was emptied before the pigs occupied the compartment. Slurry analyses were not performed in the real pig compartment because of a different ongoing experiment in this compartment. The TP compartments housed real pigs from ~25 kg until the slaughter weight to foul the pen floors. The TP compartments were emptied 5 and 18 days respectively before the start of the test. The slurry pits in the two TP compartments were emptied and refilled to slurry depth of 0.14 m, and randomly collected slurry samples at about 50 mm depth at the start and end of the test. The liquid slurry TAN concentration and pH were 2.46 mg g^{-1} and 7.28 at the start of the experiment and 2.06 mg g^{-1} and 7.70 at the end of the experiment in TP 1. The liquid slurry TAN concentration and pH were 2.09 mg g^{-1} and 7.66 at the start of the experiment and 1.90 mg g^{-1} and 7.90 at the end of the experiment in TP 2 (Figure 1a).

2.2.4 Indoor climate monitoring system

Indoor climatic conditions were continuously measured using EE08 RH & temperature sensors (E+E Elektronik, Engerwitzdorf, Austria) (Range: 0 to 100% RH, –10°C to 80°C temperature; accuracy ±3% RH and ±0.50°C) and U-type thermistors (Grant Instruments, Cambridge, UK), (range: -50°C to 150°C and accuracy <0.2ºC). The EE08 sensor measured RH and temperature at the exhaust duct while the U-type thermistors measured slurry headspace and slurry temperature. Slurry headspace and liquid slurry temperatures were measured at 0.35 m above and 0.10 m below the slurry surface, respectively. All the measured data were logged to a Squirrel SQ2040 (Grant Instruments, Cambridge, UK) data logger in 2 min interval. A Pt1000 (–50°C to +100°C) sensor of the “Hotraco System” (Hotraco Agri, Hegelsom, the Netherlands) measured the climate control temperature of the experimental compartments, 1.4 m above the floor in pen 3 (Figure 1c). The climate control temperature sensor was located at the same location in all other compartments at the experimental facility. Pt1000 sensors also measured the outside and the central underground air channel temperatures. The outside temperature sensor was located 1.4 m above the ground under the eastern roof eave of the building. The 'Hotraco System' controlled and measured ventilation rate. Ventilation rate was calculated from the measured exhaust duct damper opening size and the differential pressure between each compartment and the overhead central exhaust channel that was previously validated in a wind tunnel by 'Hotraco’ (Hotraco Agri, Hegelsom, the Netherlands). An Orion-VS12 data logger (Hotraco Agri, Hegelsom, the Netherlands) logged ventilation rate, climate control temperature, outdoor and the central underground air channel temperatures in 1 min interval.

A Fourier transform infrared spectrometer (FTIR) gas analyzer (Gasmet CX4000, Gasmet Technology Oy, Helsinki, Finland) monitored exhaust, slurry pit headspace and outside NH_3 concentrations during the study. The pit headspace gas sampling tubes were positioned 0.35 m above the slurry surface. After basic calibrations at Gasmet (Helsinki, Finland), the FTIR performed zero-point calibrations once every morning using N_2 gas during the investigation. The FTIR sequentially took three measurements per sample location in every 30 minutes.

2.2.5 Ventilation system

A climate computer automatically controlled ventilation rate in both the TP and real compartments to maintain an indoor temperature of 22°C at minimum and maximum ventilation rates of 8 and 77 m^3 h^{-1} pig^{-1} and a bandwidth of 5°C in the first experiment. The

compartments in second test had minimum and maximum ventilation settings at 14 and 70 $m^3\ h^{-1}\ pig^{-1}$ to maintain an indoor temperature of 23°C at a bandwidth of 5°C. This represents the temperature set-point for 40-60 kg fattening pigs in the TP compartments. The set-point temperature in the real compartment was at 24°C for 20-40 kg pigs. The different set-point temperatures in the TP compartments and the real compartment were because of the difference in pig weight and number. Additionally, the real pig compartment was used in a different ongoing experiment and could not be interfered with.

