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REDUCING ODOUR AND AMMONIA EMISSION BY COOLING INLET AIR IN A FARROWING FACILITY

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ABSTRACT The aim of this study was to investigate the reduction of odour and ammonia emissions for 90 sows in three units of a farrowing facility by tempering the inlet air during the year with a geothermal heating and cooling system (GHCS). By cooling the inlet air during summer, the maximum ventilation rate could be limited to 200 m^3/hour/sow, and an optimal temperature could still be maintained inside the farrowing facility. The results were compared to three control units which were traditionally ventilated with a maximum ventilation capacity of 430 m^3/hour/sow. Results showed that the temperature of the inlet air during the year could be kept between +4.3 ºC and +19.6 ºC by using the GHCS, while the outdoor temperature varied between -4 and 32 °C. During the summer, a tendency of 23 % lower odour emission on average was measured in the experimental units compared to the control units (P=0.06). Moreover, on warm days with a high airflow rate in the control units, the odour emission in the experimental units was 39 % lower when compared to the control units (P<0.01). In the summer, there was a tendency of 11 % lower ammonia emission from the experimental units compared to the control units (P=0.10). However, during the entire year there was no significant difference in ammonia emissions between the experimental and control units. For ventilation, 45 kWh less per farrowing pen was used in the experimental units compared to the control units, corresponding to savings of 4.57 € per farrowing pen. In contrast, the GHCS required 47 kWh per farrowing pen, corresponding to 4.70 € per farrowing pen. Operating costs amounted to 0.13 € per farrowing pen since the GHCS did not affect the consumption of floor heating.

Keywords: Geothermal heating and cooling, odour emission, ammonia emission, farrowing units

INTRODUCTION In recent years, the agricultural sector has been working intensely on developing technologies for reducing the environmental impact of livestock farms. In Denmark, a reduction of odour and ammonia is often required in connection with applying for environmental approval. The farmers therefore need accessible, reliable and economically viable environmental solutions to choose between.

In the Netherlands, it has been possible to install a geothermal heating and cooling system (GHCS) to temper the inlet air of a livestock facility. During the summer, a reduced ventilation rate is achievable when the inlet air is cooled by energy from the ground. A reduced airflow rate will result in a lower emission of odour and ammonia. Summer is the time of the year during which emissions of odour and ammonia are generally highest (Riis, 2006; Riis, 2008; Lyngbye & Sørensen, 2005). On the other hand, a higher ventilation rate is possible during winter since the inlet air is heated by the system. A higher airflow rate during winter will lower the concentration of dust, odour and ammonia inside the facility, which can lead to an improved working environment. A trial has been conducted in a finishing pig facility, where the inlet air was cooled with a cooling system when the ventilation requirement exceeded 50 %. The odour emission was reduced by 33 to 47 % compared to a control unit without cooling. The ammonia emission was reduced by 8 to 11 % by cooling the inlet air (Lyngbye et al., 2006).

The aim of this study was to investigate the reduction of odour and ammonia emissions from a farrowing facility where the inlet air was tempered with a GHCS.

MATERIALS AND METHODS The trial was conducted in a farrowing facility with six units. Each farrowing unit was 6.5 m wide and 26.3 m long and included 30 farrowing pens. The farrowing pens were 1.7 m wide and 2.7 m long and consisted of 1.5 m solid floor and 1.2 m slatted floor, floor heating and liquid feeding. All six units had diffuse air intake and an insulated roof surface. Three units were used as control. In these units, the air entered the attic through openings in the roof eaves. In the three experimental units, the openings in the roof eaves were sealed, and all the inlet air was tempered by a GHCS from the Dutch company INNO+. The inlet air passed through a heat exchanger placed in the gable of the farrowing facility (see Figure 1). In the farrowing facility, there was a central ventilation duct and a central outlet of all ventilation air. The ventilation air from each unit was collected in a duct under the floor of the inspection aisle. In the middle of each unit, an interconnecting duct connected the duct beneath the inspection aisle to the central duct in the attic. In the interconnecting duct of each unit, a ScanAirclean AQC damper with an integrated measuring fan controlled the airflow rate of each unit. The central ventilation duct had a cross-sectional area of 4.5 m^2 and was 30.8 m long. Three frequency-regulated ScanAirclean SGS-92-D4S 2.2 kW fans with a maximum capacity of 22,800 m^3/hour at 225 Pa were installed in the central duct. The fans blew the ventilation air through a central air cleaner from the Dutch company INNO+ before it went out through a central outlet. In all six units, the temperature curve in the ventilation controls was set at 21 ºC until day 11 with a P-band of 3 ºC. The temperature was subsequently reduced linearly to 18 ºC until day 21 and kept at this set point for the rest of the lactation period. In June 2008, a limit of 59 % in the maximum ventilation capacity was set in the ventilation controls in the experimental units, corresponding to a maximum ventilation capacity of 200 m^3/hour/sow. In the control units, a limit of 85 % was used until day 28, corresponding to 380 m^3/hour/sow. From day 28 until day 77, the limit was increased linearly to 96 %, corresponding to 430 m^3/hour/sow. The limit in the maximum ventilation capacity in all six units was maintained for the rest of the trial period.

