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Steady-state balance model to calculate the indoor climate of livestock buildings, demonstrated for finishing pigs

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Abstract The indoor climate of livestock buildings is of importance for the well-being and health of animals and their production performance (daily weight gain, milk yield etc). By using a steady-state model for the sensible and latent heat fluxes and the CO_2 and odour mass flows, the indoor climate of mechanically ventilated livestock buildings can be calculated. These equations depend on the livestock (number of animals and how they are kept), the insulation of the building and the characteristics of the ventilation system (ventilation rate). Since the model can only be applied to animal houses where the ventilation systems are mechanically controlled (this is the case for a majority of finishing pig units), the calculations were done for an example of a finishing pig unit with 1000 animal places. The model presented used 30 min values of the outdoor parameters temperature and humidity, collected over a 2-year period, as input. The projected environment inside the livestock building was compared with recommended values. The duration of condensation on the inside surfaces was also calculated.

Introduction

The performance of farm animals is a result of the genotype of the animals and parameters like nutrition, hygiene, livestock management as well as the abiotic environment. This environment should fulfil the requirements of the animals to improve the performance of the livestock. An adequate physical environment for the animals should be provided by the livestock building and the ventilation system. The physical environment of farm animals inside livestock buildings is primarily characterised by hygro-thermal parameters and air quality. These parameters are influenced by the interaction with the outdoor situation on the one hand and the livestock, the ventilation system and the building on the other. This interaction can be modelled by the steady-state balance equation for the sensible and latent heat and the carbon dioxide mass balance (Albright 1990; CIGR 1984; ASHRAE 1993; Baxter 1984; Pedersen et al. 1998). During winter time, when the recommended thermal conditions have to be achieved by restrictions of the ventilation rate, air quality is of major interest. During summer time, adequate heat removal by the ventilation system is the crucial point. On the basis of these balance equations, models are used to describe the complex system behaviour of the indoor climate of livestock buildings. Such models can be used for several purposes: first of all to ensure that the essential needs of the animals are met and to optimise the indoor climate to increase animal performance (e.g. Hartung 1994). Furthermore, this can also be seen as a contribution towards the reduction of the amount of drugs used to treat environmentally caused diseases (Straw 1992).

The model can be used in two modes: first in a prognostic mode (Schauberger 1988a, 1989) e.g. for the purpose of designing the ventilation system and the renovation of existing livestock buildings; secondly, in a diagnostic mode, when measured values of the indoor climate are compared with model calculations. Such methods can be used as a part of herd health control (Schauberger et al. 1995) as well as to check the design values of the ventilation system and its control unit (e.g. DIN 18910 1992; CIGR 1984).

Airborne emissions from livestock husbandry (e.g. Wathes 1994) are also of interest when discussing greenhouse gases like CO_2, N_2O and CH_4, ecologically relevant gases like NH_3 (e.g. Graedel and Crutzen 1993), micro-organisms and odour. The last component especially can reduce the acceptability of livestock farming in the vicinity by malodour (Schiffman 1998). By combining an indoor climate model with parameters defining

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the odour release of the animals within a livestock building, the diurnal and annual variation of the odour emission of the farm can be calculated (Schauberger et al. 1999). The aim of this paper is to apply a steady-state balance model in prognostic mode to assesse the indoor climate [hygro-thermal parameters and air quality (CO_2, odour)] on the basis of 30 min values. The result is discussed for an 1000-head pig finishing unit.

Materials and methods

Meteorological data

Meteorological data, like temperature, relative humidity, wind direction and wind speed, are needed to calculate the climate inside the livestock building and the odour emission. For this evaluation, data were collected at Wels, a site representative of the Austrian flatlands (200–400 m above sea level) north of the Alps. The sample interval was 30 min for a 2-year period between 30 January 1992 and 31 January 1994.

The selected area is characterised by a moderate climate with both maritime and continental influences. The annual average temperature is 9–10°C. Precipitation occurs all year round, culminating in summer storms, with annual precipitation totals of 700–1000 mm. In general, the area is ventilated well, with mean wind speeds ranging from about 2 m/s to 4 m/s. Apart from north-south-oriented valleys, the main wind directions are west and east.

The city of Wels in Upper Austria is a regional shopping and business centre of about 50 000 inhabitants. The annual mean temperature at Wels is 9.7°C, the temperature range (2-year period) is from –14.9°C to 35.3°C. The annual precipitation amounts to 838 mm (mean for the period 1961–1990).

