

## USING OUTSIDE TEMPERATURE TO PREDICT ODOUR EMISSION FROM MECHANICAL VENTILATED LIVESTOCK BUILDINGS

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### ABSTRACT

Odour emission of livestock buildings is of interest for the residents in the vicinity of animal husbandry due to its annoying potential. To apply a Gauss dispersion model to odour emissions, the emission parameters have to be known. The emission parameters of a mechanically ventilated livestock building, the odour flow and the volume flow of the outlet air, are calculated by combining a steady-state balance model to assess the outlet air temperature and the volume flow with a simple model for the odour release inside the livestock building. The calculations were done for a two-year period based on half hour values of the emission and meteorological parameters. The results show a distinct diurnal and annual variation of the odour concentration due to the variability of the volume flow. The mean odour concentration during daytime in the summer months lies in a very narrow range close to the overall minimum. Odour concentration derived from odour emission and the maximum volume flow of the animal house is useful for model calculations. During a clear-sky summer period, the model predicts a night-time odour concentration of about 4.6 times the daytime concentration due to the reduced volume flow at night. To improve the calculation of odour concentrations by dispersion models, the annual and diurnal variation of the odour release has to be taken into account. The model suggests that long term measurements of the odour emissions of animal houses are necessary for regulatory and legal purpose.

### INTRODUCTION

Odour emissions can effect the acceptability of livestock farming in the vicinity of residential areas (Schiffmann, 1998). The concentration of odoriphores can be handled like other volatile pollutants and can be measured by an olfactometer in odour units per volume (OU/m<sup>3</sup>). One odour unit is defined as the concentration of odoriphores which results in an odour sensation by at least half of the members of a panel (CIGR, 1994).

The dispersion of airborne emissions can be described by dispersion models. To apply a dispersion model to odour emissions, the odour concentration and the volume flow of the outlet air have to be known. In many cases, these two parameters are assumed to be constant over time, although it is well known that the ventilation system of animal houses is designed to vary the air exchange in a range of 1:5 to 1:10 between the minimum and the maximum volume flow.

The thermal behaviour of the animal house can be represented by a steady-state balance model (CIGR, 1984) in which the inside air temperature is calculated as a function of the outside temperature (Schaubberger 1988; Schaubberger, 1989). Combining such a model with the odour release of the animal house, the diurnal and annual variation of the odour emission can be calculated. The odour emission is quantified by the odour production as the product of the volume flow of the ventilation system of the livestock building and the odour concentration of the outlet air.

All these results are based on model calculations. The discussion tries to emphasise the general applicability of the approach presented.

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## MATERIAL AND METHOD

Meteorological data (temperature, relative humidity, wind direction and wind speed) are needed to calculate the climate inside the livestock building and the odour emission. The data were collected at Wels, a site representative of the Austrian flatlands north of the Alps. The sample interval was 30 minutes for a two-year period between January 30, 1992 and January 31, 1994. In Austria, the stability of the atmosphere is usually described by a discrete scheme developed by Reuter (1970) used for the Austrian regulatory dispersion model (ÖNorm 1992/1996; Kolb, 1981). Within the Reuter scheme, classes 2 to 7 can occur in Austria. Stability classes 2 and 3 occur during daytime in a well-mixed boundary layer. Class 4 is a neutral stability, classes 5 to 7 are stable conditions which occur at night.

The air temperature inside a mechanically ventilated livestock building is calculated by a balance equation of the sensible heat (CIGR, 1994; Schaubberger, 1988; Albright 1990). On the basis of equations 1, the indoor air temperature (equal to the temperature of the outlet air) and the volume flow are calculated as a function of the outdoor temperature. The balance equation (Eqn 1) consists of three terms describing the sensible heat flux of the livestock building as

$$S_A + S_B + S_V = 0 \quad (1)$$

with the sensible heat release of one animal  $S_A$ , the loss of sensible heat caused by the transmission through the building  $S_B$ , and the sensible heat flow caused by the ventilation system  $S_V$ . The model equations are summarised in Schaubberger et al. (1999 and 2000).