The design of the geothermal heating and cooling system (GHCS)

The GHCS from INNO+ was marketed by ScanAirclean A/S in Denmark. The heat exchanger was 3.0 m wide, 2.0 m high and 0.57 m deep. It was of modular contruction and consisted of 1,248 vertically placed plastic tubes (POE0600296, ITB Boxmeer) with an inner diameter of 23 mm. The heat exchanger was connected through a tube system with a 3.0 kW frequency-regulated circulation pump and 8 km of PE tubes, through which water was recirculated. The PE tubes had an inner diameter of 19.6 mm and were placed 4.0 m deep in an adjacent field. Four tubes were placed in the ground parallel to one another, so the total digging distance was only 2 km. The GHCS consisted of a GEO control where the supply and return temperature of the water, the amount of water and the internal and external air temperature of the heat exchanger were measured.

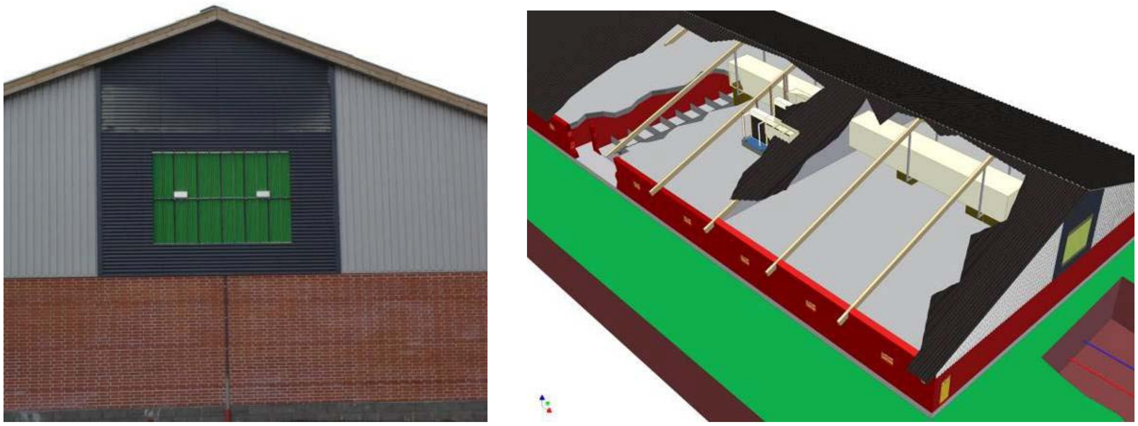

Figure 1. Design of the geothermal heating and cooling system in a farrowing facility with six units.