Model to calculate the indoor climate and the volume flow of the livestock building

The thermal situation inside a mechanically ventilated livestock building is calculated from a balance equation for the sensible heat (Schauberger 1988b; CIGR 1984; Albright 1990). On the basis of the following equations (Eq. 1–6), which refer to one animal place, 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 for sensible heat (Eq. 1) consists of three terms:

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

relating the sensible heat release of one animal, S_A, the gain or loss of sensible heat caused by the transmission through the building, S_B, and the sensible heat flow associated with 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 ($m^{0.75}$), and the relative portion, f_s, of the total energy release that appears as sensible heat is 0.6 (Pedersen et al. 1998). The evaporation on wet surfaces (manure, feed, condensation) is accounted for a correction factor, k_s, with a constant value of 0.95 (CIGR 1984). Thus,

$$S_A=Q_A \cdot f_s \cdot k_s \qquad (2)$$

The diurnal variation of the total heat production is taken into account by a sinusoidal function proposed by Pedersen and Takai (1997) on the basis of the variation of the animal activity over the time of day, t with a period τ=24 h. The amplitude for finishing pigs is assumed to be ±45% of the daily mean value (Pedersen and Rom 1998) and their minimum animal activity can be observed around 1.15 a.m, local time (Pedersen 1996; Pedersen and Takai 1997). Therefore,

$$Q_A(t)=Q_A\left\{1+0.45\sin\left[\frac{2\pi}{\tau}\cdot(t-7.25)\right]\right\} \qquad (3)$$

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) (Owen 1994).

$$S_B=U\,A\,(T_o-T_i) \qquad (4)$$

The sensible heat flow due to the ventilation system, S_V, is calculated by the volume flow V (m^3/s), the heat capacity c (J kg^{-1} K^{-1}), air density ρ (kg/m^3) and the temperature difference between outdoor (T_o) and indoor air (T_i):

$$S_V=V\,c\,\rho\,(T_o-T_i) \qquad (5)$$

The ventilation systems of 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. Idealised characteristics of the ventilation system control unit are shown in Fig. 1. Two parameters, the set-point temperature, T_C, and bandwidth (P band), ΔT_C, describe the course of the volume flow depending on the indoor air temperature, T_i, as a control value (e.g. Bruce 1999; MWPS-32 1990). For an indoor air temperature less than the set-point temperature, the minimum volume flow is supplied. In the range of the P band 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 6 gives the volume flow, V, as a function of the indoor air temperature, T_i.

$$V(T_i)=\begin{cases} V_{min} & \text{for } T_i \le T_c \\ V_{min}+(T_i-T_c)\cdot\dfrac{V_{max}-V_{min}}{\Delta T_c} & \text{for } T_c < T_i \le T_c+\Delta T_c \\ V_{max} & \text{for } T_i > T_c+\Delta T_c \end{cases} \qquad (6)$$

The minimum volume flow, V_{min}, for the winter period is calculated on the basis of the air-quality requirements of the animals. The calculation is mainly based on the CO_2 release of the animals, proportional to the total heat production and the maximum accepted CO_2 concentration inside the livestock building (between 2.0 l/m^3 and 3.5 l/m^3). The maximum volume flow, V_{max}, for the summer period is calculated by the sensible heat production and the accepted temperature difference between the indoors and outdoors to minimise heat stress. The accepted temperature difference is between 2 K and 4 K (CIGR 1984).

The latent heat balance (L) and the CO_2 mass balance (C) are calculated by taking into account the moisture and CO_2 release of the animals and the transport due to the ventilation system:

$$L_A+L_B+L_V=0 \qquad (7)$$

$$C_A+C_B+C_V=0 \qquad (8)$$

The term, describing the transport through the building shell L_B and C_B, can be neglected. The latent heat L_A released by the animals is the difference between the total heat production, Q_A (Eq. 3, CIGR 1984) and the sensible heat release, S_A (Eq. 2). The transport by the ventilations system is given by

$$L_V=V\,\rho\,(x_o-x_i) \qquad (9)$$

combining the volume flow V (m^3/s), the air density ρ (kg/m^3) and the difference of the humidity ratio (kg/kg) between outdoor, x_o, and indoor air, x_i.

The CO_2 release by the animals and the manure storage, C_A, is calculated via the total heat production, Q_A (Eq. 3, CIGR 1984) and the caloric equivalent of k_c=0.185 l h^{-1} W^{-1} (Pedersen and Takai 1997; Schauberger and Pilati 1998a and 1998b; CIGR 1994; Pedersen et al. 1998).