The ventilation systems in livestock buildings are mainly designed as temperature-controlled variable volume flow systems. The control unit uses the indoor air temperature as the control value. The supply voltage of the fans and therefore the resulting volume flow is the output of the control unit. An ideal characteristic of the control unit of the ventilation system is calculated according to Eq. 2. Two parameters, the set point temperature  $T_C$  and the proportional range  $\Delta T_C$  describe the course of the volume flow depending on the indoor air temperature  $T_i$  as a control value. For an indoor air temperature less than the set point temperature, the minimum volume flow is supplied. In the proportional range above the set point temperature, the volume flow is increased until the maximum ventilation rate is reached. Above this range, the livestock building is supplied by the maximum ventilation flow. Equation (2) gives the volume flow  $V$  as a function of the indoor air temperature  $T_i$ .

$$V(T_i) = \begin{cases} V_{\min} & \text{for } T_i \leq T_c \\ V_{\min} + (T_i - T_c) \frac{V_{\max} - V_{\min}}{\Delta T_c} & \text{for } T_c < T_i \leq T_c + \Delta T_c \\ V_{\max} & \text{for } T_i > T_c + \Delta T_c \end{cases} \quad (2)$$

The minimum volume flow  $V_{\min}$  is calculated on the basis of the requirements of the animals concerning air quality. The calculation is mainly based on the  $\text{CO}_2$  release from the animals, proportional to the total heat production and the maximum accepted  $\text{CO}_2$  concentration inside the livestock building (between 2000 to 3500 ppm). The maximum volume flow  $V_{\max}$  is calculated by the sensible heat production and the accepted temperature difference between indoor and outdoor to avoid heat stress. The accepted temperature difference lies between 2 and 4 K (CIGR, 1984). The model calculation was done for a unit of 1000 fattening pigs, with a mechanically ventilated, moderately isolated building, a situation typical for middle Europe (Schaubberger et al., 1999) summarised in Tab. 1.

The odour release from the livestock building originates from the animals, polluted surfaces and the feed. Outdoor odour sources such as slurry tanks or feed storage facilities are not taken into account. The emission of the livestock building at the outlet air is quantified by the odour flow in OU/s and the specific odour flow in OU/s LU normalised by the livestock unit (LU) equivalent to 500 kg live mass. The specific odour flow depends on the kind of animals and how they are kept. Available data are summarised by a literature review of Martinec et al. (1998). For the model

calculation presented here, a mean specific odour flow of 100 OU/s LU and a mean live mass of 60 kg per fattening pig ( $M = 0.12$  LU) were used.

Table 1 System parameters of the indoor climate (model calculation) per animal; the parameters are representative for an unit of about 1000 fattening pigs.

Parameter	
Mean total energy release of an animal $Q_A$ (continuous fattening between 30 and 100 kg)	188 W
Minimum volume flow $V_{min}$ , calculated by the maximum accepted indoor CO <sub>2</sub> concentration of 3000 ppm	13.1 m <sup>3</sup> /h
Maximum volume flow $V_{max}$ , calculated by the maximum temperature difference between indoor and outdoor for summer ( $T_i=30^\circ\text{C}$ ) of 3 K	66.0 m <sup>3</sup> /h
Area of the building (ceiling, walls, windows, doors) per animal place	1.35 m <sup>2</sup>
Thermal transmission coefficient $U$	2.0 W/m <sup>2</sup> K
Set point temperature of the control unit $T_C$	18 °C
Bandwidth of the control unit $DT_C$	4 K

As odour production is a biochemical process, the temperature has an important influence. Most authors select the appropriate value for the outdoor air temperature (Oldenburg 1989; Kowalewsky, 1981). The linear regression of Oldenburg (1989) was adapted to assess the influence of the outdoor air temperature on the odour flow.

The odour flow of the livestock building depends on the odour release and the volume flow of the ventilation system. As a result of the model calculation, the odour concentration of the outlet air is taken as the parameter to describe the odour release. The concentration is calculated by the odour flow in OU/s divided by the volume flow of the ventilation system in m<sup>3</sup>/s.

## RESULTS

The annual variation of the odour concentration  $C$  for the data set of the two years is shown in Fig. 1. The line shows the moving average (over 24 hours) of the odour concentration to eliminate the diurnal variation.

The mean diurnal variation of the odour concentration of the outlet air was calculated for the winter (December to February) and summer period (June to August). In Fig. 2, the median boxes for every hour of the day show the different time pattern for these two periods. The day-night – variation of the odour concentration of the outlet air is more pronounced during winter than during summer. In winter during night-time, the median of the odour concentration is near the maximum, but there is a large variation, which continues throughout the daylight hours. However, the median concentration is much lower throughout the day (about 1500 OU/m<sup>3</sup>). In contrast, in summer during daytime, the odour concentration of the outlet air is close to the minimum with a small variability (about 50% of the mean). Larger concentrations are calculated during the night, again with a large variability comprising the whole range of calculated values. However in general, there is less variability in odour concentrations during summer than during winter. The larger odour concentrations during winter are a result of the smaller volume flow  $V$  (see Fig. 1).