Analytical methods The trial period ran from January 2008 to December 2008. Ten days of odour and ammonia measurements were spread over the trial period during the summer from 30 June to 1 September 2008. The ammonia emission during the year and the energy consumption for the GHCS and the ventilation were recorded every 14 days in the trial period. Odour samples were taken by collecting a representative air sample in the interconnecting duct of each unit. The odour samples were collected in 30 L nalophan odour bags. The bags were placed in an airtight container and filled by creating a vacuum in the airtight container with a pump. On each day of measurement, two odour samples were taken from the air stream at each measurement point, and therefore 12 samples were collected each day. The first six odour samples were taken between 11.00 a.m. and 11.30 a.m., and the second six odour samples were taken between 12.30 p.m. and 1.00 p.m. The analyses of the odour concentration were performed at the odour laboratory at The Danish Meat Research Institute (Roskilde, Denmark). The first six odour samples were analysed by one panel, and the other six samples were analysed by a second panel. The collection of the odour samples and the analyses of odour concentration (OU_E/m^3) were performed in accordance with European olfactometric standard EN:13725 (CEN, 2003). After collection of the odour samples, and every 14 days in the trial period, the ammonia concentration was measured at the same measurement points using Kitagawa gas detector tubes 105SD (Komyo Rikagaku Kogyo K.K., Japan). The airflow rates and temperatures in each unit were logged every ten minutes (Stienen B.V.). The number of sows was recorded on each measurement day. All registration parameters in the GHCS control were logged every ten minutes (INNO+). The consumption of floor heating in each unit was recorded using energy meters. The ammonia concentrations and emissions and the logarithmically transformed odour concentrations and emissions from each unit were processed using an analysis of variance in the MIXED Procedure in SAS (SAS Inst. Inc., Cary, NC). Measurements performed during the first week of the lactation period were not included in the analysis, because the number of sows per unit differed and not all sows had farrowed.

RESULTS AND DISCUSSION Measurements of odour and ammonia emissions from the units in the summer were performed at an average outdoor temperature of 19.2 ºC (range: 17.1 – 26.8 ºC) and a mean relative humidity of 73 % (range: 48 – 92 %). On measurement days in the summer, the average number of sows per unit was 29 (range: 18 – 30 sows).

Airflow rate and temperatures Figure 2 shows the airflow rates during the summer in both the experimental and control units. The airflow rates in the experimental units during the summer were approximately constant at 6,000 m^3/hour, corresponding to 200 m^3/hour/sow, while the airflow rates in the control units varied due to variations in the outdoor temperature. Figure 3 shows the indoor temperature in both the experimental and control units compared with the outdoor temperature during the period of odour and ammonia measurements in the summer. The indoor temperature varied less in the experimental units than in the control units because the GHCS tempered the inlet air. On warm days with outdoor temperatures above 27 ºC, the indoor temperature in the control units followed the outdoor temperature. However, the temperature in the experimental units was up to 4 ºC lower than the outdoor temperature. In the first week of the lactation period, the airflow rate was at the same level in both the experimental and control units. However, the average airflow rate in the experimental units from week 2 and throughout the lactation period was 6,000 m^3/hour, whereas in the control units the airflow rate generally increased during the lactation period. Figure A3 in Appendix A shows the airflow rate in the experimental and control units in relation to the number of weeks the sows have been in the units.

On days with outdoor temperatures below 20 ºC, the temperatures in both the experimental and control units were generally 3 ºC above the set point, which corresponded precisely to the set point of the P-band in the ventilation controls. This was due to the regulation principle of the ventilation controls from the Dutch company Stienen B.V. Ventilation controls from the Netherlands are generally P-band-regulated compared to the Danish ventilation controls, which generally are PID-regulated. P-band-regulated controls add the P-band to the set point temperature. This means that, if 18 °C is the set point temperature with a 3 °C P-band, then the temperature will be 18 °C at minimum ventilation and 21 °C at maximum ventilation. P-band-regulated controls allow the temperature to be kept at the top of the P-band compared with a PID-regulated control that constantly tries to maintain the set point temperature. This means that in the Netherlands, ventilation controls allow a greater temperature variation in the unit, while ventilation performance is more constant.

