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Diurnal and Annual Variation of Odour Emission from Animal Houses: a Model Calculation for Fattening Pigs

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Odour emission from livestock buildings adjacent to residential areas may constitute an environmental nuisance and dispersion models are of interest in the regulation of air pollutants. To apply dispersion models to odour emissions, the odour concentration and the volume flow of the outlet air must be known. In this paper, the odour concentration of the outlet air is determined by combining a steady-state balance model to calculate the outlet air temperature and the volume flow with a simple model for the odour release inside the livestock building. 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 nighttime 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 purposes.

1. Introduction

Odour emissions can affect the acceptability of livestock farming in the vicinity of residential areas (Schiffman, 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^3). 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 (*e.g.* Gaussian model: Kolb, 1981; ÖNorm M 9440, 1992/1996). 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 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 (*e.g.* CIGR, 1984) in which the inside air temperature is calculated as a function of the outside temperature (*e.g.* Schauberger 1988 and 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.

The model to calculate the diurnal and annual variation of the odour emission as well as the meteorological data used as input, are presented in Section 2. The resulting indoor climate and odour release of the livestock unit as a function of the outdoor temperature is presented in

Notation

A	area of the construction elements of the building per animal, m^2
c	heat capacity of air per volume, kJ/m^3 K
C	odour concentration, OU/m^3
e	specific odour flow, OU/s LU (1 LU is equivalent to 500 kg live mass)
E	odour flow, OU/s
e_m	daily mean specific odour flow, OU/s LU (1 LU is equivalent to 500 kg live mass)
E_m	daily mean odour flow, OU/s
f_s	relative proportion of the total heat which appears as sensible heat
M	live mass, kg
Q_A	total heat production of one animal, W
$Q_A(t)$	total heat production of one animal as a function of time, W
S_A	sensible heat production of one animal, W
S_B	sensible heat flow caused by the transmission of the building, W
S_V	sensible heat flow caused by the ventilation system, W
t	time, unit depends on the scale
T_C	set point temperature of the control unit of the ventilation system, °C
ΔT_C	proportional range of the control unit for the ventilation system, K
T_i	indoor air temperature, °C
T_o	outdoor air temperature, °C
U	thermal transmission coefficient of the livestock building; W/m^2 K
V	volume flow of the ventilation system per animal, m^3/h or m^3/s
$V(T_i)$	volume flow of the ventilation system per animal as a function of the indoor air temperature, m^3/h or m^3/s
$V_{\max}$	maximum volume flow of the ventilation system per animal, m^3/h
$V_{\min}$	minimum volume flow of the ventilation system per animal, m^3/h
τ	period, h

Section 3. All these results are based on model calculations. The discussion in Section 4 tries to emphasize the general applicability of the approach presented.

2. Materials and method

2.1. *Meteorological data*

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 min for a 2-year period between January 30, 1992 and January 31, 1994. In Austria, the stability of the atmosphere is traditionally classified to a discrete scheme developed by Reuter (1970) used for the Austrian regulatory dispersion model (ÖNorm M 9440, 1992/1996; Kolb, 1981). Stability classes are determined as a function of half-hourly mean wind speed and a combination of sun elevation angle and cloud cover. The cloud cover was monitored by the meteorological station at the airport Linz-Hörsching, at a distance of about 13 km. Within the Reuter scheme, classes 2–7 can occur in Austria. Stability classes 2 and 3 occur during daytime in a well-mixed boundary layer, class 3 allowing also for cases of high wind velocity and moderate cloud cover. Class 4 is representative of cloudy and/or windy conditions including precipitation or fog and can occur during day or night. In the flatlands, it is by far the most common dispersion category. Classes 5–7 occur at night, static stability increasing with class number.