2.3 Data analysis

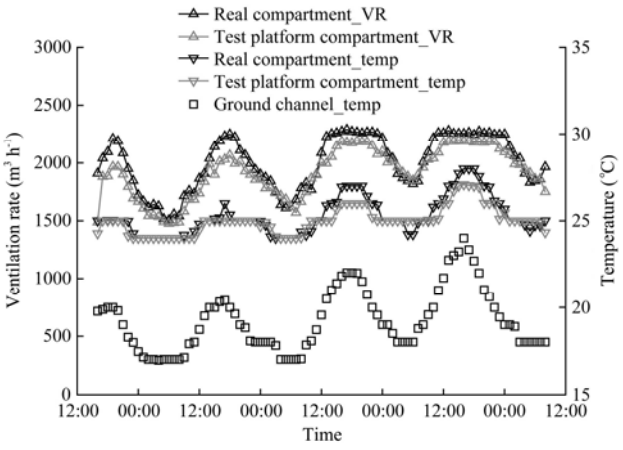
The study analyzed all the measured parameters using their hourly averages and calculated gaseous emission rates (ER) as the product of the ventilation rate and the gaseous concentrations. Six-data samples per hour per sample location from the FTIR were averaged for the gaseous concentrations. The hourly averages of ventilation rate and gaseous concentrations calculated the ER ($g\ h^{-1}$) as in Equation (1):

$$ER = VR \times (C_{ex} - C_{in}) \quad (1)$$

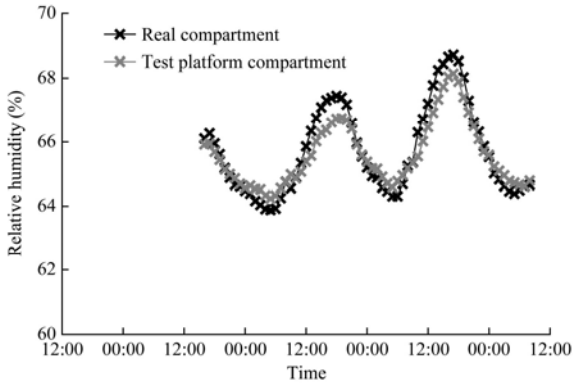
where, VR ($m^3\ h^{-1}$) is the ventilation rate, while C_{ex} and C_{in} ($g\ m^{-3}$) represent exhaust and incoming NH_3 concentrations respectively. SigmaPlot (Systat Software, San Jose, CA) was used to perform simple linear regression analysis and the graphical comparison of the hourly measured parameters between the TP and real compartments.

3 Results and discussion

Figure 4(a) compares the hourly ventilation rate and exhaust temperature between the TP and real compartments in the first experiment. During the measurement, the TP compartment recorded an average ventilation rate and exhaust temperature of 1916± 214 $m^3\ h^{-1}$ and 25.0±0.8°C compared to 2003±236 $m^3\ h^{-1}$ and 25.3±1.1°C in the real compartment, with a linear correlation of an $R^2 = 0.87$ between the two compartments in both parameters. The real compartment recorded slightly higher daily ventilation and exhaust temperature values than the TP compartment except between 03:00-10:00 a. m. in the second and third day of the experiment when the contrary was observed. Diurnal variations in pig activity/heat production seemed to explain this trend, i.e. active pig periods yielded higher indoor temperature/ ventilation rate in the real compared to the TP compartment, and the vice versa in less active periods. A rather larger linear relationship ($R^2 = 0.97$) was recorded between the TP and the real compartment for RH (Figure 4(b)) although latent heat was not simulated in the TP compartment. Clearly, moisture evaporation from the larger wetted floor area in the TP compartment compensated for respiratory moisture production in the real compartment as similar ventilation/temperature were observed in both compartments.