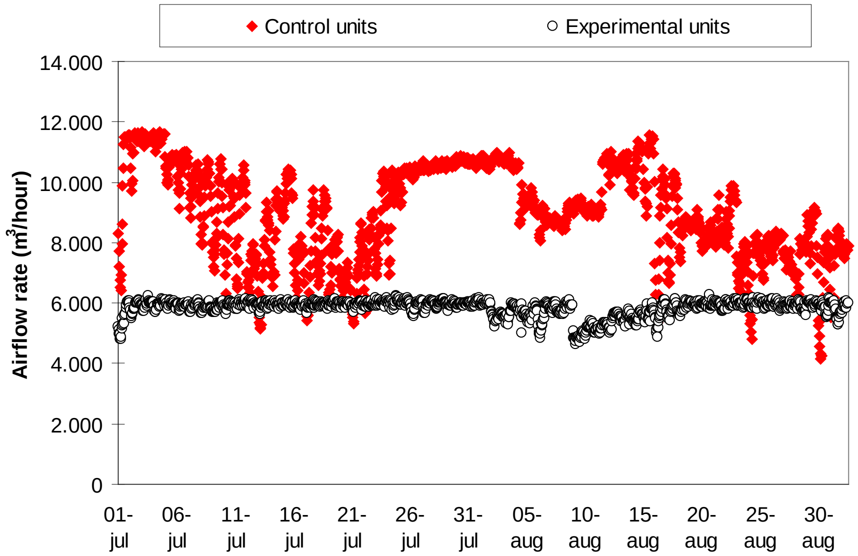

Figure 2. The airflow rate in the experimental and control units from 30 June 2008 to 1 September 2008. Data in the period where units were cleaned are not included.

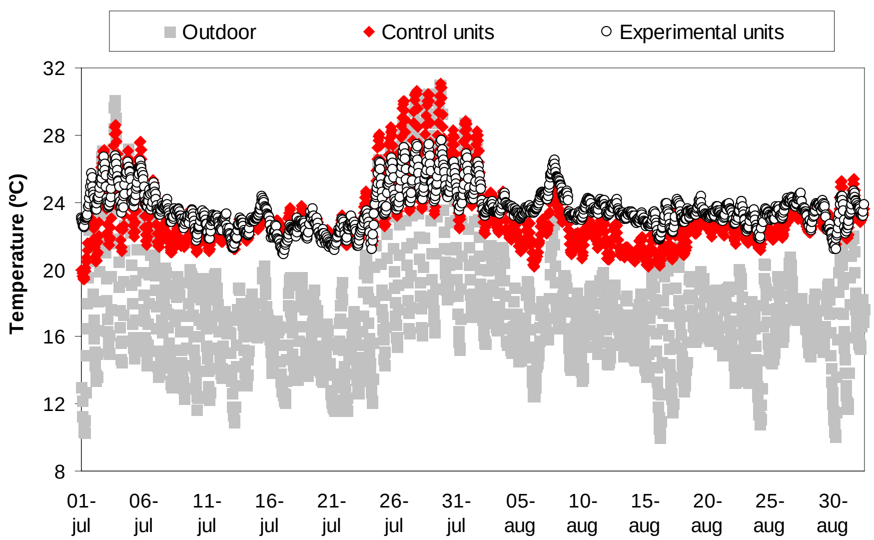

Figure 3. The indoor temperature in the experimental and control units from 30 June 2008 to 1 September 2008 compared with the outdoor temperature. Data in the period where units were cleaned are not included.

Odour emission Table 1 shows the odour emissions from the experimental and control units in relation to the airflow rate during the summer. The airflow rate in the experimental units remained generally constant throughout the measurement period in the summer at 6,000 m^3/hour, because the GHCS tempered the inlet air. This resulted in an average odour emission from the experimental units in the summer of 160 OU_E/s/sow (95 % CI: 130 – 190). In contrast, the odour emission from the control units depended on the airflow rate, which was affected by the outdoor temperature (Figures 2 and 3). When the airflow rate in the control units was low due to low outdoor temperatures, there was no difference between the odour emissions from the experimental and control units. At average airflow rates during measurements of odour emissions during the summer, there was a tendency of 23 % lower odour emission from the experimental units compared to the control units (P=0.06). On warm days with a high airflow rate in the control units, the odour emission from the experimental units was significantly lower (39 %) compared to the control units. Using the GHCS, it was possible to reduce the odour emission from the experimental units in the summer compared to the control units. No odour measurements were taken during the winter. In the winter, the airflow rate is generally low due to low outdoor temperatures, and therefore no difference between the odour emissions from the experimental and control units is expected.

Table 1. The odour emissions from the experimental and control units in relation to the airflow rate during the summer.