2.2. *Calculation of the outlet air temperature and volume flow of the livestock building*

The air temperature inside a mechanically ventilated livestock building is calculated by a balance equation of the sensible heat (Schauberger, 1988; CIGR, 1984; Albright, 1990). On the basis of the following equations [(1)–(7)] which refer to one animal, 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

$$S_A + S_B + S_V = 0 \tag{1}$$

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 sensible heat release of the animal is part of the total heat production Q_A (CIGR, 1984) which is proportional to the metabolic mass of the animal $M^{0\cdot75}$

$$S_A = Q_A f_s \tag{2}$$

The share of the sensible heat f_s depends on the indoor air temperature T_i calculated by

$$f_s = 0{\cdot}85 - 1{\cdot}85 \times 10^{-7}(T_i + 10)^4 \tag{3}$$

The diurnal variation of the total heat production $Q_A(t)$ is taken into account by a sinusoidal function with the period τ of 24 h, proposed by Pedersen and Takai (1997) on the basis of the variation of the animal activity over the time of the day t. The amplitude for fattening pigs is assumed to be ± 45% of the daily mean value (Pedersen & Rom, 1998). The minimum of the animal activity of fattening pigs occurs around 0115 local time at night (Pedersen, 1996; Pedersen & Takai, 1997):

$$Q_A(t) = Q_A\left[1 + 0{\cdot}45\sin\left(\frac{2\pi}{\tau}(t - 7{\cdot}25)\right)\right] \tag{4}$$

The sensible heat loss due to the transmission through the building S_B is calculated by the mean value of the thermal transmission coefficient U weighted by the areas of the different construction elements (walls, ceiling, doors, windows), the mean area of all these elements A and the temperature difference between outdoor T_o and indoor air T_i.

$$S_B = UA(T_o - T_i) \tag{5}$$

The sensible heat flow due to the ventilation system S_V is calculated by the volume flow V in m³/s, the heat capacity of air per volume c and the temperature difference

$$S_V = Vc(T_o - T_i) \tag{6}$$

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 shown in *Fig. 1*. Two parameters, the set point temperature T_C and the proportional range ΔT_C describe the course of the volume flow depending on the indoor air temperature T_i as a control value (*e.g.* Christiaens, 1989). 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 (7) gives the volume flow V as a function of the indoor air temperature T_i:

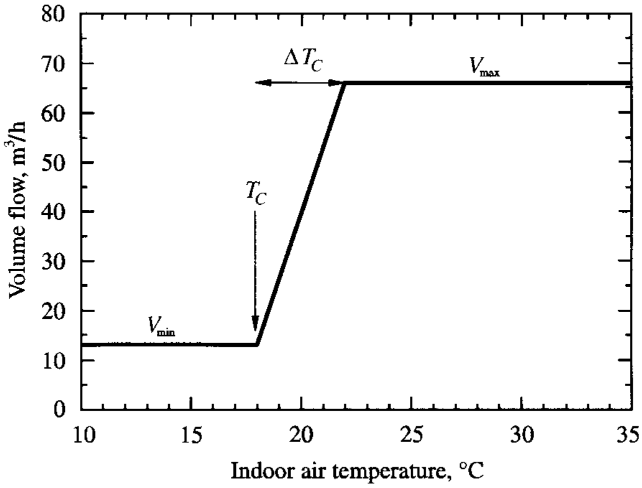

Fig. 1. Characteristics of the control unit of the ventilation system. The volume flow per fattening pig with a living mass of 60 kg is a function [(Eqn (7)] of the indoor air temperature T_i as control parameter. The control unit has two parameters: set point temperature T_C and the proportional range of the control unit ΔT_C. The minimum volume flow per animal V_{min} and the maximum volume flow V_{max} characterize the performance of the ventilation system

$$V(T_i) = \begin{cases} V_{min} & \text{for } T_i \le T_c \\ V_{min} + (T_i - T_c)\dfrac{V_{max} - V_{min}}{\Delta T_C} & \text{for } T_c < T_i \le T_c + \Delta T_c \\ V_{max} & \text{for } T_i > T_c + \Delta T_c \end{cases} \tag{7}$$

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 CO_2 release from the animals, proportional to the total heat production and the maximum accepted CO_2 concentration inside the livestock building (between 2000 and 3500 p.p.m.). The maximum volume flow V_{max} is calculated by the sensible heat production and the accepted temperature difference between the indoor and outdoor to avoid heat stress. The accepted temperature difference lies between 2 and 4 K (CIGR, 1984).

The system parameters per animal for a livestock building with the chosen specifications, typical for middle Europe, are summarized in Table 1.

