# Ammonia and odour emission from a veal calves housing system with V-shaped manure belt and 'Groene Vlag' slatted floor

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Report 1171

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Wageningen Livestock Research
Wageningen, June 2019

Report 1171

Mosquera, J., T. van Hattum, G.M. Nijeboer, J.M.G. Hol, H.J. van Dooren, S. Bokma, 2019. Ammonia and odour emission from a veal calves housing system with V-shaped manure belt and 'Groene Vlag' slatted floor. Wageningen Livestock Research, Report 1171.

Samenvatting
In dit rapport worden de resultaten gepresenteerd van metingen die in opdracht van Bettink Service Team en Beerepoot Stalinrichtingen BV op één bedrijf voor vleeskalveren zijn uitgevoerd volgens de case-control benadering om het effect te bepalen van een aangepaste roostervloer (Groene Vlag) in combinatie met een V-vormige mestband onder de vloer op de emissies van ammoniak en geur. Ammoniakemissies waren significant lager (53%) ten opzichte van de traditionele houten roostervloer met mestopslag daaronder, gemeten op hetzelfde bedrijf (control-case benadering). Geuremissies waren eveneens significant lager (47%) ten opzichte van de traditionele houten roostervloer ook gemeten op dit bedrijf (control-case benadering).

Summary
This report presents the results of measurements performed at one animal facility for veal calves using the control-case approach, to estimate the ammonia and odour emission reduction of a floor (Groene Vlag) combined with a V-shaped manure belt under the floor compared to the traditional wooden slatted floor. These measurements were commissioned by Bettink Service Team and by Beerepoot Stalinrichtingen BV. Ammonia emissions were significantly lower (53%) than the emission from the traditional floor measured simultaneously within the same farm (case-control approach). Odour emissions were significantly lower (47%) than the emission from the traditional floor measured simultaneously within the same farm (case-control approach).

This report can be downloaded for free at https://doi.org/10.18174/478308 or at www.wur.nl/livestock-research (under Wageningen Livestock Research publications).


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# Foreword

This report presents the results of measurements of the ammonia and odour emissions performed at one animal facility for veal calves using the control-case approach to determine the effect of a ‘Groene Vlag’ floor combined with a V-shaped manure belt under the floor compared to a traditional wooden slatted floor with manure storage underneath the floor.
The research project was funded by Bettink Service Team and Beerepoot Stalinrichtingen BV.

Julio Mosquera
Project leader

# Summary

This report shows the results of environmental measurements performed at one animal facility for white veal calves located near Kootwijkerbroek in The Netherlands, using the control-case approach, to estimate the ammonia and odour emission reduction of combining one floor type (Groene Vlag) with a V-shaped manure belt under the floor compared to the traditional housing on a wooden slatted floor with manure storage underneath.

During the experiment all in – all out was performed at the same time for the compartments used in this study. Management and feeding were kept identical in all involved compartments.

Ammonia and odour were measured six times in a year using a 24-hours continuous measuring strategy for ammonia and a 2-hours measuring strategy for odour (between 10:00-12:00) at approximately 2 months interval . This measuring strategy is in accordance with the Dutch emission measurement protocol (Ogink et al., 2013) and the international Vera protocol valid at that moment (VERA Test Protocol for Housing Systems Version 2:2011-08).

Based on all available data, the following emission reductions (emission of the floor compared to the emission from the traditional wooden slatted floor as simultaneously measured at the same farm location; average of all measurements) were measured:

| | **Average reduction +/- standard deviation between measurements** |
|---|---|
| Ammonia (% reduction) | 52.9 +/- 19.3 |
| Odour (% reduction) | 46.6 +/- 19.4 |

Ammonia emissions were significantly lower (53% lower; P-value: 0.01) than the emission from traditional veal calve housing measured simultaneously within the same farm (case-control approach).

Odour emissions were significantly lower (47% lower; P-value < 0.01) than the emission from traditional veal calve housing measured simultaneously within the same farm (case-control approach).

# 1 Introduction

Joop Bettink, entrepreneur and veal farmer in Kootwijkerbroek, has developed a new housing system for veal calves with special attention for both animal, environment and society. This system offers extra floor space for the calves and includes pens that are equipped with a curved soft slatted floor (Groene Vlag) for animal welfare and quick drainage of urine and faeces. The system has a V-shaped manure belt under the slatted floor for direct separation of liquid and solid manure, with continuous drainage of urine and frequent removal of the solid manure.

Bettink and Beerepoot Stalinrichtingen commissioned Wageningen UR Livestock Research to perform emission measurements following the case-control approach to study the effect of this housing system on the ammonia and odour emissions compared to the traditional wooden slatted floor with manure storage underneath. This report presents the measurement methods, main results and conclusions of this research.

# 2 Material and methods

In the following paragraphs and appendices, a description will be given of the measurement farm locations and housing systems (2.1; Appendix 1), of the measurement setup and strategy (2.2), and of the method of processing the data (2.3).

## 2.1 Measurement farm

The measurements took place in two rooms in separate buildings on a (white) veal calves farm near Kootwijkerbroek, The Netherlands.

One room ("the reference") was provided with a traditional wooden slatted floor (slats are approximately 80 mm wide, slits are approximately 30 mm wide), and was used as reference (control) floor. This room consisted of two rows of six pens separated by a feeding alley (Appendix 1). Each row included four small pens (see Table 1), with a capacity of housing six calves per pen and two larger pens (see Table 1) with a capacity of seven calves (in total 76 animal places). This is in accordance with the existing regulation prescribing at least 1.8 $m^2$ living area per animal. Manure was stored in manure pits under the slatted floors (depth approximately 115 cm).

The second room was provided with the "Groene Vlag" slatted floor (slats are approximately 130 mm wide, and provided with a convex compressible top layer; slits are approximately 29 mm wide) and a V-shaped manure belt under the floor. This room consisted of two rows of six pens separated by a feeding alley (Appendix 1). Per row six pens were available (see Table 1), with a total capacity of 74 animal places. The pens provided 2,0 $m^2$ living area per animal, 0,2 $m^2$ more than the reference and the legally required minimum. Approximately 30 cm under the slatted floor, a V-shaped manure belt was mounted. Here faeces and urine were collected separately. The urine will flow to the lowest point of the V-shaped belt and is removed to a storage outside the room continuously. The solid manure was removed by operating the belt at the beginning once and later two times daily and storing it in an underground storage outside the building.

The calves were placed in the rooms at an average initial weight of approximately 45 kg. In accordance to the existing regulations for veal calves, animals were first kept in individual boxes, and placed in groups at an age of 8 weeks until the animals reached a weight of approximately 250 kg. The production cycle amounted on average 203 days (average of the first two measured production cycles for the two measured rooms).

The rooms were at the very beginning of each production cycle additionally heated and for a few days naturally ventilated, by regulating the inlet openings, and later on force ventilated: air enters the room through an inlet opening (Appendix 1) and leaves the room by ventilation shafts placed on top of the roof above the feeding alley. For this purpose, the room with traditional floor was provided with two ventilation fans (each 40 cm diameter), controlled by a computer system. The room with the new system was provided with one ventilation fan (63 cm diameter), controlled by a computer system.