$$C_A=k_c\,Q_A \qquad (10)$$

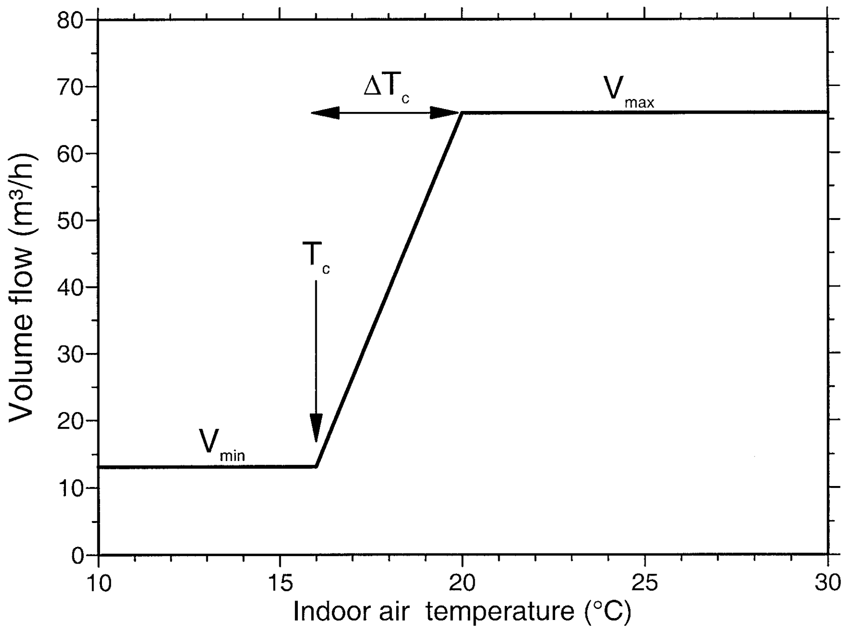


Fig. 1 Characteristics of the control unit of the ventilation system. The volume flow per animal place (finishing pigs) is a function (Eq. 6) of the indoor air temperature T_i as control parameter. The control unit has two parameters: set-point temperature T_c and bandwidth of the control unit ΔT_C (P band)

Table 1 System parameters of the indoor climate (model calculation) for one animal place. The parameters are representative for a unit of 1000 finishing pigs

Parameter	
Mean total energy release, Q_A, of an animal with a body mass of 60 kg (continuous finishing between 30 kg and 100 kg body mass)	188 W
Minimum volume flow, V_{min}, calculated by the maximum accepted indoor CO_2 concentration of 3 l/m^3	13.1 m^3/h
Maximum volume flow, V_{max}, calculated by the maximum temperature difference between indoors and outdoors in 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
Mean thermal transmission coefficient U weighted by the area of the construction elements (wall, ceiling, door, window)	1.5 W m^{-2} K^{-1}
Thermal transmission coefficient, U, of the construction elements:	
Wall	0.70 W m^{-2} K^{-1}
Ceiling	1.50 W m^{-2} K^{-1}
Door	3.00 W m^{-2} K^{-1}
Window	5.00 W m^{-2} K^{-1}
Set point temperature of the control unit, T_C	16°C
Bandwidth of the control unit, ΔT_C	4 K

The CO_2 volume flow of the ventilation system is given by

$$C_V=V\,(C_o-C_i) \quad (11)$$

with the volume flow V (m^3/s), and the difference of the CO_2 concentration (l/m^3) between outdoor c_o and indoor air c_i.

The system parameters per animal place for a pig finishing unit with the chosen specifications are summarised in Table 1.

Odour release from the livestock building

The odour release from the livestock building originates from the animals, polluted surfaces and the feed. Outdoor odour sources like 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 (OU/s) and the specific odour flow e (OU s^{-1} LU^{-1}) normalised by the livestock unit (LU) equivalent to 500 kg live mass. The specific odour flow e (OU s^{-1} LU^{-1}) depends on the kind of animals and how they are kept. Available data are summarised by a literature review by Martinec et al (1998). For the model calculation presented here, a mean specific odour flow, e_m, of 100 OU s^{-1} LU^{-1} and a mean live mass of 60 kg/finishing pig (m=0.12 LU) are assumed.

As odour production is a biochemical process, the temperature has an important influence on the odour release of the various sources. Most authors select the outdoor air temperature, T_o, instead of the more appropriate indoor temperature, because they were interested in the odour emission and not the odour release inside the livestock building (Oldenburg 1989; Kowalewsky 1981). The linear regression of Oldenburg (1989) was adapted to calculate the change of the daily mean odour flow, E_m, by Eq. 12 as a function of the outdoor air temperature, T_o.

$$E(T_o)=E_m\cdot(0.905+0.0095\,T_o) \quad (12)$$

For the model calculation no diurnal variation of the odour release was assumed.