2.3. *Odour release of the livestock building*

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 E in OU/s and the specific odour flow e in OU/s LU,

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_2 concentration of 3000 p.p.m.	13·1 m^3/h
Maximum volume flow V_{max}, calculated by the maximum temperature difference between the indoor and outdoor for summer (T_i = 30°C) of 3 K	66·0 m^3/h
Area of the building (ceiling, walls, windows, doors) per animal place	1·35 m^2
Thermal transmission coefficient U	2·0 W/m^2 K
Set point temperature of the control unit T_C	18°C
Bandwidth of the control unit ΔT_C	4 K

normalized 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 summarized by a literature review of Martinec *et al.* (1998). For the model calculation presented here, a mean specific odour flow e_m of 100 OU/s LU and a mean live mass of 60 kg per fattening pig (M = 0·12 LU) were used.

As odour production is a biochemical process, the temperature has an important influence. Most authors select the appropriate value for the outdoor air temperature T_o (Oldenburg, 1989; Kowalewsky, 1981). The linear regression of Oldenburg (1989) was adapted to assess the influence of the outdoor air temperature T_o on odour flow E_m by Eqn (8). In the model of the odour release no diurnal variation of the odour release was assumed.

$$E(T_o) = E_m(0{\cdot}905 + 0{\cdot}0095T_o) \qquad (8)$$

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 C of the outlet air is taken as the parameter to describe the odour release. The concentration is calculated by the odour flow E in OU/s divided by the volume flow V of the ventilation system in m^3/s as seen in Eqn (9):

$$C = \frac{E}{V} \qquad (9)$$

3. Results

3.1. *Outdoor climate*

The Austrian flatlands north of the Alps (200–400 m above sea level) are characterized by a moderate climate with both maritime and continental influences. The annual average temperature is 9–10°C. Precipitation occurs all the year round, culminating in summer storms, and yearly precipitation totals amount from 700 to 1000 mm from east to west. In general, there is a good ambient air movement, with mean wind speeds ranging from about 2 to 4 m/s. Except for north–south oriented valleys, main wind directions are west and east.

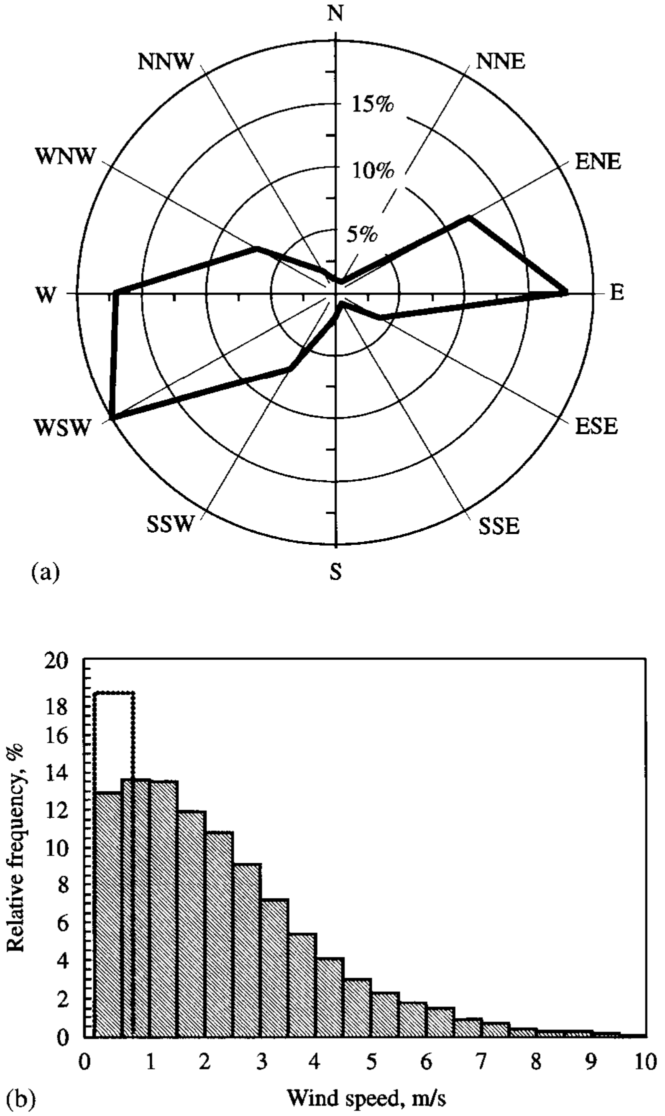

Fig. 2. Frequency distribution of (a) the wind direction and (b) wind speed at Wels; - - - - - -, calm conditions according to the Austrian regulatory dispersion model with wind speed less than 0·7 m/s (ÖNorm M9440, 1992/1996)