(a) ventilation rate, exhaust and outside temperature

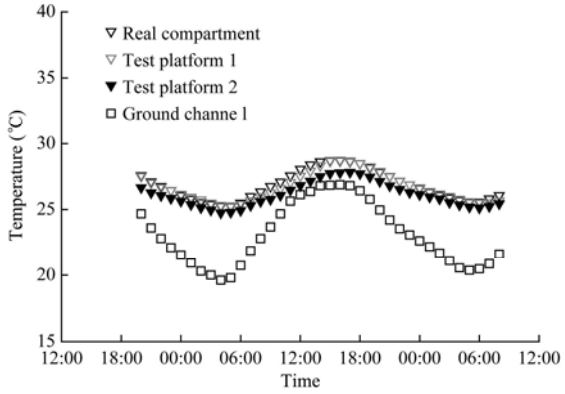


(b) RH in the real and TP compartment.

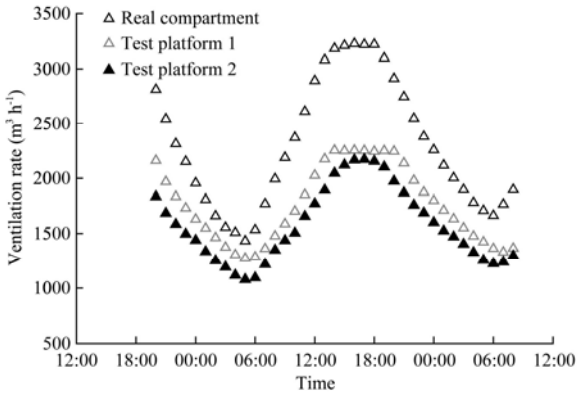
Figure 4 Diurnal temperature and RH for the first experiment (the missing data in RH was due to instrument failure)

In the second experiment, the two TP compartments also produced similar diurnal trends in indoor temperature and ventilation rate as the real pig compartment, despite the different set-point temperatures, pig weight and number (Figure 5). The differences in set-point temperatures, pig weight and number between the real and TP compartments is seen to result in relatively higher ventilation rate (31%-46%) in the real pig compartments compared to the two TP compartments (Figure 5(b)). Nonetheless, the indoor temperature in TP

1 and TP 2 linearly correlated with real pig compartment at an R^2 of 0.96 and 0.97, respectively. Also, the ventilation rate in TP 1 and TP 2 linearly correlated with real pig compartment at an R^2 of 0.95 and 0.97, respectively. Furthermore, the larger linear relationship in the indoor temperature ($R^2 = 0.99$) and ventilation rate ($R^2 = 0.97$) between TP 1 and TP 2 confirmed the similar diurnal variations in indoor temperature and ventilation rate between the two TP compartments (Figure 5).



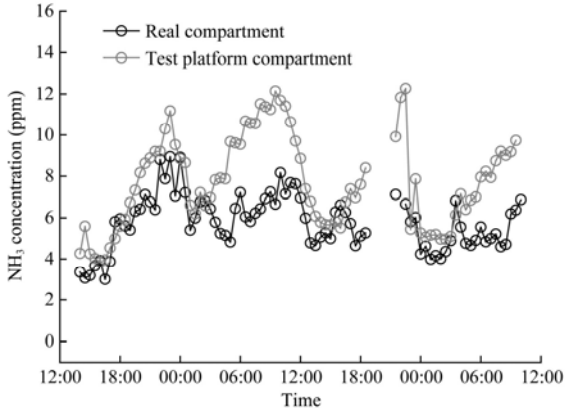
(a) exhaust and outside temperature



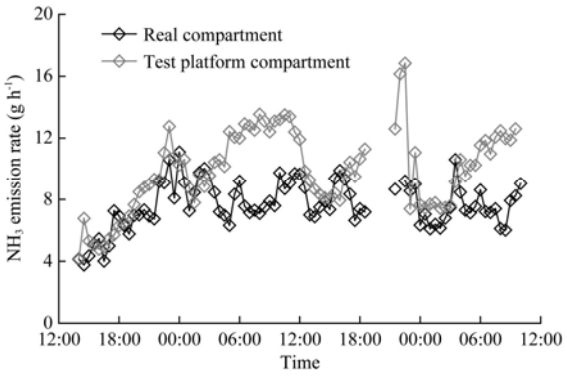
(b) ventilation rate in the real and TP compartments for the second experiment.