The calves were fed twice a day at about five in the morning and four in the afternoon. The calves were fed liquid feeding (warm milk made from water and milk powder) and were additionally provided with some roughage.

Table 1 provides an overview of the main characteristics of the different rooms.

***Table 1*** *Characteristics of the investigated rooms at the measurement location.*

| Characteristics/room | 16 | 5 |
|---|---|---|
| Number of pens | 12 (2 x 6) | 12 (2 x 6) |
| Pen dimension (width x length) per row | | |
| Pen 1 | 4.00 x 3.06 | 3.64 x 2.95 |
| Pen 2, 3 en 4 | 4.00 x 3.06 | 3.55 x 2.95 |
| Pen 5 | 4.00 x 3.06 | 4.25 x 2.95 |
| Pen 6 | 4.00 x 3.06 | 4.28 x 2.95 |
| Animal places | 74 | 76 |
| Walking area per animal ($m^2$) | 2,0 | 1.8 |
| Slatted floor (% of walking area) | 100 | 100 |
| Slatted floor type | "Groene Vlag" slats | Wooden slats (traditional) |
| Manure storage | V-shaped manure belt with daily removal | Manure storage underneath slatted floor |
| Manure pit depth (cm) | 65 | 115 |
| Ventilation fans: | | |
| Number | 1 | 2 |
| Diameter (cm) | 63 | 40 |
| Total max capacity ($m^3$/h) | 13500 | 9000 |

## 2.1.1 Emission reduction principle

The (soft)floor evaluated in this project (Figure 1) is considered not only to have positive effects on the animals (increasing technical and economic value), but also to have the potential to reduce ammonia emissions from the animal building. The main emission reduction principles combined in this system are:

- Fast removal of urine from the floor. Using a convex rubber top layer may favour fast removal of urine and faeces to the manure pit underneath the floor. By removing the urine to the pits with less favourable emission conditions the emission of ammonia will be reduced.
- Reduction of urease activity. Using rubber materials may reduce the urease activity on the floor and belt and the pH of the urine left on the slatted floor, and make the conditions less favourable for ammonia production.
- Reduction of contact (time) between urine and feces. The V-shaped manure belt under the floor (Figure 2 and Appendix 1), with continuous drainage of urine and frequent removal of the solid manure, reduces the contact between urine and faeces, therefore reducing ammonia emissions.


***Figure 1*** *Measured floors. A) Traditional wooden slatted floor; B) "Groene Vlag" floor with C) V-shape belt.*

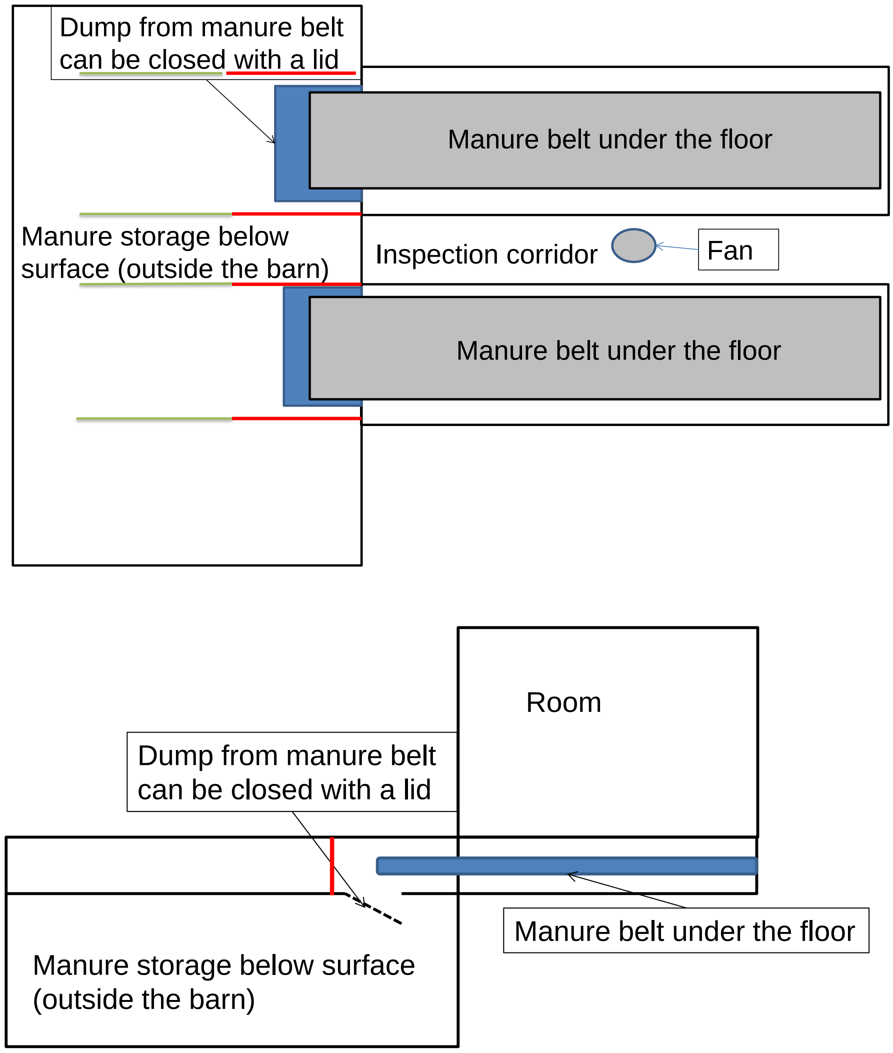



***Figure 2*** *Schematic view of the position of the V-shaped manure belt (Top: View from above; Bottom: cross-section).*

## 2.2 Measurements

### 2.2.1 Measurement strategy

Measurements were performed at one animal facility for veal calves using the control-case approach. The all-in all-out approach was implemented, meaning that the rooms were filled simultaneously with animals at the beginning of each production cycle. Besides, at each animal facility management and care of the veal calves was similar for all the rooms being considered in this research project. The rooms are forced ventilated except for the first few days of the rearing period.

Measurements were performed in the period March 2014 – May 2015, following the measurement protocol described in Ogink et al. (2013) for ammonia ($NH_3$), and in Ogink (2011) for odour. Shortly, these protocols specify the implementation of six measurements of at least 24 hours, evenly distributed in a calendar year (approximately every two months) and over the production cycle of the animals, taking into account the agronomic requirements as presented in the measurement protocols. For animals with a growing production cycle, and expected linear increase in ammonia emission during the production cycle, such as veal calves, the protocols also specify that:

- Per farm location and housing system, three of the six measurements should be performed in the first half of the production cycle, and the other three measurements in the second half of the production cycle.
- The measurements in the second half of the production cycle must be implemented over three different seasons (summer, winter and autumn/spring).