The city of Wels in Upper Austria, for which the statistics of stability classes (Section 2.1.) has been calculated, is a regional shopping and business centre of about 50 000 inhabitants. The surroundings are rather flat and consist mainly of farmland. The mean wind speed in an undisturbed environment is 2·2 m/s, maximum speeds amounting to about 13 m/s. The distribution of wind directions and wind speeds are shown in *Fig. 2*. The prevailing wind directions at Wels are west and WSW, as

Table 2
Two-dimensional frequency distribution in ‰ of stability classes (2–7) and wind speed in m/s at Wels

	Stability class					
Wind speed, m/s	*2*	*3*	*4*	*5*	*6*	*7*
< 1·0	13	35	42		41	71
1·0–1·9	44	55	79		35	59
2·0–2·9	30	39	91	30	22	7
3·0–3·9	10	19	91	25	12	
4·0–4·9	5	8	63	4		
5·0–5·9		5	31			
6·0–6·9			22			
≥ 7			12			
Sum	102	161	431	59	110	137

well as east and ENE. Calm conditions according to the Austrian regulatory dispersion model with wind speed of less than 0·7 m/s amount to 18·2%; weak winds (wind speeds less than 1 m/s) comprise 26·5% of all cases. Less than 10% of all wind speeds are larger than 5 m/s.

The annual mean temperature at Wels is 9·7°C, the temperature range (two-year period) is from − 14·9 to 35·3°C. The annual precipitation amounts to 838 mm (mean over the period 1961–1990). The occurrence of stability classes is given in Table 2.

Some combinations of stability class and wind speed do not occur by definition (ÖNorm M 9440, 1992/1996). Stability class 4 is by far the most common dispersion category because it occurs both during the day and night. Its occurrence peaks at wind speeds of 2 and 3 m/s. Wind speeds larger than 6 m/s are almost entirely connected with class 4 (since a frequency of 1‰ is equal to about 18 half-hours in the two-year statistics, smaller occurrences do not show up in Table 1). Stability classes 2 and 3, which by definition occur only during the daylight hours, peak slightly below or around the average windspeed. They cover 26% of all cases. Class 5 occurs with higher wind speeds during nights with low cloud cover, a situation which is not observed frequently at Wels. Classes 6 and 7 are relevant for clear nights, when a surface inversion, caused by radiative cooling, traps pollutants near the ground. Such situations occur in 25% of all cases.

3.2. *Outlet air temperature and volume flow of the livestock building*

The thermal environment of the calculated livestock building is characterized by the indoor temperature as a function of the outdoor temperature (*Fig. 3*). Three subsets can be distinguished in relation to the indoor air temperature: (1) an indoor temperature below the set point T_c of the control unit occurs during about 20% of the year; (2) about 59% of the time, the indoor air temperature is within the relatively small temperature range between T_C and $T_C + \Delta T_C$. (3) The indoor temperature lies 29% of the time above the controllable range $T_C + \Delta T_C$.

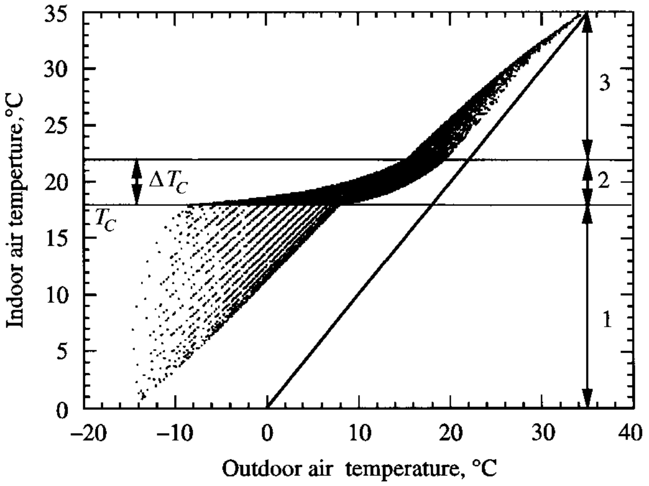

Fig. 3. Indoor air temperature in relation to the outdoor temperature of the livestock building calculated for the system parameters of Table 1. The data set can be divided into three parts indicated by arrows: (1) indoor air temperature below the set point temperature T_C *of the control unit, (2) the controllable range, and (3) indoor air temperature above* $T_C + \Delta T_C$. *Each point represents a half-hour mean value, calculated by the time series of Wels. —, inlet air temperature*

3.3. *Odour release*

The annual variation of the odour concentration *C* for the data set over a period of two years is shown in *Fig. 4*. The line shows the moving average (over 24 h) of the odour concentration to eliminate the diurnal variation.