Figure 5 Diurnal temperature and ventilation rate in the real and TP compartments for the second experiment

Figure 6 compares the diurnal exhaust NH_3 concentration and emission rate between the real and the TP compartment in the first experiment, i.e. compartment 16 and 14, respectively (Figure 1(a)) as specified in section 2.1. An average NH_3 concentration of 7.7±2.2 ppm was measured in the TP compartment compared to 5.8± 1.3 ppm in the real compartment, with a linear relationship of $R^2 = 0.49$. A rather lower linear correlation ($R^2 = 0.27$) was obtained for NH_3 emission between the TP and the real compartment as the TP produced higher NH_3 emissions (9.9±2.6 g h^{-1}~2.7±0.7 kg pig^{-1} $year^{-1}$) than the real compartment (7.6±1.5 g h^{-1}~2.1±0.5 kg pig^{-1} $year^{-1}$). The approximated emission factors are comparable to the 2.3±2.0 to 3.5±0.9 kg pig^{-1} $year^{-1}$ reported by Van Ransbeeck et al. (2013) and Philippe et al. (2007) for fully slatted mechanically ventilated pig houses in Belgium. The cited emission factors, however, were obtained from measured data spread over the whole year while calculated for only four days data in this study.



(a) exhaust NH_3 concentration

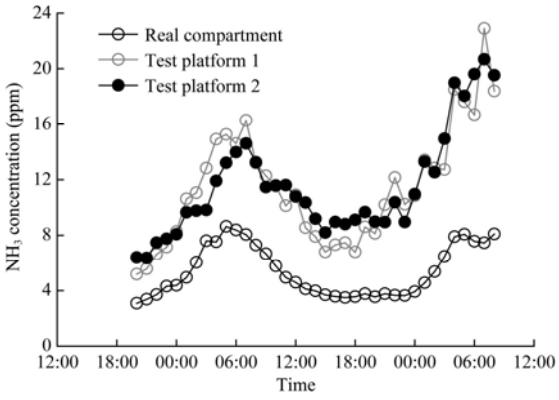


(b) NH_3 emission rate

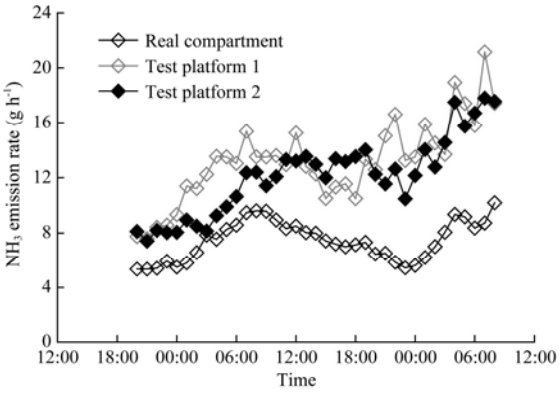
Figure 6 Diurnal exhaust NH_3 concentration and NH_3 emission rate in the real and TP compartment for the first experiment (missing data due to instrument failure)