The odour concentration inside the livestock building depends on the odour release and the volume flow of the ventilation system, under the assumption that the odoriphores inside the live-

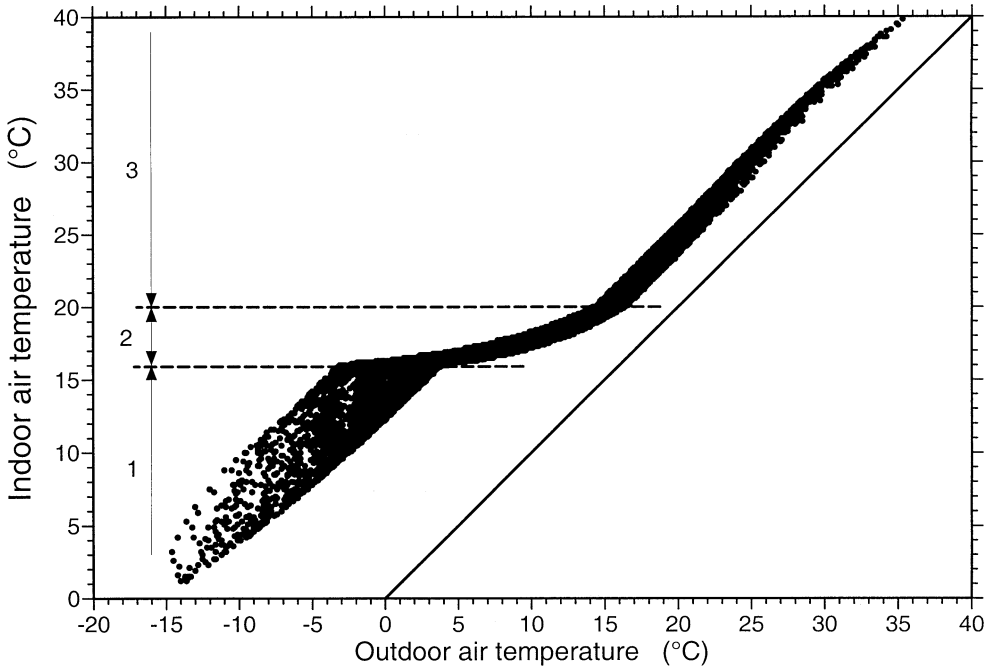


Fig. 2 Indoor air temperature in relation to the outdoor temperature of the livestock building calculated for each 30-min meteorological data sample for the system parameters of Table 1. The data set can be divided into three parts, indicated by arrows: *1* indoor air temperature below the set-point temperature T_C of the control unit, *2* the controllable range, *3* indoor air temperature above $T_C+\Delta T_C$

stock building are homogeneously mixed by the volume flow of the ventilation system. The concentration is calculated by the odour flow *E* (OU/s) divided by the volume flow *V* of the ventilation system (m^3/s) as seen in Eq. 13.

$$c_{OD} = \frac{E}{V} \quad (13)$$

Comparison of model calculations with recommended values for the indoor climate

The model calculations were done for each meteorological data sample (i.e. every 30 min) and evaluated against the hygrothermal environment and air quality recommendations for animals. The boundaries of the optimum range of air temperature and humidity were selected as follows: 16°C and 20°C, 50% and 70% (e.g. ASHRAE 1997; DIN 18910 1992; CIGR 1984; MWPS-32 1990). The deviation, as a percentage of the time, were developed as a 3×3 matrix of conditions with the optimum area in the centre.

The air quality inside the livestock building was evaluated by the CO_2 and the odour concentration. Levels used for CO_2 were (MWPS-32 1990; CIGR 1994, 1984; Wathes 1994): good air quality below 2 l/m^3, i.e. about seven times the normal atmospheric concentration of 0.35 l/m^3; acceptable air quality of 2–3 l/m^3; bad air quality above 3 l/m^3. The threshold limit value for workspace for humans (8 h/day instead of 24 h/day) is 5 l/m^3 (ACGIH 1991).

To evaluate the air quality in terms of the odour, the relationship between odour concentration, c_{OD}, and intensity of odour sensation *I* was used according to Misselbrook et al. (1993) and based on the Weber-Fechner law that the response is proportional to the logarithm of the stimulus. The following scale was used: 0 no odour, 1 very faint, 2 faint, 3 distinct, 4 strong, 5 very strong, 6 extremely strong).

$$I=0.45+1.61 \log_{10} c_{OD} \quad (14)$$

The occurrence of condensation because of insufficient insulation of the building and/or high indoor humidity levels was used to assess the amount of wet surfaces. For four types of construction elements (*U* value of walls, ceiling, windows and doors) the surface temperature was calculated. If the dew-point temperature of the indoor air is below these values, condensation is assumed.

Results

The thermal situation of the livestock building on the basis of the modelled indoor temperature was evaluated as a function of the outdoor temperature (Fig. 2). Three subsets can be distinguished on the basis of the indoor air temperature (1) Below an indoor temperature that is the set point (T_C) of the control unit, the indoor temperature cannot be controlled by the ventilation system because the minimum volume flow has to fulfil the requirements of the air-quality needs of the animals. The change of the indoor temperature is then proportional to the change of the outdoor temperature as a result of the constant volume flow V_{min} (2) In the relatively small temperature range between T_C and $T_C+\Delta T_C$, the indoor temperature can be influenced by the ventilation system by changing the volume flow (3) Above $T_C+\Delta T_C$, the change of the indoor temperature is again proportional to the change of the outdoor temperature caused by a constant volume flow (V_{max}). The volume flows for the three ranges are defined by Eq. 6.