The statistics of the odour concentration (Table 3) give an impression of the distribution over the two-year measuring period. The centre line (median), as well as the 50% region bordered by the first and third quartiles, show a distinct course over the year. The minimum values (687–969 OU/m^3) and the maximum values (2583–3226 OU/m^3) are almost in the same ranges over the whole year.

The mean diurnal variation of the odour concentration of the outlet air was calculated for the winter (December–February) and summer period (June–August). In *Fig. 5*, 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 the nighttime, the median of

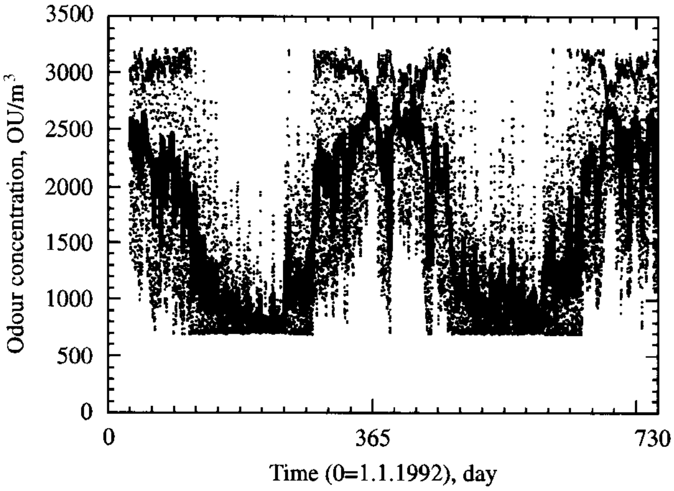

Fig. 4. Calculated odour concentration in OU/m³ of the outlet air over the measurement period. Each point represents a half-hour mean value, calculated by the time series of Wels. The line shows the smoothed average (over 24 h) to eliminate the diurnal variation

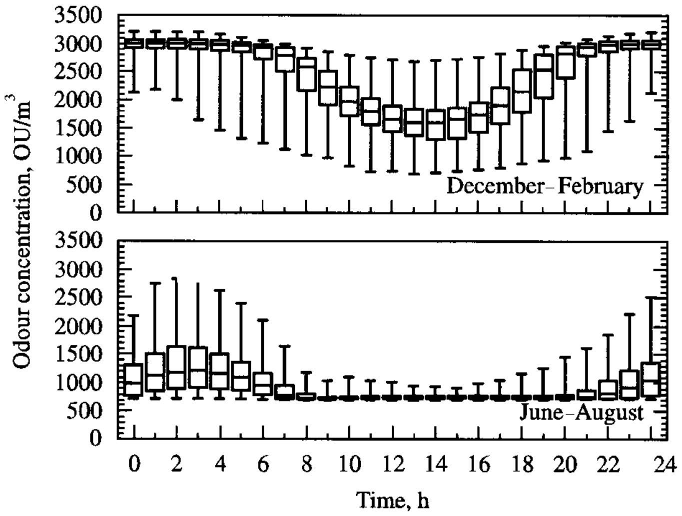

Fig. 5. Diurnal variation of the odour concentration during the winter months (December–February) and the summer months (June–August) as median boxes (median, upper and lower hinges, and the extremes)

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^3). 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 the summer than during the winter. The larger odour concentrations during winter are a result of the smaller volume flow V (see *Fig. 4*).