In the second experiment, the average hourly NH_3 concentration was 11.5±4.1 ppm vs. 11.6±2.8 ppm between TP 1 and TP 2, respectively. The average hourly NH_3 emission rate was 13.2±3.0 g h^{-1} vs. 12.1±2.9 g h^{-1}, which corresponded to the linear relationship of an $R^2 =$ 0.63 between the two TP compartments. Overall, the difference in NH_3 emission rate was 9% on average, which suggests a good repeatability for this kind of experiments. Of course, random errors occurred from the measurement equipment and in the ventilation rate (Figure 5(b)) since there was about 10.5% difference in ventilation rate between the two TP. Furthermore, the test compartments in the second experiment captured a better diurnal trend in the NH_3 concentration and emission rate in the real pig compartment compared to the first

experiment, although they both still overestimated the NH_3 emission (Figure 7). In addition, the average hourly NH_3 concentration was 5.4±1.8 ppm vs. 11.5±3.9 ppm between the real and the average of the two TP compartments, while the average hourly NH_3 emission rate was 7.5±1.8 g h^{-1} vs. 12.7±3.0 g h^{-1} between the real and the average of the two TP compartments in the second experiment. TP 1 and TP 2 overestimated the average NH_3 emissions of the real compartment by 38% ($R^2 = 0.36$) and 44% ($R^2 = 0.37$), respectively.



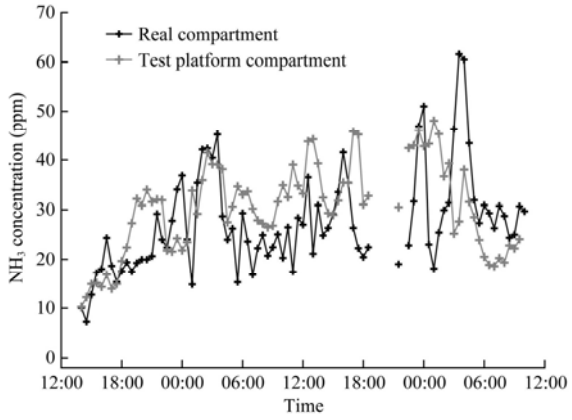
(a) exhaust NH_3 concentration



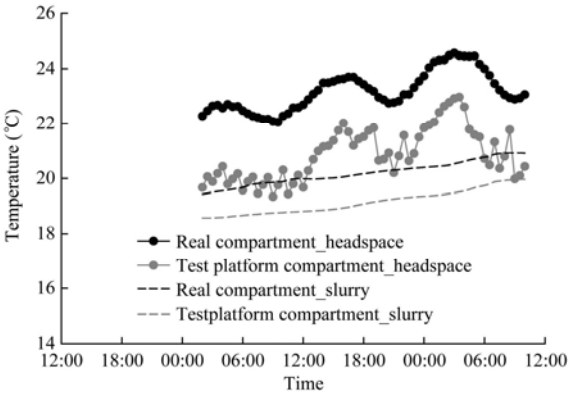
(b) NH_3 emission rate

Figure 7 Diurnal exhaust NH_3 concentration and emission rate in the real and TP compartments during the second experiment

Figure 8 shows the diurnal slurry pit headspace NH_3 concentrations, temperature, and liquid slurry temperature in the first experiment. On average, the liquid and pit headspace temperature in the real compartment was 1.1°C±0.1°C and 2.3°C±0.5°C respectively, higher than the TP compartment. The lack of conductive heat transfer from mock-up pigs (insulated against the floor) positioned at the same location on the slatted floor throughout the experiment could explain the lower slurry pit temperatures in the TP compared to the real compartment. However, despite the higher slurry and headspace temperatures in the real compartment, relatively lower headspace NH_3 concentrations were measure in the real than the TP compartment (Figure 8(a)). The lack of fecal deposition in the TP compartment could have interfered with the results. Additionally, pig movement and heat production on the slatted floor by lying pigs, probably promoted higher airflow and interfered with the pit airflow pattern in the real compartment.