The change from outdoor to indoor air conditions is shown as a psychrometric chart (e.g. Albright 1990) in Fig. 3. For an increment of 2 K and 1 g/kg the vectors give the change of the temperature and humidity ratio. For low outdoor temperatures the end-points of the vectors were below the saturation curve (10.5% of the time), which means that inside the animal house the relative humidity is 100% and the surplus of moisture is reduced by condensation.

The deviation from the optimum hygro-thermal environment was assessed by a 3×3 matrix of the duration of deviation (Table 2); 16% of the year falls into the central section with optimum temperature and humidity for the animals, 27% of the time it is too hot and about 17% of the time it is too cold. During the cold period all observations show a relative humidity above the optimum range.

Wet surfaces are one of the main problems during middle-latitude cold periods inside livestock buildings. The evaporation process can be assumed to be adiabatic (Schauberger and Pilati 1998a and 1998b; Pedersen et al. 1998). Evaporation can be interpreted as a sink of sensible heat and a source of latent heat. Therefore the assessment of the amount of wet surfaces to be expected inside the livestock building is a useful tool to evaluate this effect (Table 3 and Fig. 4). The condensation occurring is calculated from the inside surface temperature and the dew-point temperature. For 52.5% of the time, no condensation takes place; for 16.2% of the time, all surfaces are wet. A big contribution to wet surfaces is made by the ceiling, comprising 74% of the inside surface for 22.8% of the time. This is a typical situation resulting from the lower insulation of concrete ceiling constructions without additional thermal insulation (U=1.5 W m^{-2} K^{-1} of the ceiling compared to 0.7 W m^{-2} K^{-1} of the walls, see Table 1). The development of the condensation over time can be seen in Fig. 4.

The air quality is evaluated by the odour and CO_2 concentration. In Fig. 5 the correlation between the volume flow of the ventilation system and the two concen-

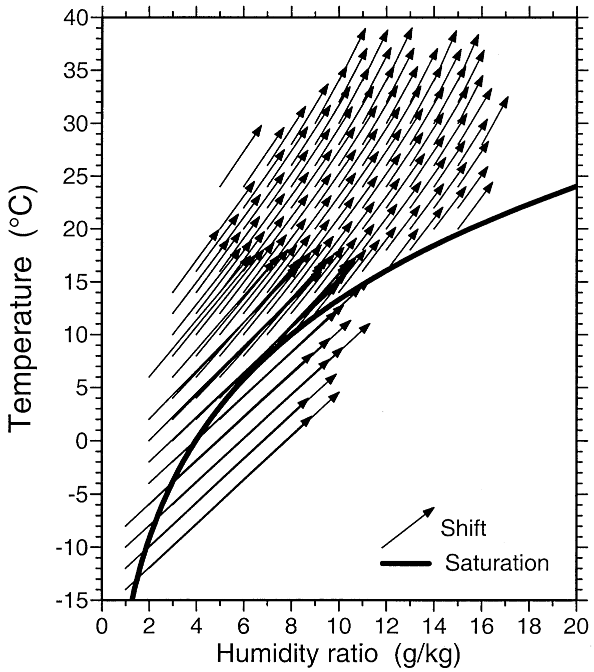


Fig. 3 Psychrometric chart of the indoor and outdoor air conditions. The vectors show the change of air temperature and humidity ratio due to the livestock, the building and the ventilation system. Tail of the vector: outside situation, head: indoor. For the heads of the vectors below the saturation curve a relative humidity of 100% and condensation of the surplus of humidity is assumed

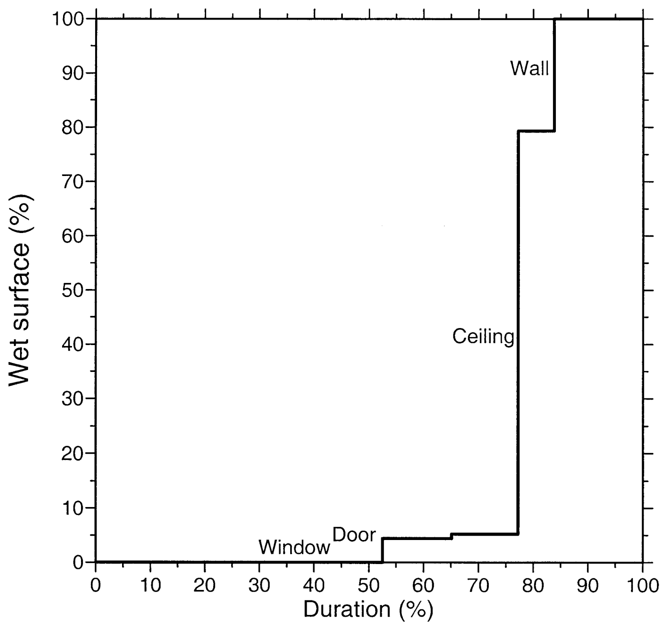


Fig. 4 Portion of wet surfaces of the inside areas of the livestock building as a function of the duration (%) of condensation. The wetted surface areas of the building elements are summarised in Table 3