The diurnal variation of the parameters of the ventilation system as calculated by the model is shown for four exemplary days (September 5–8, 1992), in *Fig. 6*. The lower panel of *Fig. 6* 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 nighttime (stability class 6 (stable) or 7 (very stable)) to a well-mixed boundary layer during the daytime (*Fig. 7*). 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 September 5. The data for September 6 shows a large amplitude

Table 3
Descriptive statistics of odour concentration C in OU/m^3 for the months of the year

	Odour concentration				
Month	*Minimum*	*1st quartile*	*Median*	*3rd quartile*	*Maximum*
January	701	1703	2545	2957	3207
February	969	1971	2694	2951	3213
March	689	1451	2169	2966	3226
April	688	995	1456	2501	3220
May	688	721	843	1376	3116
June	687	720	758	1074	2583
July	690	721	750	959	2751
August	687	727	756	849	2832
September	687	725	1015	1523	3213
October	688	1136	1559	2450	3210
November	794	1590	2292	2907	3226
December	877	1895	2696	2973	3173

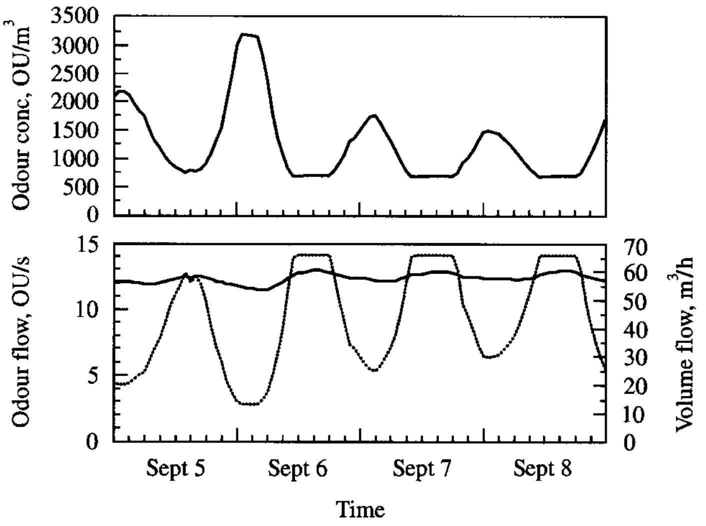

Fig. 6. Calculated odour concentration in OU/m^3 (upper panel); —, odour flow in OU/s and - - - - - -, volume flow in m^3/h (lower panel) per animal between September 5 and 8, 1992

of air temperature due to the 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 (*Fig. 6*, lower panel) of the ventilation system varied between the maximum V_{max} during the daytime and the minimum V_{min} during the night [(Eqn (7) and Table 1)]. On the next two days this effect is reduced due to cloudiness, decreasing the 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.

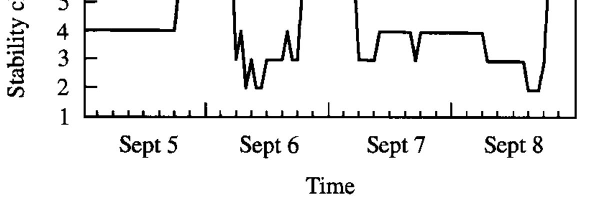

Fig. 7. Ambient conditions for the period from 5 to 8 September 1992; - - - - -, outdoor air temperature in °C); —, wind speed in m/s (upper panel); stability class of the boundary layer (lower panel)

4. 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 the coasts which are exposed to periodically changing land–sea breezes. On the other hand, the results achieved here are applicable to all the areas, especially in Central and Eastern Europe, that experience similar average temperatures and ventilation conditions, such as the large parts of southern Germany, Hungary, or Poland.

The review concerning the odour emission of livestock buildings by Martinec *et al.* (1998) shows a wide spread of published data describing the odour release. For example, the specific odour flow for fattening pigs varies between 38 and 495 OU/s LU for fully slatted floors and between 8 and 134 OU/s LU with bedding material. For the model calculation, a specific odour flow of 100 OU/s LU was assumed. The main factors affecting its variation (Martinec *et al.*, 1998) are the various methods of keeping pigs and the influence of the management of the livestock building. The imprecision of assessing the odour flow also contributed to the variability of the volume flow [(Eqn 9)] as seen in *Fig. 6* for selected summer days.

Total energy and CO_2 release by the animals show a typical diurnal variation (Pedersen & Takai, 1997; Schauberger & Pilati, 1998a, 1998b; van Ouwerkerk & Pedersen, 1993), strongly correlated to the physical animal activity (Pedersen & Pedersen, 1995). 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 cannot 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 the 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 [(Eqn (9]), a weaker diurnal variation of the odour concentration of the outlet air can be expected. Dust, as an important carrier of odoriphores (Hoff *et al.*, 1997), shows the same diurnal variation (Pedersen, 1993; 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; Hartung *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 the maximum and the minimum odour concentration of the outlet air will be reduced according to Eqn (9).