(a) slurry pit headspace NH_3 concentration



(b) slurry pit headspace and liquid slurry temperature in the real and TP compartments for the first experiment (missing data due to instrument failure)

Figure 8 Diurnal slurry pit headspace NH_3 concentration and temperature and liquid slurry temperature in the real and TP compartments for the first experiment (missing data due to instrument failure)

The higher NH_3 emissions in the TP compared to the real compartment was probably due to differences in pen floor fouling characteristics. The average wetted floor area in the TP was 0.8±0.3 m^2 per pen (~0.2 m^2 pig^{-1} excluding slatted floor openings), while the visually inspected fouled pen floor area in the real pig compartment showed a less wetted floor area than in the TP compartments. Indeed, pen floors in the TP were wetted by pressurized urea solution droplets opposed to stream flow urination by pigs in the real compartment, consequently leading to a larger wetted floor area in the

TP compared to the fouled pen area in the real compartment. Literature suggested that the fouled pen floor area in real pig housing is related to indoor temperature, floor type and pig weight and range between 0.07-0.11 m^2 pig^{-1} in a partly slatted fattening pig house with concrete slat width of 10 cm, slat gap size of 2.0 cm and opening area of 15% (Aarnink et al., 1996, Aarnink et al., 1997, Aarnink and Elzing, 1998).

The lack of fecal deposition in the TP, difference in chemical properties between pig urine and urea solution applied in the TP and slurry properties could also be contributory factors. Especially, as the TP compartment measured lower TAN concentration and higher slurry pH compared to the real compartment (Section 2.2.3). Additionally, the average pH of the urea solution in the TP compartment (8.63±0.14) was higher than the pH of fattening pig urine (7.48-7.87) reported in Canh et al. (1997) fed ~15.6% crude protein diet, as pigs in this study. Note that pig urine in the study of Canh et al. (1997) had the same urea concentration (0.2 mol L^{-1}) as the TP compartment. Furthermore, pig urine contains salts and organic acids with buffering effect that was absent in the prepared urea solution. Indeed, the experiment measured an average urea solution electrical conductivity (EC) of 6.2 μS cm^{-1} while in Willers et al. (2003) an average EC of 41200 μS cm^{-1} was measured in fresh pig urine.

The factors mentioned above (e.g. larger urea spray floor area and lack of pen floor fecal deposition in the TP compartment, and the difference in urea solution chemical properties compared to real pig urine etc.) are reported to strongly influence ammonia volatilization in livestock housing. Furthermore, diurnal variations in pig activity, urination and wallow behavior also influenced NH_3 emission (Aarnink and Elzing, 1998). It could have been interesting to optimize the NH_3 emission performance in the TP compartments by modulating the heat production, urination frequency and the wetted floor area to simulate diurnal pig activity and urination behavior throughout the day and/or add the various nitrogenous compounds and salts in real pig urine to the urea solution (Kool et al., 2006). However, the aim of this study was to generate similar climatic conditions/trends but not identical conditions, so that tests on the different emission reduction techniques could be tested in the TP compartment to acquire knowledge on pollutant transport behavior focusing on relative rather than absolute emission reductions. Nonetheless, the similar NH_3 emission between the two TP compartments in the second experiment showed the facility could be used in such studies.

4 Conclusion

(1) In the two experiments, the test platform captured comparable heat production and diurnal trends in indoor temperature, RH, ventilation rate and NH_3 concentrations as in a real pig compartment.

(2) The second experiment showed similar average NH_3 emission rate (13.2±3.0 g h^{-1} vs. 12.1±2.9 g h^{-1}) between the two test platform compartments.

(3) The test platform over-estimated the average hourly NH_3 emissions in the real pig compartment by 23% - 44% during the two experiments.

(3) The over-estimation of NH_3 emission by the test platform compared to the real pig compartment was probably due to difference in pen fouling characteristics, liquid slurry and urea solution vs. pig urine chemical properties.

(4) The similar NH_3 emission rates between the two test platform compartments in the second experiment indicates that the test platform could be used to perform indicative performance testing of low-emission techniques.

