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# Potential energy savings through $CO_2$ controlled ventilation in farrowing houses

In farrowing houses with very good thermal insulation the ventilation causes up to 90% of the total heat losses. Using real-time $CO_2$ measurements to control the fan speed, the ventilation rate can be automatically and continuously adapted to the real needs of the animals. However, according to tests conducted at ART, this only works if $CO_2$ is measured in short time intervals and if the fan is adjusted accordingly. The set point of the $CO_2$ concentration has to be aligned with the $NH_3$ concentration in the building. The potential energy savings through $CO_2$ controlled ventilation are substantial.

**Keywords**
Energy, ventilation, $CO_2$ measurement, fan regulation

**Abstract**
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The new Standard 380/1 [1] of the Swiss Association of Engineers and Architects (SIA) specifies very good heat insulation for farrowing houses. If these specifications are observed, the majority of the heat is lost via the ventilation which means that savings here represent some of the easiest ways of saving heating energy. In practice, the ventilation rate rarely tallies with the actual fresh air requirement of the animals. The main reason lies in the major fluctuations in the fresh air requirement, as this is not only dependent on the complement of livestock and animal output, but also on animal activity, something which changes considerably over the course of the day. Ventilation tailored to suit the need therefore calls for consistent adjustments to the ventilation.

## Experimental set-up

In the experimental farrowing house at the ART Research Institute, the effect of $CO_2$ controlled ventilation on $CO_2$ concentration over the course of a day and the energy requirement for room heating was studied in one of the two existing farrowing houses. The farrowing house incorporates eight farrowing bays (FAT2 type) with insulated and temperature-controlled farrowing nests. It was ventilated by balanced pressure (two ETA-vent FC040-41Q.4C.3 fans). The fresh air was obtained from a subsoil heat exchanger. The fan control system was based on temperature and $CO_2$ concentration (Veng System, **figure 1**). In addition to the inside temperature and the $CO_2$ concentration, the temperature of the outside and the incoming air, the fan speed in the incoming air duct, the relative humidity of the incoming air and inside air, the concentration of $NH_3$ of the inside air as well as the energy required for the fans and to heat the farrowing nests as well as the room were recorded. The $CO_2$ and $NH_3$ measurement was carried out using a multi-sensor with pre-heating (VE 18). A filter was used to take samples of the air from both chambers alternately as well as from outside. Flushing with external air after each sampling exercise was carried out so as to prevent the $NH_3$ sensor becoming saturated. The accuracy of the $CO_2$ and $NH_3$ measurements was checked at regular time intervals using Dräger tubes. The ventilation rate was based on the air speed in the air intake channel. All the elements were connected up to the climate computer (VE 108) and the PC.

## Results of the experiments

From 01.10.2009 to 10.02.2010 the data was recorded at intervals of 30 minutes. Because of the incomplete nature of recorded data due to the fluctuations of various parameters within this time period, the interval was shortened to five minutes over the remainder of the process. During the experiment, the set point of the inside temperature was 18°C, the initial temperature of the heating 17 °C and the $CO_2$ concentration 1 600 ppm.

## $CO_2$ production over the course of the day

Based on the ventilation rate ($V_L$), the concentration of $CO_2$ in the stall ($[CO_2]_i$), the outside air ($[CO_2]_a$) and the air density ($\rho$), the $CO_2$ produced by the animals ($V_{CO_2}$) can be calculated under constant conditions, in standard cubic metres per hour [2] (**Equation 1**).

$$V_{CO_2} = V_L \cdot ([CO_2]_i - [CO_2]_a) \cdot 10^{-6} \cdot \frac{1.29}{\rho} \qquad \text{(Eq. 1)}$$

Since, however, constant conditions do not predominate in the animal house, but instead the ventilation is constantly fluctuating due to the $CO_2$ control system, the building volume (*vol*) needs to be taken into account in the calculations. The animals' production of $CO_2$ in the time period $\Delta t$ is calculated in standard $m^3/h$ on the basis of the difference in $CO_2$ concentration between the momentary period ($[CO_2]_i$) and the previous period ($[CO_2]_{i-1}$) (**Equation 2**).

$$V_{CO_2} = V_L \cdot ([CO_2]_i - [CO_2]_a) \cdot 10^{-6} \cdot \frac{1.29}{\rho} + \frac{[CO_2]_i - [CO_2]_{i-1}}{\Delta t} \cdot vol \cdot 10^{-6} \cdot \frac{1.29}{\rho} \qquad \text{(Eq. 2)}$$

The animals' $CO_2$ production, calculated on the basis of the $CO_2$ concentration and ventilation rate in accordance with **Equation 2**, shows very marked fluctuations over the course of the day (**figure 1**). The differences between the maximum and minimum values are more than 300 %. The progression of $CO_2$ production is day-specific. The relationship between the maximum and minimum values is, however, roughly equal every day. The average amount of $CO_2$ released per hour is, in the period 07.04.2010 to 08.04.2010, around 30 % less during the night (20.00–06.00 hrs) than in the daytime (06.00–20.00 hrs). In this period there were eight sows with 78 piglets in the animal house.