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 the volume flow, odour flow, air temperature and outlet velocity have to be known (Piringer & Schauberger, 1998). 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. 7*). 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, in *Fig. 6* on September 6, 1992, the value of C_{max} was 3188 OU/m^3 and C_{min} was 696 OU/m^3. In addition to the variability of the odour concentration, the diurnal variation of the stability of the boundary layer increases this effect (*Fig. 7*). 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.

The mean odour concentration during daytime in the summer months lies in a very narrow range close to the overall minimum. This means that an assumption of the odour concentration by the odour production and the maximum volume flow of the livestock building for model calculations is a useful approximation under such conditions (Piringer & Schauberger, 1998).

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.

5. Conclusions

The combination of a simple steady-state balance equation with the assumption of an odour release from livestock buildings without a diurnal variation gives a first crude approximation to the diurnal and annual variation of the odour concentration of the outlet air.

A constant odour concentration of the outlet air over the year, as usually assumed when calculating the separation distances between the livestock buildings and the residential areas, is not valid.

The annual variation of the odour concentration of the outlet air calculated for a pig fattening unit is between 687 and 3226 OU/m^3.

When the minimum ventilation flow during nighttime and the maximum ventilation flow during the daytime is observed, the diurnal variation of the odour concentration of the outlet air can achieve a value of 4·6.

For the summer period, when most of the complaints of the neighbours are registered, it is useful to assume a fixed value of the odour flow and the maximum volume flow of the livestock building in order to calculate the odour concentration of the outlet air during daytime.

A time pattern of the odour release in phase with the animal activity seems probable, with respect to the known diurnal variation of other parameters (*e.g.* dust and ammonia).

Long-term measurements of the odour release from livestock buildings are necessary to improve the application of the dispersion models and to calculate the separation distances necessary to prevent nuisance in the vicinity of the animal production enterprises.

References

Albright L D (1990). Environment control for animals and plants. ASAE Textbook No. 4, American Society of Agricultural Engineers, St. Joseph

Christiaens J P A (1989). Ventilation and heating control in animal houses. In: Commission International du Génie Rural (CIGR): Climatization of Animal Houses. 2nd Report. Centre for Climatization of Animal Houses. Ghent State University, Ghent

CIGR Commission International du Genié Rural (1984). Climatization of animal houses. Scottish Farm Buildings Investigation Unit, Aberdeen, Scotland

CIGR Commission International du Génie Rural (1994). Aerial environment in animal housing—concentration in and emission from farm buildings. CEMAGREF, Rennes

Hartung E; Martinec M; Brose G; Jungbluth Th (1998). Diurnal course of the odor release from livestock housings and the odor reduction of biofilters. In: Animal Production Systems and Environment. An International Conference on Odor, Water Quality, Nutrient Management and Socioeconomic Issues (Scanes C; Kanwar R eds), Iowa State University of Science and Technology, Iowa

Hoff S J; Bundy D S; Li X W (1997). Dust effects on odor and odor compounds. In: Ammonia and Odour Emission from Animal Production Facilities (Voermans J A M; Monteny G J eds), pp 677–684, Rosmalen, The Netherlands

Kolb H (1981). Ein normatives Modell zur Simulierung der Ausbreitung von Schadstoffen in der Atmosphäre unter besonderer Berücksichtigung der Verhältnisse in Österreich. [A regulative model to simulate the dispersion of pollutants in the atmosphere for the situation in Austria]. Publ. 29. Abteilung für Theoretische Meteorologie, University Vienna, Vienna

Kowalewsky H H (1981). Messen und Bewerten von Geruchsimmissionen. Chemische und sensorische Bestimmung des Geruchs in der Umgebung von Ställen, offenen Güllebehältern und begüllten Feldern [Measurement and evaluation of odour concentration. Chemical and sensorial evaluation of odour in the vicinity of livestock housings, open slurry tanks and fields dunged with slurry]. KTBL-Schrift 260, Kuratorium für Technik und Bauwesen in der Landwirtschaft e.V. KTBL., Darmstadt

Martinec M; Brose G; Hartung E (1998). Course of the day of odour release from livestock housing and odour reduction with biofilters. International Conference on Agricultural Engineering AgEng 98, Oslo, Norway