Table 2 Duration (%) of the deviation from the optimum hygro-thermal parameters for finishing pigs (temperature range 16–20°C; relative humidity, F_i, 50%–70%) calculated for the input parameters in Table 1

Indoor temperature (T_i)	Duration of the conditoins (%)			
	F_i<50%	50%≤F_i≤70%	F_i>70%	Sum
T_i>20°C	12.6	10.5	3.9	27.0
16°C≤T_i<20°C	1.4	16.0	39.0	57.4
T_i<16°C	0	0	16.6	16.6
Sum	14.0	26.5	59.5	100

Table 3 Duration (%) of condensation at the inside surfaces of wall, ceiling, window and door. The areas of construction elements are calculated for a finishing unit with 1000 animal places (see also Table 1)

Construction element	U (W m^{-2} K^{-1})	Duration (%)	Area (m^2)
Window	5.00	12.6	60
Window and door	3.00	12.1	70
Window, door, and ceiling	1.50	6.6	1070
Window, door, ceiling, and wall	0.70	16.2	1350

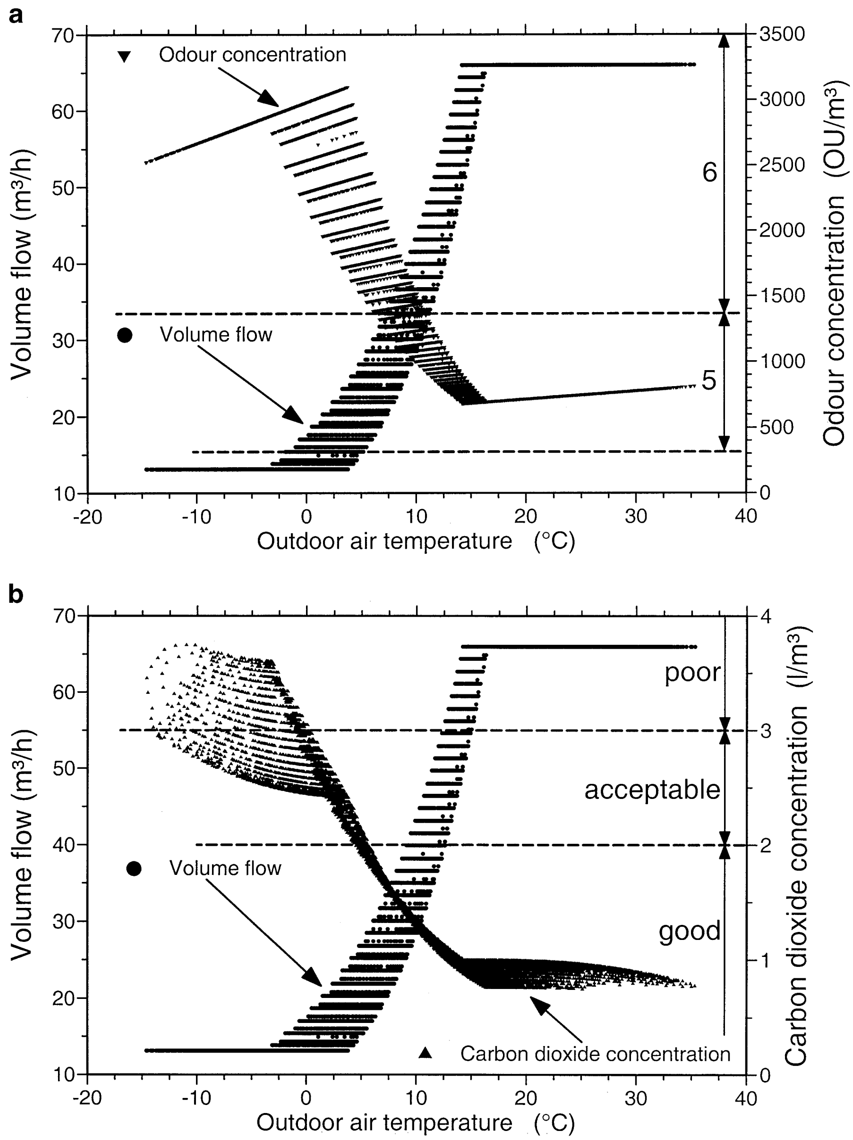


Fig. 5a, b Volume flow and odour concentration (*a*) and volume flow and carbon dioxide concentration (*b*) as a function of outdoor temperature