	Odour emission from experimental units (OU_E/s/sow)	Odour emission from control units (OU_E/s/sow)	Difference in odour emission between experimental units and control units (%)
Low airflow rate 25 % fractile (200 vs. 320 m^3/hour/sow)	160 (130 – 190	160 (130 – 200)	~ 0 (NS)
Average airflow rate 50 % fractile (200 vs. 350 m^3/hour/sow)	160 (130 – 190)	210 (170 – 260)	23 (P=0.06)
High airflow rate 75 % fractile (200 vs. 380 m^3/hour/sow)	160 (130 – 190)	270 (200 – 350)	39 (P<0.01)

Ammonia emission Figure 4 shows the ammonia emissions from the experimental and control units in relation to the number of weeks sows have been in the farrowing units in the summer. The average ammonia emission from the control units in the summer was 0.46 g NH_3-N/hour/sow (95 % CI: 0.42 – 0.50), while the experimental units had an average ammonia emission of 0.40 g NH_3-N/hour/sow (95 % CI: 0.36 – 0.44). During measurement days in the summer, there was a tendency of 11 % lower ammonia emissions from the experimental units compared to the control units (P=0.10). Because of the lower airflow rate in the experimental units, a significantly higher ammonia concentration was measured compared to the control units. The average ammonia concentration measured in the experimental units during the summer was 3.4 ppm (95 % CI: 3.2 – 3.6) compared to the control units, where it was 2.3 ppm (95 % CI: 2.1 – 2.6) (P<0.001). Measurements of odour and ammonia emissions in the summer were in accordance with a previous trial in a finishing pig unit, where the inlet air was cooled with a cooling system (Lyngbye et al., 2006).

Throughout the year, the average ammonia emission from the control units was 0.36 g NH_3-N/hour/sow (95 % CI: 0.33 – 0.39) and was not significantly different from the ammonia emission from the experimental units, which was 0.34 g NH_3-N/hour/sow (95 % CI: 0.30 – 0.37). The average ammonia concentration measured in the experimental units was 3.7 ppm (95 % CI: 3.3 – 4.2) and had a tendency to be higher than in the control units, where it was 3.2 ppm (95 % CI: 2.7 – 3.6) (P=0.07).

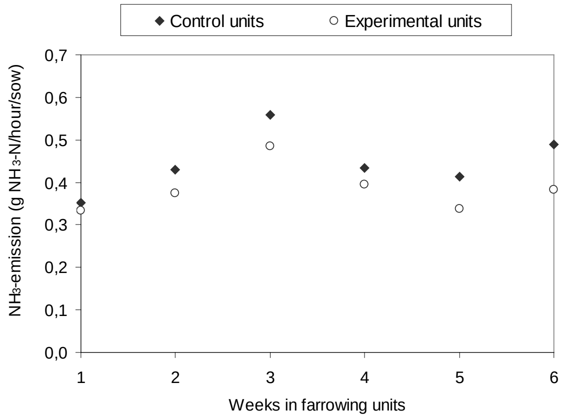

Figure 4. The ammonia emissions from the experimental and control units in relation to the number of weeks the sows have been in the farrowing units in the summer.

Energy conversion in the Geothermal Heating and Cooling System Figure 5 shows the temperature in the air before (outer side) and after (inner side) the heat exchanger during the trial period. During the year, the GHCS was able to maintain the temperature of the inlet air between 4.3 and 19.6 °C, while the outdoor temperature varied between -4 and 32 °C. During the year, the amount of energy used to cool the air in the trial period totalled 27,200 kWh, whereas the amount of energy to heat the air totalled 14,800 kWh. The electricity consumption for the GHCS during the same period totalled 4,246 kWh, corresponding to 47 kWh per farrowing pen. Figure A4 in Appendix A shows the GHCS momentary cooling and heating effect in relation to the outdoor temperature. Figure 6 shows the GHCS supply and return temperature in the water during the year in the trial period. The supply temperature in the water ranged between 6 and 15 °C throughout the year. During the spring and summer, the temperature in the water increased due to the high air temperatures. In contrast, the temperature in the water decreased during the autumn and winter due to the low air temperatures. Although the temperature of the water in the ground varied during the year, the water temperature in the ground was at the same level one year later.