For every measurement period, the following measurements (per floor type/room) were performed (see Appendix 1 for scheme with sampling points):

- The concentration of ammonia in the outgoing air (through the ventilation fans) and in the incoming air (background), using the method described in 2.2.2.
- The concentration of odour in the outgoing air (through the ventilation fans), using the method described in 2.2.3.
- The ventilation rate using the method described in 2.2.4.
- The temperature and relative humidity in all the measured rooms, and outside the rooms, using the method described in 2.2.5.
- Feeding and production data, agronomic requirements as described in 2.2.6.
- Visual inspection of the degree of cleanliness of the floor and the animals (see 2.2.7).
- The urease activity on the V-shaped manure belt (see 2.2.8).

### 2.2.2 Ammonia concentration

The ammonia concentration in both the incoming (background) and outgoing (room) air was measured for all rooms in duplicate using gas washing (impingers, acid traps, acid scrubbers or absorption flasks; Wintjens, 1993). In this method, an air sample is taken and drawn at a known flow rate (~1,0 l/min) using a pump (Thomas Industries Inc., model 607CD32, Wabasha, Minnesota ,VS) and critical orifices through a set of three absorption flasks (Figure 3). The first flask (filled with 100 ml 0,05 M nitric acid) is for collecting the ammonia, the second one (also filled with 100 ml 0,05 M nitric acid) to check for saturation, and the third one (empty) to collect any remaining liquids in the air before reaching the pump. The samples are analysed in a certified laboratory by using HPLC spectrophotometry. The flow rate through the acid traps is measured before and after performing the measurements by using a calibrated flow meter (Defender 510-m, Bios Int. Corp, USA).

***Figure 3*** *Measurement method for ammonia concentration measurements. Left: acid traps; Middle: flow meter; Right: pump.*

### 2.2.3 Odour concentration

Odour concentrations in the outgoing (room) air were measured in all rooms using the lung method as described in Ogink and Mol (2002). In this method, a 40 litre Nalophan sampling bag is first inserted in a closed container and kept under vacuum conditions (Figure 4). An air sample is then taken from the sample location by using Teflon sampling lines, and sucking air from the container at a known flow rate (~0,4 l/min) using a pump (Thomas Industries Inc., model 607CD32, Wabasha, Minnesota ,VS) and critical orifices. This creates an under pressure in the container, allowing the air sample to be drawn into the sampling bag, after first being led through a dust filter (type #1130, diameter: 50 mm, 1-2 μm, Savillex® Corp., Minnetonka, VS). Odour samples are analysed within 24 hours after sampling by olfactometry by an accredited odour laboratory, following the European Normative EN 13725 (CEN, 2003). Unlike ammonia, odour concentrations are measured during a shorter period of time (2 hours, between 10:00am and 12:00 am, instead of 24 hours). For odour, single measurements (per room) were performed.

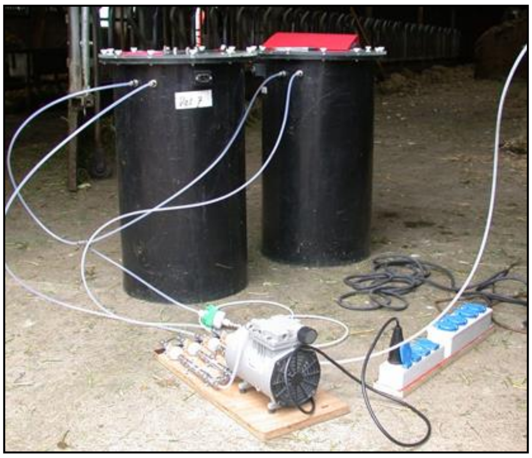


***Figure 4*** *Measurement method for odour concentration measurements.*

### 2.2.4 Ventilation rate

Both rooms were force ventilated by means of a computer controlled ventilator (Fancom). The reference room had two ventilators of 40 cm diameter each. The case room hade one ventilator of 63 cm diameter. Ventilation rate was determined using an temperature-bodyweight algorithm and controlled by the ventilation computer based on feed-back of a free running measuring fan (FMS40 and FMS63 respectively). The pulse signal of the free running measuring fan was also registered and logged into a logging system (Campbell Scientific Inc., Logan, VS) during the whole measurement period. The relation between pulse signal (Hz) and ventilation rate was known an provided by manufacturer. This characteristic was checked between production cycle one and two as follows:

1) The ventilation rate was set manually (through the computer system on farm) to different constant values while logging the pulse signal from the free running measuring fan.
2) At each ventilation level, the air speed through the ventilation shaft was measured at about 25% of the shaft diameter. From this air speed and the surface of the shaft, a ventilation rate in $m^3/h$ was calculated.
3) The regression line through the plotted data for each type of ventilator (40 cm vs 63 cm) separately represents the relation between pulse signal and ventilation rate and is used to calculate ventilation rate for all emission measurements in all production cycles (see Figure 5).

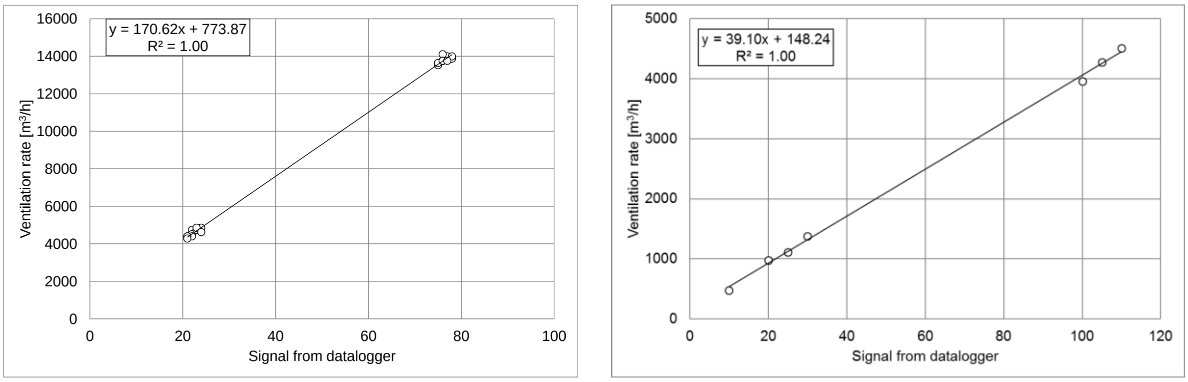



***Figure 5*** *Calibration lines used to determine the ventilation rate (Left: case room; right: control room).*

The calibration line used for the control room is based on measurements of four ventilators used in four different rooms during simultaneous emission measurements reported in Mosquera et al. (2017).

### 2.2.5 Temperature and relative humidity

Room and outdoor temperatures and relative humidity were continuously measured by using temperature and relative humidity sensors (Rotronic; ROTRONIC Instrument Corp., Huntington, VS; Figure 6) with an accuracy of respectively ± 1,0 °C en ± 2%. Data was stored in a logging system (Campbell Scientific Inc., Logan, VS).