The diurnal variation of the parameters of the ventilation system as calculated by the model is shown for four exemplary days (September 5 to 8, 1992) in Fig. 3. The second panel shows that the day and night fluctuations were mainly caused by the change of the volume flow of the ventilation system. Besides the variation of volume flow and odour flow, the meteorological situation was changing from a stable situation during night-time (stability class 6 (stable) or 7 (very stable)) to a well-mixed boundary layer during day-time. The first day started with above-average wind speed and stability class 4. This is probably the reason why the volume flow did not

reach a maximum value on Sept. 5. Data for September 6 show a large amplitude of air temperature due to clear skies giving rise to nocturnal radiative cooling accompanied by a high stability (class 7) and to pronounced surface heating after sunrise (stability classes 2 and 3). On this day, the volume flow of the ventilation system varied between the maximum during daytime and the minimum during night. On the next two days this effect is reduced due to cloudiness decreasing day-night temperature differences. Nevertheless the diurnal variation of the air temperature caused a corresponding variation of the volume flow, and hence the contrary time course of the odour concentration of the outlet air.

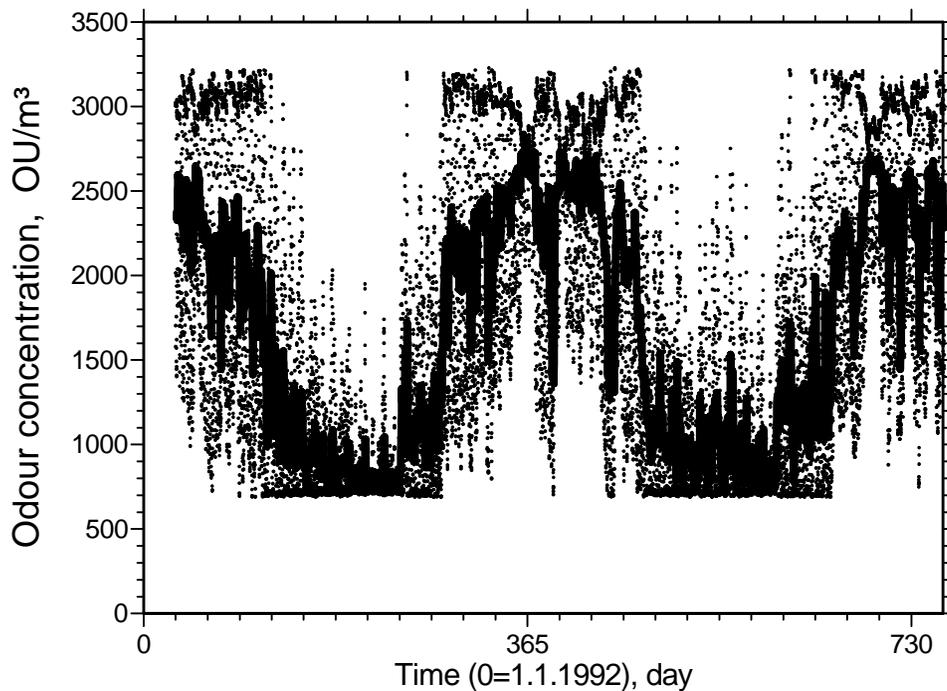


Figure 1. Calculated odour concentration in  $\text{OU}/\text{m}^3$  of the outlet air over the measurement period. Each point represents a half hour mean value, calculated by the time series of Wels. The line shows the smoothed average (over 24 hours) to eliminate the diurnal variation.