## $CO_2$ concentration and $NH_3$ concentration

According to the climatization standard for animal houses [2], the limit value for $CO_2$ concentration is 3 000 ppm. Because experience has shown that, at this concentration, it is impossible to comply with the limit value for $NH_3$ concentration (20 ppm) in the majority of piggeries, the standard recommends a maximum value of only 2 000 ppm for the daytime mean value in terms of $CO_2$ concentration.

In the course of a short preliminary experiment with a $CO_2$ concentration of 2 000 ppm, the $NH_3$ concentration shortly before weaning the piglets from time to time exceeded 15 ppm. Because of the relatively high concentration of $NH_3$, the set point value as regards $CO_2$ concentration during the experiment was established at 1 600 ppm. In this way it was also possible to ensure that the fan control was invariably based on the concentration of $CO_2$ rather than the inside temperature.

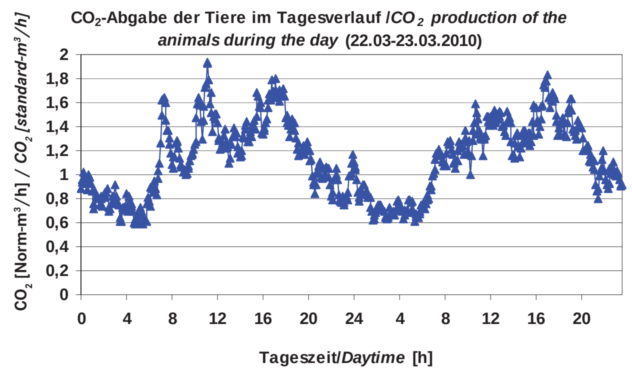
The fan control based on $CO_2$-concentration has as consequence the reduction in the ventilation rate during the animals' rest phases. Concerns that this could trigger a marked rise in the ammonia concentration in the inside air have proved to be unfounded (**figure 2**).

## Measuring frequency and uniformity $CO_2$ concentration

To ensure a constant $CO_2$ concentration it is necessary that the fan should be able to react quickly and adequately to changes in $CO_2$ output. In practice, fluctuations in the $CO_2$ concentration cannot be avoided in their entirety because the animals change their $CO_2$ production markedly within very short periods of time. Any adjustment of the fan speed is always subject to a time lag because it is based on the $CO_2$ concentration in the previous time phase. Any increase in the animals' $CO_2$ output will, in addition, affect the rise in the concentration of $CO_2$ only slowly due to the buffer effect of the building volume. For these reasons it frequently happens that the ventilation rate only changes once the level of $CO_2$ production is already starting to fall or vice versa.

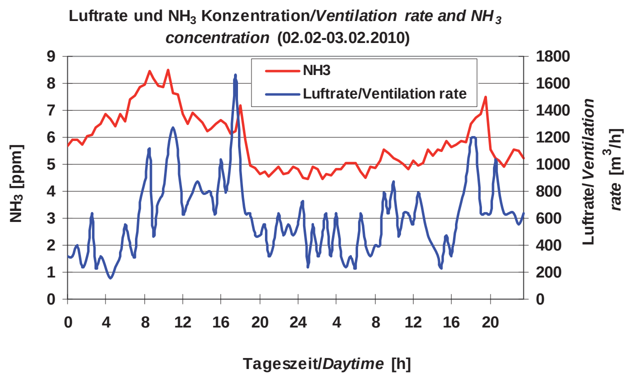
From this it may be deduced that the fluctuations in the concentration of $CO_2$ can only be combated effectively if the $CO_2$

Fig. 1




*The $CO_2$ production of the animals is changing strongly during the day*

Fig. 2




*The $NH_3$ concentration has the tendency to decrease during the resting phase despite the strongly reduced ventilation rate* measurements and fan adjustments are carried out at very short time intervals. If the $CO_2$ measuring device is used for measuring the concentration in different compartments, extended interval times will be noted. This was the case during the initial experimental period (01.10. to 10.01.2010). The interval between measurements in this period was 16 minutes due to the long flushing times for the $NH_3$ sensor. The low measuring frequency is reflected in the relatively large deviations of the $CO_2$ concentration from the set point value (1600 ppm, **figure 3**).