***Figure 6*** *Rotronic for temperature and relative humidity measurements.*

### 2.2.6 Production data and agronomic conditions

The following information about the production and agronomic conditions was collected:

- Number of animals (per room)
- Average weight of the animals at start of the period
- Slaughtered weight of the animals
- Daily gain of the animals (calculated from weights)
- Feed composition
- $CO_2$ concentration

Carbon dioxide ($CO_2$) concentrations in the outgoing (room) air were measured in most of the cases using the lung principle, collecting air in sample bags placed in air tight vessels, similar to the procedure for odour sampling. $CO_2$ concentrations in the sampling bags were analysed in laboratory by a GC (GC 8000 TOP, Interscience, Breda, The Netherlands; column Molsieve 5A; detector: HWD). In some cases not enough vessels were available and measurements were performed by using an infrared photoacoustic multi-gas monitor (Figure 7; INNOVA 1312, LumaSense Technologies, Ballerup, Denmark).

***Figure 7*** *Infrared photoacoustic monitor for $CO_2$ concentration measurements.*

### 2.2.7 Cleanliness of floor and animals

During each measuring period the cleanliness of the floors and animals was visually checked and rated according to the following scheme (Table 2).

***Table 2*** *Categories of cleanliness of floor and animals.*

| Code | Description |
|---|---|
| 1 | Clean (<10% dirty) |
| 2 | Reasonably clean (10-40% dirty) |
| 3 | Largely dirty (40-70% dirty) |
| 4 | Dirty (>70% dirty) |

### 2.2.8 Urease activity (V-shaped manure belt)

At the start of the measurement period in March 2014 measurements were performed to determine the urease activity of the V-shaped manure belt below the slatted floor. Urine samples were taken at the end of the manure belt, where urine drops off, at three different moments: one period with relatively old urine, just before the manure belt was turned on, and two periods within a time lag of 2 hours just before the manure belt was turned off. From every urine sample, two tests were performed in duplicate: 1) adding 2 ml urine to 1 ml water; 2) adding 2 ml urine to 1 ml acid (nitric acid). The idea behind these tests is that, by adding acid, the conversion of urea into ammonium ($NH_4^+$) is stopped, whereas in water all the urea still can be converted into ammonium. In this way, it is possible to determine how much urea (conversion factor: CF, in %) has already being converted into ammonium on the manure belt:

$$CF(\%) = 100 * \frac{NH4 - N\ in\ acid\ (g/l)}{NH4 - N\ in\ water\ (g/l)}$$

## 2.3 Data analysis

### 2.3.1 Ammonia emissions

Ammonia emissions ($E(NH_3)_{ij}$ in [kg/year per animal place]) per 24-hour measurement period (i=1, 2, ..., 6) and treatment (j=1: Traditional wooden slatted floor; j=2: "Groene Vlag" slatted floor with V-shaped manure belt), were calculated based on the measured ventilation rates ($V_{ij}$ in [$m^3$/h]; average over the 24-hour measurement period) and ammonia concentrations in the outgoing ($Cout_{ij}$ in [g/$m^3$] average over the 24-hour measurement period) and incoming (background; $Cbackg_{ij}$ in [g/$m^3$]; average over the 24-hour measurement period) air, the number of animal places at the measured rooms, and the percentage of the days the rooms were occupied (93% for white veal calves; Groenestein and Aarnink, 2008) according to:

$$E(NH_3)_{ij} = V_{ij} \times (Cout_{ij} - Cbackg_{ij}) \times \frac{1\,\text{kg}}{1000\,\text{g}} \times \frac{24\,\text{h}}{1\,\text{d}} \times \frac{365\,\text{d}}{1\,\text{year}} \times \frac{1}{\text{animal places}} \times 0.93$$

Ammonia emissions per treatment ($E(NH_3)_i$ in [g/year per animal place]) were then calculated by averaging the emissions measured during the six measurement periods.

### 2.3.2 Odour emissions

Odour emissions ($E(odour)_{ij}$ in [$OU_E$/s per animal place]) per measurement period (i=1, 2, ..., 6) and treatment (j=1: Traditional wooden slatted floor; j=2: "Groene Vlag" slatted floor with V-shaped manure belt), were calculated based on the measured ventilation rates ($V_{ij}$ in [$m^3$/h]; average over the 2-hour measurement period), odour concentrations in the outgoing air ($Cout_{ij}$ in [$OU_E/m^3$] average over the 2-hour measurement period), the number of animal places at the measured rooms, and the percentage of the days the rooms were occupied (93% for white veal calves; Groenestein and Aarnink, 2008) according to:

$$E(odour)_{ij} = V_{ij} \times Cout_{ij} \times \frac{1\,\text{h}}{3600\,\text{s}} \times \frac{1}{\text{animal places}} \times 0.93$$

Odour emissions per treatment ($E(odour)_i$ in [$OU_E$/s per animal place]) were then calculated as follows:

- First, measured emissions were transformed into the natural logarithm scale.
- Then, the average of these emissions (per treatment) was calculated.
- Finally, the averaged Ln-emissions were transformed back into the normal scale, leading to a median (instead of average) emission per treatment.

### 2.3.3 Emission reduction

The reduction in ammonia and odour emission for the housing system "Groene Vlag" slatted floor with V-shaped manure belt (Egv) compared to the traditional wooden slatted floor (Etr) was calculated as:

- First, the emission reduction for ammonia ($ER(NH_3)_i$) and odour ($EF(odour)_i$) are calculated per measurement period (i=1, 2, ..., 6) as:

$$ER(NH_3)_i = 100 \times \left(1 - \frac{Egv(NH_3)_i}{Etr(NH_3)_i}\right) \qquad ER(odour)_i = 100 \times \left(1 - \frac{Egv(odour)_i}{Egv(odour)_i}\right)$$

- Then, the calculated emission reductions are averaged for all measurement periods to obtain an average emission reduction.

### 2.3.4 Statistical analysis

A two-sided paired t-test was used to determine the probability that the differences in emission between treatments was significantly deviating from zero. All analyses were done using the GenStat software. Probability values $P<0.05$ were considered statistically significant. Values between 0.05 and 0.10 ($0.05<P<0.10$) were considered to have a weak significance level, and values $P>0.10$ were considered to be not significant.

# 3 Results and discussion

## 3.1 Technical results and agronomic requirements

Table 3 shows the production results of the production cycles. To place these results in a national perspective, Table 3 also shows the average production results, as reported in the Quantitative Livestock Information (KWIN, 2014).
The compartments were occupied with two-week old male veal calves from Dutch, Belgium or German origin. Animal loss was on average less than 5 % and occurred mostly in the first weeks after the start of each cycle. For the control room animal loss was lower in the second production cycle (on average 3%) than in the first production cycle (on average 8%). Animal loss for the case-room was lower than for the control-room, and for both production cycles less than 2%. In order to keep up the occupation rate, the losses were replaced by similar aged calves from elsewhere on the farm.
The average weight of placed and delivered animals were similar in both rooms and between production cycles. The average weight of delivered animals was somewhat higher than the agronomic requirements, but also the production cycles were on average 12 days longer than national average. Forage provided to the animals had on average over the whole production cycle more than 250 grams of feed rich in fibre, as required in the Directive 91/629/EEG for veal calves older than eight weeks. The average feed conversion (milk consumption related to growth rate) was 1.5, and similar between rooms and production cycles.