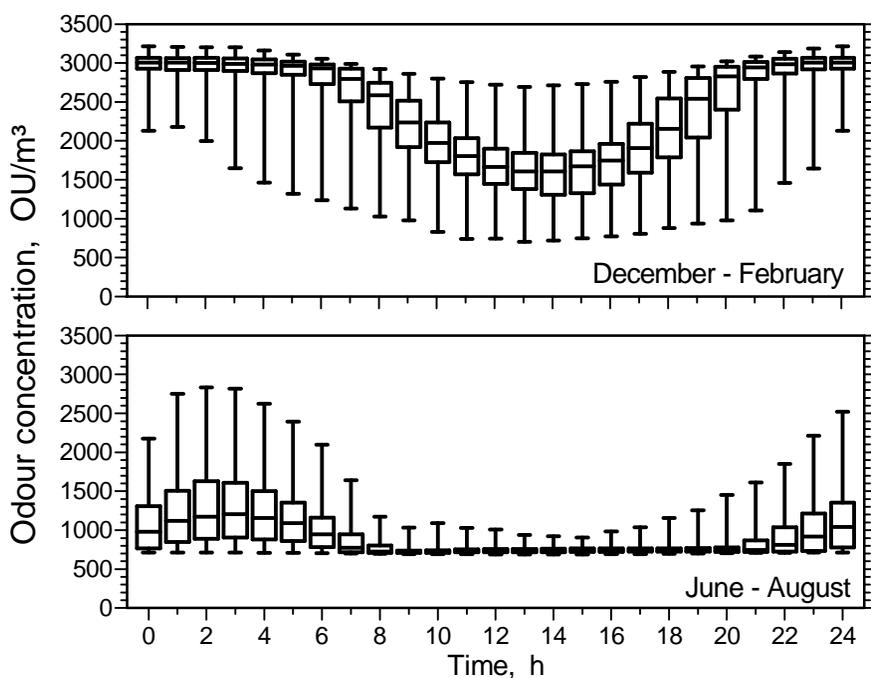


Figure 2. Diurnal variation of the odour concentration during winter months (December - February) and summer months (June - August) as median boxes (median, upper and lower hinges, and the extremes).

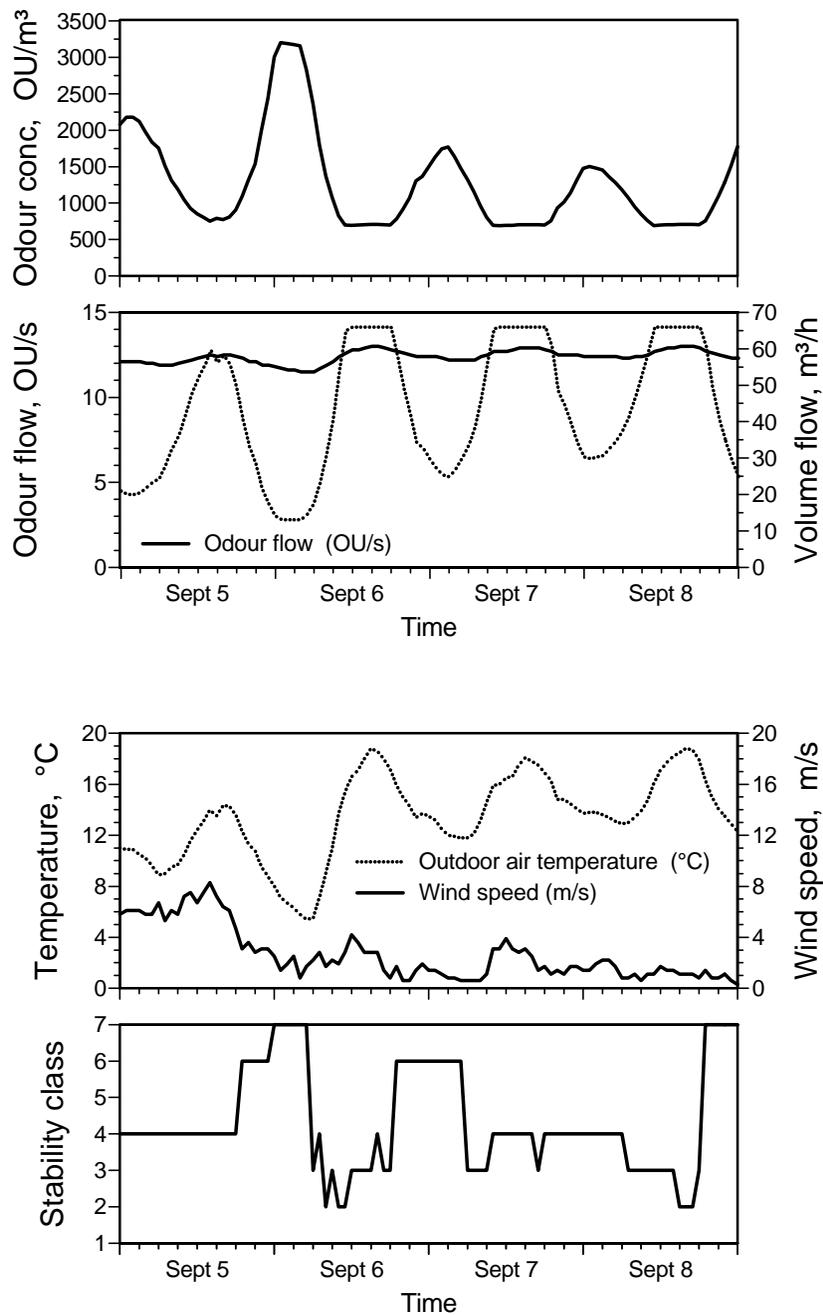


Figure 3. Calculated odour concentration in OU/m<sup>3</sup> (first panel); odour flow in OU/s and volume flow in m<sup>3</sup>/h (second panel) per animal between September 5 to 8, 1992 and ambient conditions for the period from 5 to 8 September 1992: outdoor air temperature in °C and wind speed in m/s (third panel); stability class of the boundary layer (fourth panel).