On average these amount to 126 ppm. The difference between the maximum and minimum value is 730 ppm. Once a separate $CO_2$ measuring device has been installed for the test chamber, it proved possible to reduce the interval between measurements to 45 seconds. The adjustment of the $CO_2$ concentration by the set point value of 1 600 ppm proved considerably more successful (**figure 4**). The mean deviation from the set point value was still only 53 ppm and the difference between maximum and minimum value was 500 ppm.

## Fan Regulation and Uniformity of $CO_2$ concentrations

For any fluctuations to remain only very minor, not only a short measuring interval is required but the fan speed and, in consequence, the ventilation rate will need to be adjusted to the variation in the $CO_2$ concentration registered. Model calculations show the shorter the interval between measurements is, the greater the speed change after each measurement can be. The change in the ventilation rate ($V_{L,i}$ – $V_{L,i-1}$) takes place in proportion to the deviation of the $CO_2$ concentration from the set point value ($[CO_2]_i$) - ($[CO_2]_{set\ point}$) (**Equation 3**). The optimum proportionality factor (also termed „Integration Constant“) ($a$) is dependent on the room volume in addition to the measuring time.

$$V_{L,i} = V_{L,i-1} \cdot (1 + a \cdot \frac{[CO_2]_i - [CO_2]_{setpoint}}{[CO_2]_{setpoint}}) \qquad \text{(Gl. 3)}$$

The integration constant ($a$) must be as large as possible but still must not exceed a certain value: this is so as to avoid any over-reaction of the fan. If the fan response is too strong, then the control may start to oscillate. The ideal value for each animal house can only be determined by experimenting.

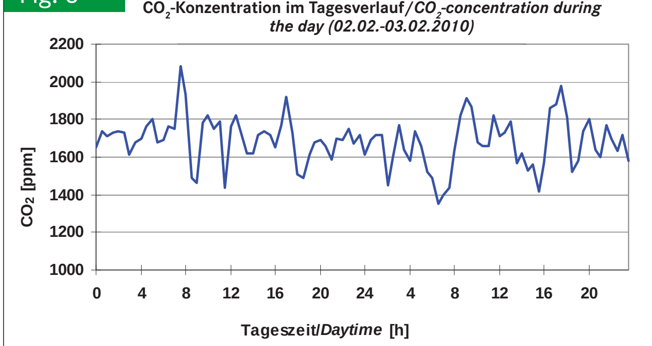
In the ART farrowing house the calculated variations in the concentration of $CO_2$ based on the $CO_2$ output on 22.03.2010 were minimal when the amount of integration constant ($a$) was 25. The difference between the maximum and the minimum value will then be only 116 ppm (**figure 5**). Due to the danger of over-reaction of the fan, under practical conditions one may find oneself having to select a smaller value for „a“ and having to accept greater deviations from the $[CO_2]$ setpoint.

## Energy saving potential at $CO_2$ controlled ventilation

The animals are at their least activity at night. If the ventilation rate is not reduced dramatically, the need for heat at this time will increase significantly once the outside temperature falls due to the scarcely perceptible heat output of the animals. This is the case with traditional ventilation systems because their minimum fan speed does not vary over the course of the day; instead this speed is adapted, at most from one day to the next, either manually or automatically, to the changes in livestock numbers.

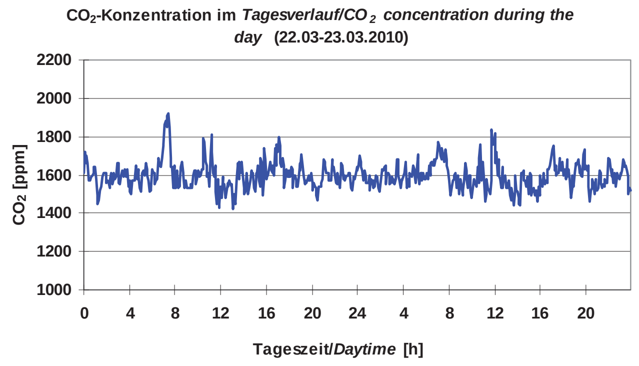
So as to ensure that the limit value for $CO_2$ concentrations and, possibly, the concentration of $NH_3$ too, are not exceeded, the minimum ventilation rate should be aligned with the maximum $CO_2$ output during the day. The effect of this will be that there will be too much ventilation at night. However, once the minimum ventilation rate ceases to be a specified fixed value, but instead depends on the concentration of $CO_2$, the need for heating will in theory, be reduced. How much energy is saved under practical conditions through $CO_2$ control of the ventilation rate by comparison to a conventional (temperature-controlled) ventilation system is to a very great extent specific to individual operations. The saving in energy depends on how high the constant minimum ventilation rate setting is and, consequently, the demands in terms of air quality in the case of conventional ventilation systems. In addition, the regularity of adjustment of the minimum ventilation