***Table 3*** *Production results for three production cycles, national averages (KWIN, 2014), and agronomic requirements.*

| Floor type | Characteristics | Production cycle 1 | Production cycle 2 | Production cycle 3 | National average | Agronomic requirements |
|---|---|---|---|---|---|---|
| "Groene Vlag" with V-shaped manure belt | Number of days | 204 | 203 | 198 | 180 | -- |
| | Number of animals placed | 74 | 75 | 74 | -- | ≥ 40 |
| | Number of animals delivered | 74 | 74 | 73[2] | -- | -- |
| | Loss (%) | 0 | 1.3 | 1.4 | -- | < 5% |
| | Average weight of placed animals | 44 | 47 | 45 | 47 | ≥ 45 |
| | Average weight of delivered animals[1] [kg] | 234[2] | 246 | 234[2] | 225 | ±225 |
| | Growth rate [kg/animal/day] | 0.93[2] | 0.98 | 0.96 | 0.99 | -- |
| | Milk consumption [kg milk powder/animal] | 303[2] | 274[2] | 312[2] | -- | -- |
| | Roughage consumption [kg/animal] | 251[2] | 268[2] | 235[2] | -- | -- |
| | Concentrates consumption [kg/animal] | --- | --- | --- | -- | -- |
| | Feed conversion[3] [$kg_{melk}/kg_{groei}$] | 1.6 | 1.4 | 1.6 | -- | -- |
| Traditional housing | Number of days | 204 | 203 | 196 | 180 | -- |
| | Number of animals placed | 76 | 76 | 76 | -- | ≥ 40 |
| | Number of animals delivered | 70 | 74 | 76 | -- | -- |
| | Loss (%) | 8.2[2] | 2.6 | 0.0 | -- | < 5% |
| | Average weight of placed animals | 45 | 41 | 46 | 47 | ≥ 45 |
| | Average weight of delivered animals[1] [kg] | 234 | 243 | 233 | 225 | ±225 |
| | Growth rate [kg/animal/day] | 0.93 | 0.99 | 0.95 | 0.99 | -- |
| | Milk consumption [kg milk powder/animal] | 303 | 274 | 309 | -- | -- |
| | Roughage consumption [kg/animal] | 251 | 269 | 234 | -- | -- |
| | Concentrates consumption [kg/animal] | --- | --- | --- | -- | -- |
| | Feed conversion[3] [$kg_{melk}/kg_{groei}$] | 1.6 | 1.4 | 1.7 | -- | -- |

[1] Calculated as 154% of slaughtered weight
[2] Individual room data not known. Calculated as average of all rooms included in Mosquera et al (2017) simultaneous measured in the same production cycle.
[3] Calculated as milk consumption per day divided by growth rate

## 3.2 Cleanliness of floor and animals

Table 4 shows the degree of cleanliness of the floor and animals (visually inspected and rated) during the measurements, for both floor types. In general, animals were considered to be clean to reasonably clean for both floor types. Regarding the cleanliness of the floors, large differences were observed. The "Groene Vlag" floor with V-shaped manure belt scored generally as "reasonably clean", while the traditional wooden slatted floor scored generally as "dirty".

***Table 4*** *Cleanliness of floor and animals as observed during the measurements.*

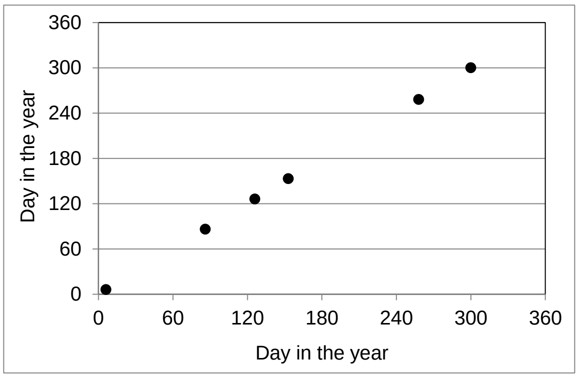
| Measurement | Floor type | Cleanliness farm location 2 | |
|---|---|---|---|
| | | Floor | Animals |
| 1 | "Groene Vlag" with V-shaped manure belt | 2 | 1-2 |
| | Traditional wooden slats | 4 | 1-2 |
| 2 | "Groene Vlag" with V-shaped manure belt | 2 | 1-2 |
| | Traditional wooden slats | 4 | 1-2 |
| 3 | "Groene Vlag" with V-shaped manure belt | 2 | 1-2 |
| | Traditional wooden slats | 4 | 1-2 |
| 4 | "Groene Vlag" with V-shaped manure belt | 2 | 1-2 |
| | Traditional wooden slats | 4 | 1-2 |
| 5 | "Groene Vlag" with V-shaped manure belt | 2 | 1-2 |
| | Traditional wooden slats | 4 | 1-2 |
| 6 | "Groene Vlag" with V-shaped manure belt | 2 | 1-2 |
| | Traditional wooden slats | 4 | 1-2 |

## 3.3 Measurement conditions

Table 5 gives an overview of the measurement conditions during the measurements. The measurements were performed within a period of 294 days distributed over the year (Figure 8a) and the production cycle (Figure 8b) according to the requisites of the measurement protocol (half of the measurements on the first half of the production cycle, half of the measurements on the second half of the production cycle and distributed over three different seasons). Considering all six measurements, the average measurement day in the year was 155. The average day in the production cycle was 99 days. The degree of occupation (number of animals in the rooms compared to the number of animal places based on 1.8 $m^2$/animal) varied between 99 % and 101 % (average 100 %). The concentration of carbon dioxide ($CO_2$) in the rooms was always below 3000 ppm. As pointed out in section 3.1, animals were provided with roughage having (on average over the whole production cycle) at least 250 grams of feed rich in fibre. Animals were provided with standard veterinary care (see Appendix 2 for an overview of the animals being treated for the production cycles were measurements took place).