trations is shown as a function of the outdoor temperature. The contrary trend of the volume flow and the concentration demonstrates the importance of the ventilation system and its control unit, defined by the design values (Table 1). The model calculation indicates that there is odour with an intensity of 5 for 52% of the time (very strong) and of 6 (extremely strong) for 47% of the time. The CO_2 concentration shows good air quality for 66% of the time (below 2.0 l/m^3), acceptable for 29% and poor air quality (above 3.0 l/m^3) for 5% of the time.

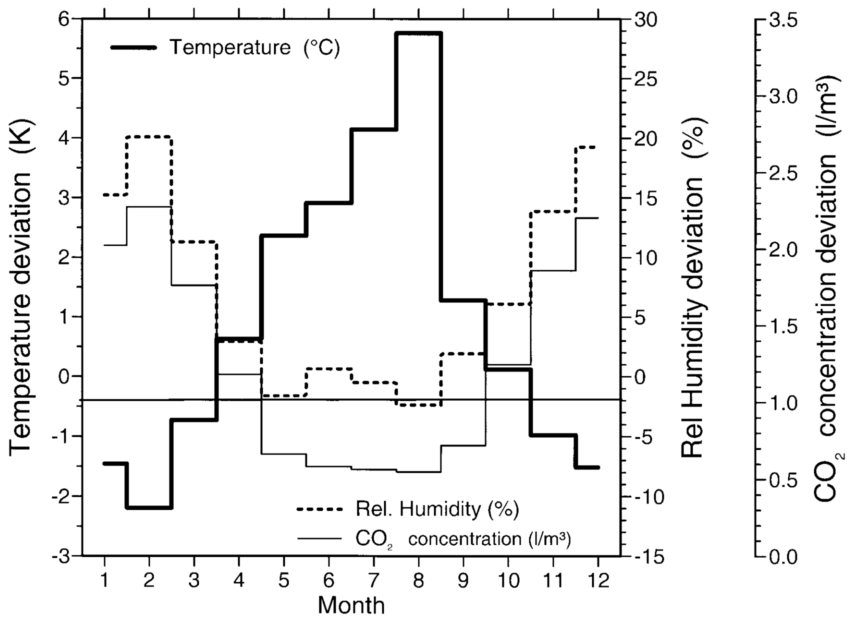
In Fig. 6 the monthly means of the deviation from the optimum temperature (between 16°C and 20°C), the relative humidity (between 50% and 70%) and the outdoor CO_2 concentration of 0.35 l/m^3 are shown. The yearly course shows that the incidence of deviations from the optimum coincide. During winter time, indoor air temperatures that are too low accompany excessive humidity and high CO_2 concentrations. During the summer months, the problem of excessive temperatures dominates the other deviations.

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 ventilation conditions prevail throughout the year. Situations that can give rise to enhanced concentrations of pollutants, like calm conditions, low-base temperature inversions or periodically changing wind regimes are not as frequently observed in these areas as in inner-Alpine valleys or in the basins south of the Alps. The results achieved here are applicable to all areas, especially in Central and Eastern Europe, that experience similar average temperatures and ventilation conditions, like large portions of Bavaria, Hungary or Poland (Schauberger et al. 1999)

The model presented here describes mechanically ventilated livestock buildings. In Austria about 20% of cattle houses and 39% of pig houses (63% of finishing

Fig. 6 Monthly means of the deviation from optimum temperature (between 16°C and 20°C), relative humidity (between 50% and 70%) and outdoor CO_2 concentration of 0.35 l/m^3



units) are mechanically ventilated (Schauberger et al. 1993). The models are especially appropriate for pigs and poultry, (which are mostly housed in environmentally controlled buildings) to investigate the system behaviour of the indoor climate. Whereas sheep and cattle are often housed in naturally ventilated buildings (e.g. Cooper et al. 1998), in which the volume flow is caused by buoyancy and wind pressure (van't Klooster 1994).

The steady-state balance model used has been validated for a wide range of input parameters, like the livestock, the insulation of the building, and the ventilation system, by comparing measurements of the indoor climate with model calculations. For beef cattle, Schauberger and Pilati (1998a and 1998b) propose the following improvements: (1) diurnal variation of the total heat release due to the animal activity and (2) taking account of the evaporation from wet surfaces by a temperature-dependent factor, k_s, describing the portion of sensible heat used to transfer liquid water into the gaseous phase. Pedersen et al. (1998) have done the validation for cattle, pigs and poultry. Their modifications of the basic equations given in CIGR (1984) are used here to improve the balance model especially for the portion of the total heat that appears as latent heat. The constant value f_s=0.61 obtained by Pedersen et al. (1998) for the portion of the total energy release of the animals that is sensible heat is in good agreement with the rationale of Webster (1994) that pigs and poultry have only limited ability to lose heat by evaporation at elevated air temperature.