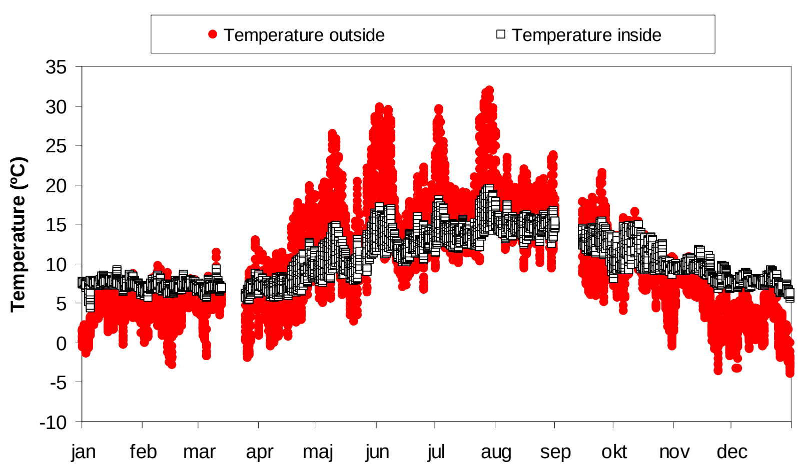

Figure 5. The temperature in the air before (outer side) and after (inner side) the heat exchanger during the trial period.

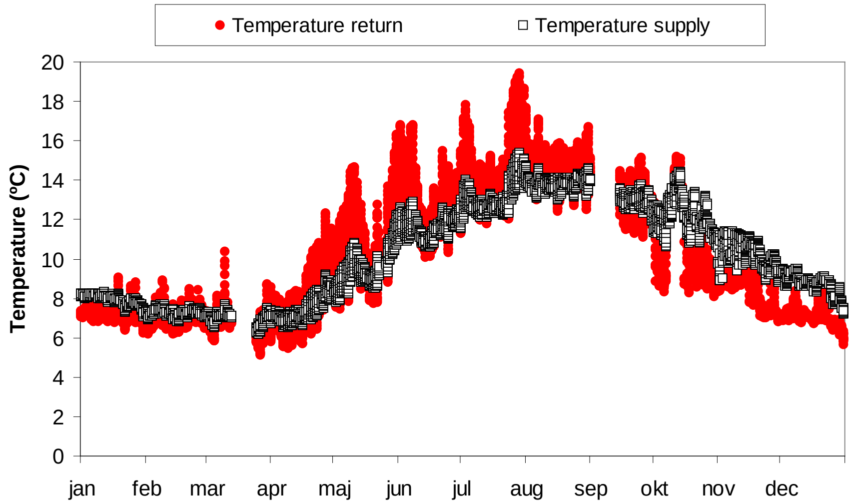

Figure 6. The supply and return temperature in the water from the GHCS during the trial period.

In the experimental units, 9.5 % fewer cubic meters of air were ventilated during the year compared to the control units. Using this percentage distribution of airflow rate between the experimental and control units, an approximate breakdown of electricity consumption for the ventilation can be calculated. In the experimental units, the consumption of electricity for ventilation was equal to 204 kWh per farrowing pen and 249 kWh per farrowing pen in the control units. However, this method does not take into account the fact that the last cubic meters of air have a higher energy cost than the first ones due to an increasing pressure drop at higher airflow rates. Therefore, the actual electricity consumption was presumably lower in the experimental units and higher in the control units. In the experimental units, a total of 505 kWh per farrowing pen was used for floor heating and in the control units 481 kWh per farrowing pen. The use of energy for floor heating was at the same level, and the GHCS did not affect the consumption of floor heating. There was no room heating in the six units, and it is unknown whether the GHCS could affect the use of room heating.

Operating costs For ventilation, 45 kWh less per farrowing pen was used in the experimental units than in the control units, corresponding to savings of 4.57 € per farrowing pen. In contrast, the GHCS required an electricity consumption of 47 kWh per farrowing pen, corresponding to 4.70 € per farrowing pen and was higher than the savings for ventilation. If the GHCS had been adjusted to recirculate the water in the system only when the outdoor temperature was below 9 ºC and above 15 ºC throughout the trial period and not just in the last 3 months of the period, the electricity used for the circulation pump would have been lower as would the total operating costs.

Operational problems At the beginning of the trial, leaks were discovered in the attic of the three experimental units, resulting in a false air intake. A pressure test of the attic revealed that up to 1/3 of the total ventilation capacity entered the attic through leaks at maximum ventilation. Leaks were found at the joints between the ceiling and the wall and along the gable at the joints between the attic and the wall. Leaks were also found at the joints between the steel rafters and the ceiling insulation. All leaks were sealed, and a new pressure test of the attic subsequently revealed that the false air intake was limited to a maximum of 10 % at maximum ventilation. The pressure drop across the heat exchanger was 18 Pa at maximum ventilation, which stressed the importance of an airtight attic so the inlet air only passed through the heat exchanger.