**Table 5** *Measurement conditions.*

| Floor type | Characteristics/ measurement | 1 | 2 | 3 | 4 | 5 | 6 |
|---|---|---|---|---|---|---|---|
| General information | Date | 27-3-2014 | 2-6-2014 | 15-9-2014 | 27-10-2014 | 6-1-2015 | 6-5-2015 |
| | Day in the year | 86 | 153 | 258 | 300 | 6 | 126 |
| | Outside temperature [ºC] | 11.4 | 18.6 | 19.3 | 12.6 | 3.4 | 13.3 |
| | Outside relative humidity [%] | 53.3 | 56.8 | 83.0 | 84.4 | 89.9 | 70.6 |
| "Groene Vlag" with V-shaped manure belt | Animal places | 74 | 74 | 74 | 74 | 74 | 74 |
| | Number of animals | 74 | 73 | 75 | 74 | 74 | 74 |
| | Occupation rate | 1.00 | 0.99 | 1.01 | 1.00 | 1.00 | 1.00 |
| | Day in the production cycle | 107 | 174 | 39 | 81 | 152 | 36 |
| | Animal weight [kg] | 162 | 225 | 74 | 115 | 211 | 58 |
| | Inside temperature [ºC] | 16.4 | n.a. | n.a. | 19.0 | 15.6 | 17.8 |
| | Inside relative humidity [%] | 62.2 | n.a. | n.a. | 84.5 | 79.5 | 61.4 |
| | $CO_2$ concentration inside [ppm] | 1120 | 975 | 770 | 1430 | 1222 | 978 |
| Traditional housing | Animal places | 76 | 76 | 76 | 76 | 76 | 76 |
| | Number of animals | 76 | 76 | 76 | 75 | 75 | 76 |
| | Occupation rate | 1.00 | 1.00 | 1.00 | 0.99 | 0.99 | 1.00 |
| | | | | | | | |
| | Day in the production cycle | 107 | 174 | 40 | 82 | 153 | 41 |
| | Animal weight [kg] | 162 | 220 | 73 | 117 | 210 | 60 |
| | Inside temperature [ºC] | 17.5 | 23.7 | 23.0 | 19.6 | 16.3 | 18.7 |
| | Inside relative humidity [%] | 64.1 | 59.1 | 73.2 | 98.1 | 84.0 | 62.8 |
| | $CO_2$ concentration inside [ppm] | 1020 | 1160 | 980 | 1490 | n.a. | 1083 |



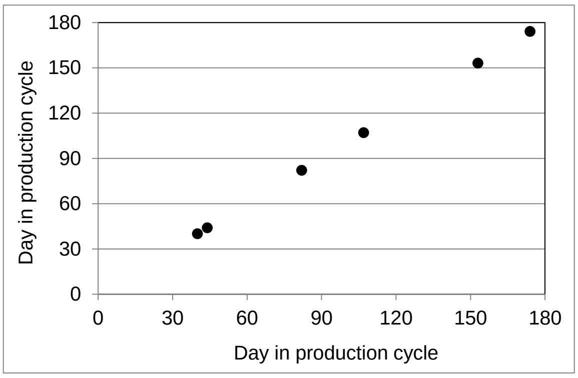




***Figure 8*** *Distribution of measurements in the year (a;left) and in the production cycle (b;right).*

Figure 9 shows the average outside temperature at the days were measurements were performed, compared to the average outside temperature as measured in the weather station De Bilt (in the middle of the Netherlands) during the last 10 years (period 2004-2013). The average outside temperature during the measurements was 13.1 ºC, higher than the average of the last 10 years (10.5 ºC).

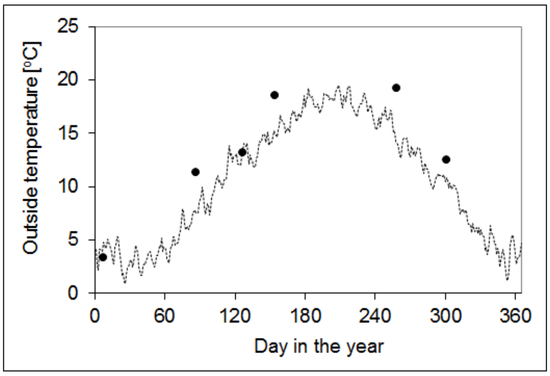



***Figure 9*** *Outside temperature compared to the average (2004-2013) outside temperature measured in the Netherlands at the weather station De Bilt (www.knmi.nl; shown as dotted line).*

Figure 10 shows the ventilation rate ($m^3$/h per animal) measured in both investigated rooms. The ventilation rate was higher for the room with the "Groene Vlag" floor with V-shaped manure belt compared to the room with traditional wooden slatted floor.

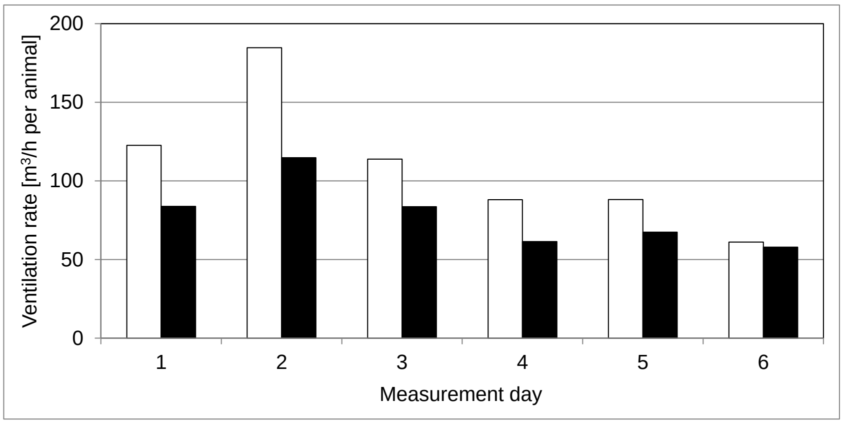



***Figure 10*** *Ventilation rate ($m^3$/h per animal) for both rooms (White: "Groene Vlag" with V-shaped manure belt; black: traditional wooden slatted floor).*

## 3.4 Ammonia and odour emissions

Table 6 gives an overview of the available data regarding the emission of ammonia and odour during all measurement periods.

***Table 6.*** *Measurement results. Emissions are corrected for the percentage of the days the rooms were occupied (93% for white veal calves; Groenestein and Aarnink, 2008).*

| Floor type | Characteristics/ measurement | 1 | 2 | 3 | 4 | 5 | 6 |
|---|---|---|---|---|---|---|---|
| | **Production cycle** | **1** | **1** | **2** | **2** | **2** | **3** |
| **"Groene Vlag" with V-shaped manure belt** | Ventilation rate [$m^3$/h per animal] | 122.6 | 184.7 | 113.8 | 88.0 | 88.2 | 61.0 |
| | $NH_3$ concentration inside [ppm] | 3.4 | 3.6 | 2.3 | 4.5 | 7.6 | 3.0 |
| | $NH_3$ background concentration [ppm] | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 |
| | $NH_3$ emission [kg/year per animal place] | 2.4 | 3.7 | 1.4 | 2.2 | 3.8 | 1.0 |
| | **$NH_3$ emission reduction [%]** | **41.1** | **36.1** | **74.2** | **56.4** | **32.7** | **76.7** |
| | Odour concentration inside [$OU_E/m_3$] | 802 | 568 | 449 | 798 | 745 | 1034 |
| | Odour emission [$OU_E$/s per animal place] | 25.4 | 26.7 | 13.4 | 18.1 | 17.0 | 16.3 |
| | **Odour emission reduction [%]** | **51.7** | **47.8** | **6.8** | **42.9** | **55.3** | **61.2** |
| **Traditional slatted floor** | Ventilation rate [$m^3$/h per animal] | 83.8 | 114.7 | 83.6 | 61.4 | 67.4 | 57.8 |
| | $NH_3$ concentration inside [ppm] | 8.5 | 8.8 | 11.7 | 14.7 | 15.0 | 13.1 |
| | $NH_3$ background concentration [ppm] | 0.1 | 0.1 | 0.1 | 0.1 | 0.1 | 0.2 |
| | $NH_3$ emission [kg/year per animal place] | 4.0 | 5.8 | 5.6 | 5.1 | 5.7 | 4.3 |
| | **$NH_3$ emission reduction [%]** | **---** | **---** | **---** | **---** | **---** | --- |
| | Odour concentration inside [$OU_E/m_3$] | 2431 | 1727 | 665 | 2030 | 2209 | 2811 |
| | Odour emission [$OU_E$/s per animal place] | 52.6 | 51.2 | 14.4 | 31.8 | 37.9 | 42.0 |
| | **Odour emission reduction [%]** | **---** | **---** | **---** | **---** | **---** | --- |

Based on all available data, the following emissions were determined (Table 7).