Fig. 3



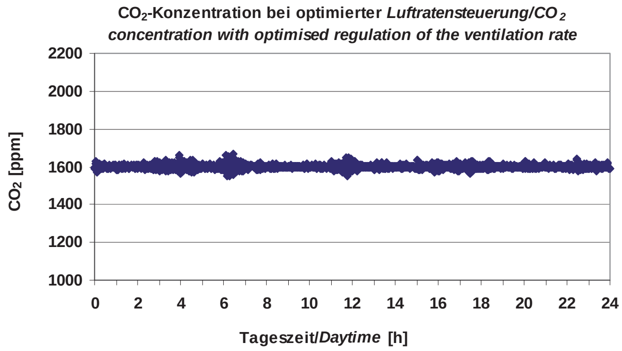

*If the ventilation rate is regulated only every 16 minutes, the $CO_2$ concentration is fluctuating strongly*

Fig. 4



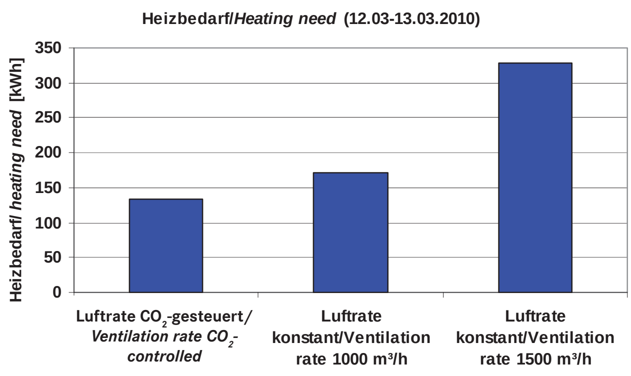

*More frequently adjusting the ventilation rate (interval 45 seconds) leads to a better approximation of the $CO_2$ concentration to the set point (1 600 ppm)*

Fig. 5




*In case of optimal regulation of the ventilation rate the difference between the maximum and the minimum $CO_2$ concentration would only be 116 ppm (22.03.2010)*

Fig. 6




*Heating demand with a variable minimal ventilation rate ($CO_2$ controlled) compared to a constant minimal ventilation rate of 1 000 or 1 500 $m^3/h$*

rate to take account of the changing stock of animals plays a significant role in conventional ventilation systems.

On 12/13.03.2010 the heating requirement in the test chamber with $CO_2$ controlled ventilation was 134 kWh. If the ventilation rate had not been $CO_2$-controlled, but had it instead been at a constant setting of 1 000 $m^3/h$ both day and night, the heat requirement would in theory have been 171 kWh (**figure 6**). At a ventilation rate of 1 500 $m^3/h$ we would need to be looking at 329 kWh. At a constant ventilation rate of 1 000 $m^3/h$ the $CO_2$ set point value was exceeded over 42 % of the study period. The maximum $CO_2$ concentration is 169 % of the set point value. At 1 500 $m^3/h$ the overrun in terms of time was limited to 6 %. The maximum $CO_2$ concentration was 121 % of the set point value. In the period from October 2009 to March 2010 the amount of energy saved by heating the space, in the test chamber using $CO_2$ controlled ventilation by comparison to the chamber with traditional temperature-controlled ventilation was 40 % (2 160 kWh).

## Conclusions

In farrowing houses featuring very good heat insulation, up to 90 % of total heat losses are caused by the ventilation system. Consequently, the first step when it comes to reducing the need for heat lies in avoiding superfluous ventilation. With $CO_2$ control of the fans it is possible, in theory to constantly adjust the ventilation rate to the needs of the animals at any specific point in time. How precisely the ventilation rate can be aligned with the set point value of the $CO_2$ concentration by means of a control system of this type and what sort of energy saving is possible by so doing, has been studied in a farrowing stall at the ART.

Due to the rapidly changing $CO_2$ production of the animals and the delayed reaction of the fan, as well as the buffer effect of the volume of air in the animal house, fluctuations in $CO_2$ concentration can only be effectively combated if the $CO_2$ measurements and fan adjustments are carried out at very short time intervals. In addition, the fan control must operate satisfactorily. The integration factor which, together with the deviation in the $CO_2$ concentration from the set point value, determines the fan adjustment, should be as great as possible but must still not be permitted to lead to any over-reaction on the part of the fan.

The possible savings in energy with $CO_2$ control of the ventilation rate will be all the greater by comparison to conventional ventilation systems the higher the demand for a ventilation system tailored to the specific need is. During the period of the experiment (October 2009 to March 2010) it proved possible to make energy savings of 40 % in space heating. The concern that, as a result of the significant reduction in the ventilation rate during the animals' rest phases, the ammonia concentration in the inside air could demonstrate a marked increase, has proved to be unfounded.

## Literature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