## DISCUSSION

The time series of meteorological parameters used for this study is representative for the Austrian flatlands and the North-Alpine foreland. These are regions where, apart from valleys with their specific flow regimes, good ambient air movement prevails throughout the year. Situations which can give rise to enhanced pollution concentrations, such as calm conditions, low-base temperature inversions or periodically changing wind regimes, are not as frequently observed in these areas, as for example in inner-Alpine valleys or in the basins south of the Alps. The variability of the odour concentration of the outlet air found in this investigation might be quite different there. This may also be the case for locations near coasts which are exposed to periodically changing land-sea breezes. On the other hand, the results achieved here are applicable to all areas, especially in Central and Eastern Europe, that experience similar average temperatures and ventilation conditions, such as large parts of southern Germany, Hungary, or Poland.

Total energy and CO<sub>2</sub> release by animals show a typical diurnal variation (Schauberger et al., 2000), strongly correlated to the physical animal activity. The release of odour seems to be very similar to ammonia. A correlation between the two airborne pollutants is not very strong (Oldenburg, 1989). Therefore ammonia can not be used as a surrogate substance for odour. Nevertheless, the ammonia concentration shows a distinct day/night fluctuation. For eight different sow houses the ratio of the mean ammonia concentration between day and night is about 1.28, for the daily extremes 2.10 (Phillips et al, 1998). As the ventilation flow counteracts this diurnal variation due to the animal activity, a weaker diurnal variation of the odour concentration of the outlet air can be expected. Dust, as an important carrier of odoriphores, shows the same diurnal variation (CIGR, 1994). Nevertheless, no diurnal variation of the odour release was used in the model, because very little data are available (Martinec et al, 1998).

Considering that odour is mainly released by the animals, by polluted surfaces and by feed, a diurnal variation in phase with animal activity seems probable. By the fact that the time course of the animal activity and the volume flow of the ventilation system counteract over the day, the ratio between maximum and minimum odour concentration of the outlet air will be reduced.

The model presented here describes only mechanically ventilated livestock buildings. Naturally ventilated livestock buildings cannot be handled in this way because there is a lack of information about the specific odour flow for such systems. Furthermore, appropriate models are not available to calculate the volume flow caused by buoyancy and wind pressure.

If dispersion models, such as the Gaussian plume model, are used to calculate the outdoor odour concentration, input parameters, such as volume flow, odour flow, air temperature and outlet velocity have to be known (Piringer and Schauberger, 1999). In general, these input parameters are assumed to be constant due to a lack of appropriate information. Variations in the calculated odour concentrations result primarily from variations in the time series of meteorological parameters (Fig. 3). The model calculations and also the meteorological considerations presented here demonstrate, however, that the diurnal as well as the annual variation of the stack parameters have to be taken into account. Especially for some outstanding meteorological situations the error of a constant odour flow can be considerable. For sunny days after a clear night causing a high diurnal variation of the air temperature, the odour concentration of the outlet air can change by a factor of 4.6 for example, on September 6, 1992 the value of  $C_{\max}$  was 3188 OU/m<sup>3</sup> and  $C_{\min}$  was 696 OU/m<sup>3</sup>. In addition to the variability of the odour concentration, the diurnal variation of the stability of the boundary layer increases this effect. During daytime, a well-mixed boundary layer and a low odour concentration of the outlet air reduce the necessary separation distance to avoid odour annoyance. At night, a high odour concentration and a reduced dilution by a stable boundary layer increases the separation distance. For the neighbourhood this obvious change of the odour sensation (intensity and/or duration) is exclusively caused by the livestock building. Such cases are a challenge for models and guidelines calculating a separation distance to avoid odour nuisance.

To improve the calculation of odour concentrations in the vicinity of livestock farms by dispersion models, the annual and diurnal variation of the odour release has to be taken into account. Long-term measurements of odour emissions of livestock buildings are required to achieve such improvements.

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