***Table 7*** *Overview of emission results.*

| Floor | Average ± standard deviation between measurements | |
|---|---|---|
| | Ammonia emission [kg/year per animal place] | Odour emission [$OU_E$/s per animal place] |
| "Groene Vlag" with V-shaped manure belt | 2.4 ± 1.1 | 18.9 ± 5.3 |
| Traditional wooden slatted floor | 5.1 ± 0.7 | 35.4 ± 14.1 |

Average ammonia emission from the traditional wooden slatted floor (on average 5.1 kg/year per animal place, corrected for the percentage of the days the rooms were occupied (93% for white veal calves; Groenestein and Aarnink, 2008)) was higher than the emission factor (3.5 kg/year per animal place) provided in the Regulation Ammonia and Livestock (Rav, Regeling ammoniak en veehouderij; Staatscourant, 2015). These emissions are also higher than the emissions reported in Hol and Groenestein (1997) and Beurskens and Hol (2004): 2.5 kg/year per animal place and 3.4 kg/year per animal place, respectively.

Odour emissions from the traditional wooden slatted floor (on average 35.4 $OU_E$/s per animal place, corrected for the percentage of the days the rooms were occupied (93% for white veal calves; Groenestein and Aarnink, 2008)) were similar to the assigned emission factor of 35.6 $OU_E$/s per animal place (Staatscourant, 2013). These emissions are also similar to the emissions reported in Beurskens and Hol (2004): 41.8 $OU_E$/s per animal place.

Based on all available data, the following ammonia emission reductions (emission of the floor compared to the emission from the traditional wooden slatted floor as simultaneously measured at the same farm location) were determined (Table 8).

***Table 8*** *Overview of emission reduction.*

| | Average reduction +/- standard deviation between measurements |
|---|---|
| Ammonia (% reduction) | 52.9 +/- 19.3 |
| Odour (% reduction) | 46.6 +/- 19.4 |

Ammonia emissions (Figure 11a) were significantly lower (53% lower; P-value: 0.01) than the emission from the traditional floor measured simultaneously within the same farm (case-control approach). Reductions were higher at the beginning of the production cycle, and lower at the end of the production cycle.

Odour emissions (Figure 11b) were significantly lower (47% lower; P-value < 0.01) than the emission from the traditional floor measured simultaneously within the same farm (case-control approach). Reductions were similar for all measurements, with the only exception of measurement 3. This low odour emission reduction cannot be explained using the available information.

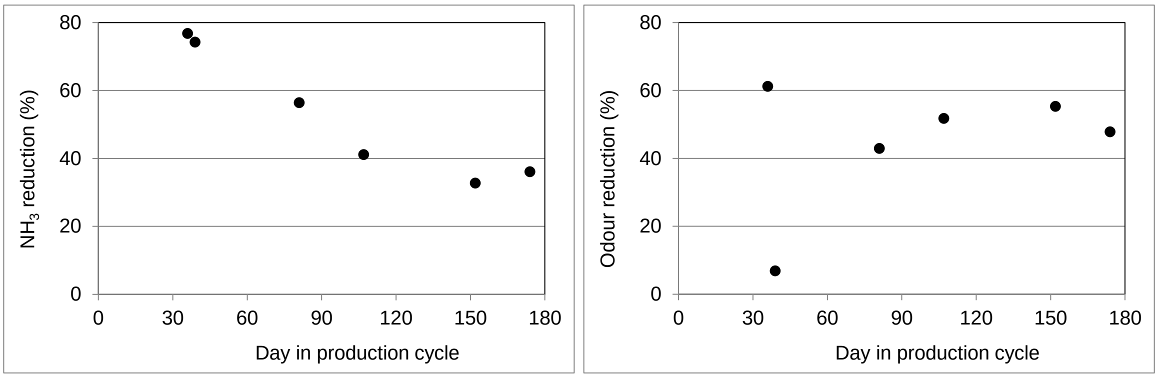



***Figure 11*** *Ammonia (a;left) and odour (b;right) emission reduction (compared to the traditional wooden slatted floor).*

## 3.5 Urease activity (V-shaped manure belt)

Table 9 shows the results of the measurements performed to determine the urease activity of the manure belt. Although not negligible, the urease activity of the manure belt seems to be low. On average, approximately 25% of the urea is converted into ammonium at the manure belt before being transported into the underground manure storage outside the building. As a result, only a small part of the ammonia emission is expected to be emitted from the manure pit/manure belt.

***Table 9*** *Ammonium content of the urine (in g NH4-N/l) treated with water (total conversion of urea into ammonium) and nitric acid (reduced conversion of urea into ammonium), and the resulting conversion factor (%) as a measure of the urease activity of the manure belt.*

| Period | Sample | $NH_4$-N urine in water (g $NH_4$-N/l) | $NH_4$-N urine in nitric acid (g $NH_4$-N/l) | Conversion factor (%) |
|---|---|---|---|---|
| **1** | **1** | 2.03 | 0.53 | 25.9 |
| | **2** | 2.03 | 0.50 | 24.8 |
| **2** | **1** | 1.81 | 0.40 | 22.2 |
| | **2** | 1.81 | 0.41 | 22.5 |
| **3** | **1** | 1.80 | 0.46 | 25.8 |
| | **2** | 1.79 | 0.47 | 26.3 |

## 3.6 Reflection on emission results and agronomic requirements

Production results of case and control room in all three production cycles were according to agronomic requirements with two exceptions:

- The animal loss in the control room in production cycle 1 was slightly higher than required (8.2% versus less than 5%). Losses were directly replaced by animal of comparable weights from other rooms in order to keep both compartments comparable.

- The average starting weight of animals in case room at start in production cycle 1 was 1 kg lower than required (44 kg instead of ≥ 45 kg).

In both cases it is not likely that these exception had a decisive influence on the emission results.

Not all agronomic requirements in the case room were recorded (see Table 3) on room level. When necessary average data were calculated based on results from other rooms in the same production cycle that were measured simultaneously and reported in Mosquera et al. (2017).

For animals with a growing production cycle and expected linear increase in ammonia emission during the production cycle, such as veal calves, the protocols also specify that:

- Per farm location and housing system, three of the six measurements should be performed in the first half of the production cycle, and the other three measurements in the second half of the production cycle.
- The measurements in the second half of the production cycle must be implemented over three different seasons (summer, winter and autumn/spring).