On 1 January 2009, there was a power failure in part of the farm's power supply. This power failure switched off the GHCS. The power supply where the power failure occurred was not connected to the farm's alarm system, which is why it took several days before the power failure was noticed. At the same time, the outdoor temperature was below 0 ºC, and this caused the plastic tubes in the heat exchanger to burst. A battery-operated safety valve was installed next to the heat exchanger. This was controlled by a GEO Frost Protection control, which should have emptied the water from the heat exchanger in case of a power failure at low outdoor temperatures. However, the battery in the GEO Frost Protection control was flat when the power failure occurred. This episode stresses how important it is to have an alarm system that detects all power failures. Similarly, it is important that safety devices are checked regularly.

CONCLUSION During the summer, by cooling the inlet air with the GHCS a tendency of 23 % lower odour emission on average was measured in the experimental units compared to the control units. On warm days with a high airflow rate in the control units, the odour emission from the experimental units was significantly lower (39 %) compared to the control units. In the summer, there was a tendency of 11 % lower ammonia emission from the experimental units compared to the control units. However, during the year there was no significant difference between the ammonia emissions from the experimental and control units.

During the year, the GHCS was capable of maintaining the temperature of the inlet air between 4.3 and 19.6 °C, while the outdoor temperature varied between -4 and 32 °C. For ventilation, 45 kWh less per farrowing pen was used in the experimental units compared to the control units, corresponding to savings of 4.57 € per farrowing pen. In contrast, the GHCS required an electricity consumption of 47 kWh per farrowing pen, corresponding to 4.70 € per farrowing pen. Operating costs amounted to 0.13 € per farrowing pen since the GHCS did not affect the consumption of floor heating.

REFERENCES

CEN. 2003. Air quality determination of odour concentration by dynamic olfactometry (EN13725). Brussels, Belgium: European Committee for Standardization.

Lyngbye, M., Riis, A. L. and A. Feilberg. 2006. Luftskiftets betydning for lugt- og ammoniakemission fra slagtesvinestalde. Meddelelse nr. 756. Dansk Svineproduktion. (In Danish).

Lyngbye, M. and G. Sørensen. 2005. Metode til test af fodringens indflydelse på ammoniak- og lugtemissionen. Meddelelse nr. 691. Landsudvalget for Svin. (In Danish).

Riis, A. L. 2006. New Standards for odour emissions from pig facilities in Denmark. In Proceedings Workshop on Agricultural Air Quality: State of the Science, Washington D.C. pp 1039-1043.

Riis, A. L. 2008. Lugtemission fra so- og smågrisestalde om vinteren. Erfaring nr. 0802. Dansk Svineproduktion. (In Danish).

APPENDIX A

Figure A1. The frequency-regulated circulation pump and GEO control (left) and the heat exchanger (right).

Figure A2. 8 km of PE tubes were placed 4.0 m deep in an adjacent field using a chain excavator.

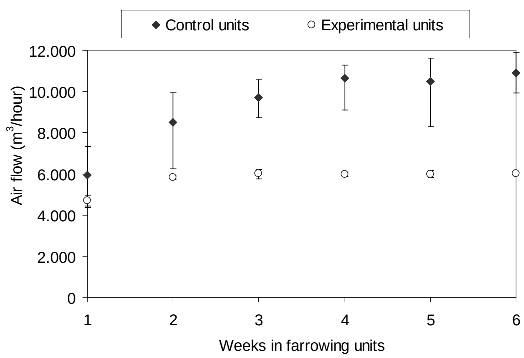

Figure A3. Average airflow rate in the experimental and control units in relation to the number of weeks the sows have been in the units from 30 June 2008 to 1 September 2008.

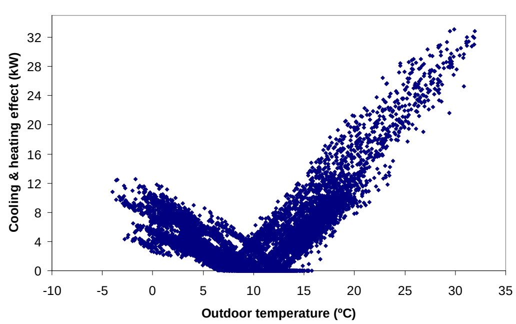

Figure A4. The momentary cooling and heating effect in relation to the outdoor temperature.