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Appendix

The investigation calculated the sensible heat Q_S (W) production from the real pigs using the CIGR (2002) heat and moisture production models:

$$Q_S = K_S(0.62 \times Q_{tot} + 1.15 \times 10^{-7} T_{room}^6$$

$$Q_{tot} = 5.09m^{0.75} + (1-(0.47+0.003m))$$
$$(n \times 5.09m^{0.75} - 5.09m^{0.75})$$

where, Q_{tot} (W) is the total heat production at the thermoneutral temperature of 20°C; m is pig weight (at 82 and 25 kg in the first and second experiments, respectively); n is the maintenance energy coefficient (3.19 in the first experiment and 3.09 in the second experiment) at growth rate of 800 g day^{-1} in the Netherlands and K_S (0.95) is the correction factor for sensible heat production at the house level in a Northern European pig house; T_{room} is the measured average room temperature (at 25°C and 24°C in the first and second experiments, respectively) The total sensible heat production is the sum of Q_S and the pig activity heat production. The pig activity heat production is assumed as 8.6% of the metabolizable energy intake ($n \times 5.09m^{0.75}$) from Labussière et al. (2013).

The ventilation heat and transmission heat loss in the real pig compartment of the first experiment was calculated using Table 1 and 2, and Equations (3)-(11)

assuming a perfectly mixed room air, steady-state conditions and no significant contribution of solar and light heating.

Table 1 Material description of compartment

Component	Material	Area (m²)	U-values (W m^{-2} K^{-1})
Sidewall (sw)	PVC sandwich air panel	64.65	0.56
Endwall (ew)	Fabricated reinforced concrete wall	10.5[a], 6.1[b]	0.39
Roof (rf)	Polyurethane and corrugated fibre cement sheet	26.5[c], 33.7[d]	0.25
Window (win)	Double glazed glass	1.99	1.11
Floor (fl)	Concrete slab	40.875	4.5

Note: [a] Endwall_in; [b] Endwall_out; [c] Roof_in; [d] Roof_out.

Table 2 The measured mean parameters used to calculate the ventilation and transmission heat loss from the real pig compartment in the first experiment

Parameter	Value
Ventilation rate (m^3 s^{-1})	0.56
T_{room} (°C)	25
T_{GC} (°C)	19
T_{out} (°C)	20
T_{slurry} (°C)	20
T_{ground} (°C)	16
ρ_{in} (kg m^{-3})	1.208
C_p (J kg^{-1} K^{-1})	1006

$$Q_v = VR \times \rho \times C_p \times (T_{room} - T_{GC}) \quad (3)$$

$$Q_{sw\_out} = A_{sw\_out} \times U_{sw\_out} \times (T_{out} - T_{room}) \quad (4)$$

$$Q_{sw\_in} = A_{sw\_in} \times U_{sw\_in} \times (T_{comp15} - T_{room}) \quad (5)$$

$$Q_{ew\_out} = A_{ew\_out} \times U_{ew\_out} \times (T_{out} - T_{room}) \quad (6)$$

$$Q_{ew\_in} = A_{ew\_in} \times U_{ew\_in} \times (T_{out} - T_{room}) \quad (7)$$

$$Q_{rf} = 2A_{rf} \times U_{rf} \times (T_{out} - T_{room}) \quad (8)$$

$$Q_{win} = A_{win} \times U_{win} \times (T_{out} - T_{room}) \quad (9)$$

$$Q_{fl} = A_{fl} \times U_{fl} \times (T_{slurry} - T_{ground}) \quad (10)$$

$$Q_{shell} = Q_{sw\_out} + Q_{sw\_in} + Q_{ew\_out} + Q_{ew\_in} + Q_{rf} + Q_{fl} \quad (11)$$

Reference

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Nomenclature

Q	heat loss (W)
T	temperature (°C)
A	area (m^2)
U	U-value (W m^{-2} K^{-1})
VR	ventilation rate (m^3 s^{-1})
C_p	specific heat capacity of air (J kg^{-1} K^{-1})
ρ	density of air (kg m^{-3})

Abbreviations

GC	ground channel
sw_out	outside sidewall
sw_in	inside sidewall
en_out	outside endwall
en_in	inside endwall
*comp*15	compartment 15
win	window
fl	floor
rf	roof