The second requirement was not met as two of the three measurements in the second half of the production cycle were done in spring (27-3-2014 and 2-6-2014). The third measurement was done in winter (6-1-2015). However, as the first measurement was only 6 days after start of spring 2014 and the second only 19 day before the end of spring 2014 we believe that circumstances during measurements were discriminative enough. Moreover, the average temperatures at these days showed enough difference (11.4 $^{o}$C vs 18.6 $^{o}$C).

Ventilation rate (in cubic meter per animal per hour) in reference room was during all measurements lower than in the over room. As higher ventilation rates in general will lead to higher emissions the emission reductions are probably under estimated.

Floor space per animal in the rooms with a V-shaped manure belt and “Groene Vlag” floor was around 10 % higher than in the reference room (2.0 $m^2$ per animal instead of 1.8 $m^2$ per animal). Additional space has in general a negative effect on emission reduction. It is therefore likely that emission reductions would have been even higher if floor spaces per animal would have been similar to the reference room.

The case control measurement strategy used here is one of the measurement strategies described in the protocol for ammonia emission valid at the moment of measurements (Ogink et al., 2013). The protocol for odour emission measurements (Ogink, 2011) does not include case control measurements as a possible measurement strategy. As case control measurements are the preferred strategy for ammonia emission measurements it was decided at the start of the measurements to use this case control strategy also for the odour emission measurements. The protocol for odour measurements also prescribes in duplo samples of odour concentration at each sampling point. The results of odour emission described in this report were based on single measurements per sampling point. Assuming that the average of the two samples per sampling point would have been at the same level as the odour concentration based on single measurements, duplo sampling would have increased the power of the t-test. However, emission reduction results and following conclusions (“Groene Vlag” floor combined with V-shaped manure belt does reduce odour emission significantly) would not have been changed.

Emission measurements reported here were done simultaneously with those reported by Mosquera et al. (2017) and share the same reference (control) room. Ammonia emission reduction of the ‘Groene Vlag’ slatted floor without valves and traditional manure storage reported by Mosquera et al. (2017) was 5.5% ± 2.6% (not significantly different from reference) and ammonia emission reduction of the ‘Groene Vlag’ slatted floor with valves was 22.3% ± 5.5% (significantly different from reference; p=0.03). Odour emission reductions were -11.1% ± 12.5% and 12.5% ± 14.7 for ‘Groene Vlag’ slatted floor without and with valves respectively (not significantly different from reference). Comparing these results with the emission reduction reported here the V-shape manure belt underneath the slatted floor contributed in a large extend to the emission reduction. Quick and continuous urine removal combined with a low urease activity on the belt (see Table 9) are possible explanations for these results.

# 4 Conclusions

This rapport shows the results of measurements performed at one animal facility for white veal calves using the control-case approach, to determine the ammonia and odour emission reduction of a housing system consisting on a “Groene Vlag” slatted floor combined with a V-shaped manure belt under the floor, compared to a reference (traditional housing with wooden slatted floor and manure storage underneath the floor).

Based on all available data, average emission reductions were reached as outlined in Table 10.

***Table 10*** *Overview of emission reduction.*

| | Average reduction +/- standard deviation between measurements |
|---|---|
| Ammonia (% reduction) | 52.9 +/- 19.3 |
| Odour (% reduction) | 46.6 +/- 19.4 |

Ammonia emissions were significantly lower (53% lower; P-value: 0.01) than the emission from the traditional floor measured simultaneously within the same farm (case-control approach).

Odour emissions were significantly lower (47% lower; P-value < 0.01) than the emission from the traditional floor measured simultaneously within the same farm (case-control approach).

# References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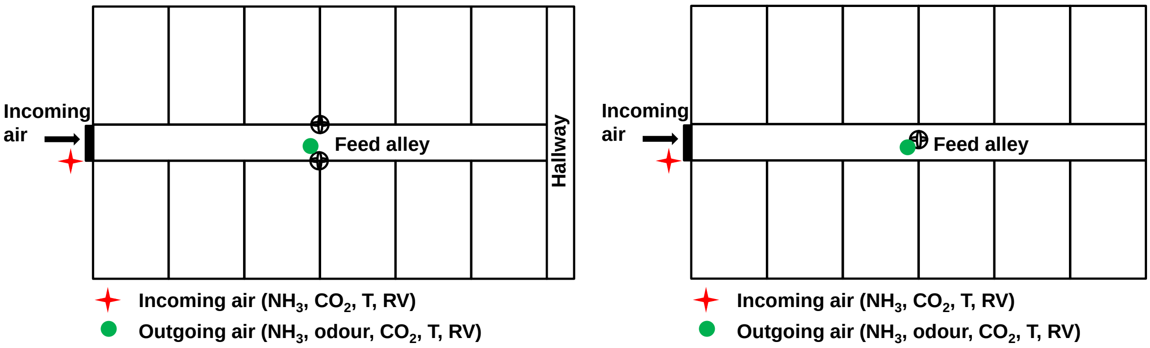
# Appendix 1 Additional farm information

*Positioning of the farm in the neighbourhood. Red: Facility with reference room. Blue: New facility with rooms with manure belt and soft floor.*




*Floor plan of the measured rooms, including sampling points. Left: room with traditional floor. Right: rooms with "Groene-Vlag" floor and V-shaped manure belt under the slatted floor.*

*Inlet opening (outside the rooms)*

*Inlet opening (inside the rooms)*

*Ventilation fans (room with traditional floor)*

*Ventilation fan (room with manure belt)*

*Feeding alley*

*V-shaped manure belt. Top left: collection area of urine and faeces. Top right: manure belt underneath slatted floor. Below: operating mechanism.*

# Appendix 2 Veterinary care

## Production cycle 1

| ***Floor*** | Traditional | V-shaped manure belt |
|---|---|---|
| ***Percentage of animals treated:*** | 53 % | 47 % |
| ***Cause (percentage of treatments)*** | Respiratory (80 %)<br>Intestinal (18 %)<br>Other (2 %) | Respiratory (77 %)<br>Intestinal (20 %)<br>Other (3 %) |

## Production cycle 2

| ***Floor*** | Traditional | V-shaped manure belt |
|---|---|---|
| ***Percentage of calves treated:*** | 38 % | 36 % |
| ***Cause (percentage of treatments)*** | Respiratory (90 %)<br>Intestinal (3 %)<br>Other (7 %) | Respiratory (88 %)<br>Intestinal (6 %)<br>Other (6 %) |

## Production cycle 3

| ***Floor*** | Traditional | V-shaped manure belt |
|---|---|---|
| ***Percentage of calves treated:*** | 54% | 51[4]% |
| ***Cause (percentage of treatments)*** | Respiratory 54%<br>Intestinal (1%)<br>Other (0%) | Respiratory[4] (49%)<br>Intestinal[4] (4%)<br>Other[4] (3%) |

[4] Individual room data not known. Calculated as average of all other rooms in the same production cycle

To explore the potential of nature to improve the quality of life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