Martinec M; Hartung E; Jungbluth Th (1998). Geruchsemissionen aus der Tierhaltung (Literaturstudie) [Odour emission of livestock husbandry (a literature survey)]. pp 68, Ministerium für Umweld und Verkehr, Baden-Würthenberg, Germany

Oldenburg J (1989). Geruchs- und Ammoniak-Emissionen aus der Tierhaltung [Odour and ammonia emission of livestock husbandry]. KTBL-Schrift 333, Kuratorium für Technik und Bauwesen in der Landwirtschaft e.V. KTBL, Darmstadt

ÖNorm M 9440 (1992/1996). Ausbreitung von luftverunreinigenden Stoffen in der Atmosphäre; Berechnung von Immissionskonzentrationen und Ermittlung von Schornsteinhöhen [Dispersion of pollutants in the atmosphere — calculation of the ambient air concentrations and determination of stack heights]. Österreichisches Normungsinstitut, Vienna

Pedersen S (1993). Time based variation in airborne dust in respect to animal activity. In: 4th International Livestock Environmental Symposium (Collins E; Boon C eds), Coventry, England

Pedersen S (1996). Døgnvariationer i dyrenes aktivitet i kvæg-, svine- og fjerkræstalde [Diurnal variation of the animal activity of calve, pig and poultry]. Internal Report 66. Danish Institute of Animal Science. Horsens, Denmark

Pedersen S; Pedersen C B (1995). Animal activity measured by infrared detectors. Journal of Agricultural Engineering Research, **61**, 239–246

Pedersen S Rom H B (1998). Diurnal variation in heat production from pigs in relation to animal activity. International Conference on Agricultural Engineering AgEng 98, Oslo, Norway

Pedersen S; Takai H (1997). Diurnal Variaton in animal heat production in relation to animal activity. In: 5th International Livestock Environmental Symposium (Bottcher R W; Hoff S J eds), Bloomington, Minnesota

Phillips V R; Holden M R; Sneath R W; Short J L; White R P; Hartung J; Seedorf J; Schröder M; Linkert K H; Pedersen S; Takai H; Johnsen J O; Groot P; Koerkamp W G; Uenk G H; Scholtens R; Metz J H M; Wathes C M (1998). The development of robust methods for measuring concentrations and emission rates of gaseous and particulate air pollutants in livestock buildings. Journal of Agricultural Engineering Research, **70**(1), 11–24

Piringer M; Schauberger G (1999). Comparison of a Gaussian diffusion model with guidelines for calculating the separation distance between livestock farming and residential areas to avoid odour annoyance. Atmospheric Environment, **33**, 2219–2228

Reuter H (1970). Die Ausbreitungsbedingungen von Luftverunreinigungen in Abhängigkeit von meteorologischen Parametern [Dispersion conditions of airborne pollutants in dependence on meteorological parameters]. Archiv für Meteorologie und Geophysik, Bioklimatologie A **19**, 173–186

Schauberger G (1988). Ein quasi-stationäres Bilanzmodell zur Stallklima-Simulation [A steady-state balance model to simulate the indoor climate in livestock buildings]. Deutsche Tierärztliche Wochenschrift, **95**, 200–205

Schauberger G (1989). Computersimulation des Stallklimas am PC in der tierärztlichen Praxis [Computer simulation of the indoor climate in livestock buildings on the PC]. Berliner Münchner Tierärztliche Wochenschrift, **102**, 58–63

Schauberger G; Pilati P (1998a). Evaluation of a steady-state balance model to simulate the indoor climate inside livestock buildings: a comparison with measurements of a cattle house. International Conference on Agricultural Engineering AgEng'98, Oslo, Norway

Schauberger G; Pilati P (1998b). Evaluierung eines quasi-stationären Bilanzmodells zur Stallklimasimulation: Vergleich mit Messungen eines Rindermaststalles [Evaluation of a steady-state balance model to simulate the indoor climate in livestock buildings: a comparison with measurements of a cattle house]. Wiener Tierärztliche Monatsschrift, **85**, 49–55

Schiffman S S (1998). Livestock odors: implications for human health and well-being. Journal of Animal Science, **76**, 1343–1355

van Ouwerkerk E N J; Pedersen S (1993). Application of the carbon dioxide mass balance method to evaluate ventilation rates in livestock buildings. In: 4th International Livestock Environmental Symposium (Collins E; Boon C eds), Coventry, England