Nevertheless, the assessment of evaporation from wet surfaces is important for the energy balance of livestock buildings (Økland 1980; Albright 1990; Mothes 1973; Kapuinen 1993; Schauberger and Pilati 1998a and 1998b; Zappavigna and Liberati 1997). A principle problem is that transpiration by animals (f_s in Eq. 2) can not be separated from the evaporation of wet surfaces (k_s in Eq. 2) by measuring the different heat fluxes of a livestock building at the housing level. Whether it is appropriate to improve the model by a modification of the latent heat loss by the factor f_s (proposed by Pedersen et al. 1998) or by evaporation through the factor k_s is still an open question.

The temporal behaviour of livestock buildings can be described as steady-state. The storage capability of the system, mainly the walls and ceiling, can be neglected because the sensible heat flux due to the ventilation system dominates. Schauberger and Pilati (1998a and 1998b) found a time lag between indoor and outdoor temperature of about 60 min during summer time (high ventilation rate) and 80 min during winter time (low ventilation rate). By introducing the diurnal variation of the animals, causing a variation in energy and CO_2 release (Eqs. 3, 11), the model can be used on an hourly basis and not only on a daily basis (Pedersen and Takai 1997; Pedersen and Rom 1998; van Ouwerkerk and Pedersen 1994). Since this increases the temporal resolution of the outdoor parameters (air temperature and humidity), 30 min mean values were used over a 2-year period in the current analyses instead of a two-dimensional frequency distribution of temperature and humidity (Schauberger 1988) or simple design values for these parameters (Albright 1990; CIGR 1984).

The presentation of the results is a simple assessment of the indoor air quality with respect to animals and farmers. The thermal coupling between the outdoor and the indoor temperature is shown in the same way as Baxter (1984) proposed in his biolclimatic charts. Using such charts, the behaviour of the control unit can be assessed for diagnostic purposes in the field of herd health control (Schauberger et al. 1995).

Odour is a relevant parameter of indoor air quality for stockmen and farmers as well as an airborne emission in the vicinity of livestock buildings. The potential effects of odour on health are discussed by Schiffman (1998).

Skinner et al. (1997) report that about a quarter of the complaints received by the Environmental Health Officers in the United Kingdom are related to odour. Inside the livestock building, the odour intensity is projected to be level 5 (very strong) or 6 (extremely strong) all the time. Such high levels have to be judged by the fact that the relation of Misselbrook (1993) in Eq. 14 was devided for outdoor odour concentrations, where normally the expected concentration is close to zero.

Such high concentrations could have effects on health, as described by Schiffman et al. (1995), ranging from respiratory problems to nausea, fatigue, headaches and plugged ears as well as psychological symptoms.

The indoor carbon dioxide concentration is mainly selected as a key parameter to evaluate the indoor air quality in relation to animals (CIGR 1994). Therefore the maximum concentration of 3 l/m^3 is used as a criterion for poor air quality instead of 5 l/m^3 as the threshold for a human workspace (Fig. 5).

For design purposes, studies of the sensitivity of various system parameters (see also Table 1) are helpful. Schauberger (1988b) used a static model for animal density, insulation of the livestock building, and the ventilation rate. Model calculations are also a useful tool for decisions on herd management. By comparing model calculations with measurements of the thermal environment inside animal buildings over longer times (e.g. a 4-month finishing period for pigs), the design values of the ventilation system, the quality of the control unit and the influence of livestock management (e.g. feeding time) can be investigated (Schauberger et al. 1995).

Future work is needed to include further air pollution components like NH_3, dust and micro-organisms in the model, which are important to describe the risks to the health of animals and farmers (e.g. CIGR 1994; Robertsen et al. 1990).

Besides the indoor climate, the emission characteristics of livestock buildings can be described by such a model. In addition to gases like CO_2, NH_3 and N_2O, the emission of airborne micro-organisms and odour are relevant to livestock production. Grant et al. (1994) and Wathes (1994) reported on the susceptibility herds to various diseases, and their infection, caused by airborne micro-organisms. In many cases, the odour concentration of the outlet air is assumed to be static over the whole year. Schauberger et al. (1999) calculated the temporal course of odour emission to improve model calculations using a more realistic scenario.

The dispersion of such substances can be described by well-known dispersion models, like the Gaussian one. To apply dispersion models to airborne emissions, the concentration of the substance and the volume flow of the outlet air have to be known (Schauberger et al. 1999).

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