

Dynamic model of the indoor climate inside livestock buildings: A case study for fattening pigs

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ABSTRACT

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 CO₂ 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 livestock buildings whose ventilation systems are mechanically controlled (this is the case for a majority of pig fattening units), the calculations were done for a pig fattening unit with 1000 animal places. The model presented needs half-hour values of the outdoor parameters temperature and humidity, here collected for a two-year period, as input. The environment inside the livestock building is evaluated according to a comparison with recommended values for animals. Further, the duration of condensation of the inside surfaces is calculated. The sensitivity of the model is investigated by varying the livestock, the insulation and the ventilation system of the livestock building with the control unit.

KEYWORDS: pig, indoor climate, simulation, livestock building

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. The livestock building should provide an adequate physical environment for the animals. 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 hand. 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, 1972; Baxter, 1984; Pedersen et al., 1998). During winter time, when the recommended thermal conditions have to be archived due to restrictions of the ventilation rate, air quality is in the centre of interest. During summer time, an 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 a covering of essential needs of the animals and to optimise the indoor climate to increase animal performance. Furthermore, this can also be seen as a contribution to reduce 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 (Schaubberger and Pilati, 1998a and 1998b) e.g. for the purpose of designing the ventilation system and the renovation of existing

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livestock buildings. Secondly, the models are used in a diagnostic mode. In this case measured values of the indoor climate are compared with model calculations. Such methods can be used as a part of herd control (Schauberger et al., 1995) as well as to check the design values of the ventilation system and its control unit (CIGR, 1984). The goal of this paper is the application of a model to assess the indoor climate (hygro-thermal parameters, air quality - CO₂, odour) on the basis of half-hourly values. The result is discussed for a 1000 head pig fattening unit.

MATERIALS AND METHODS

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. The data are collected at Wels, a site representative for the Austrian flatlands north of the Alps. The sample interval is 30 minutes for a two-year period between January 30, 1992 and January 31, 1994.

The thermal situation inside a mechanically ventilated livestock building is calculated via a balance equation of the sensible heat (Albright, 1990; CIGR, 1984; Schaubberger and Pilati 1998a, Schaubberger et al 1999a). On the basis of the following equation 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 of sensible heat (Eq. 1) consists of three terms:

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

with the sensible heat release of the animals 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 ventilation systems of livestock buildings are mainly designed as temperature-controlled variable volume flow systems. The control unit uses the indoor air temperature as control value. The supply voltage of the fans and therefore the resulting volume flow is the output of the control unit. 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 (Schauberger et al., 1999a).

The minimum volume flow V_{\min} for the winter period is calculated on the basis of the requirements of the animals concerning air quality. The calculation is mainly based on the CO₂ release of the animals, proportional to the total heat production and the maximum accepted CO₂ concentration inside the livestock building (between 2.0 l/m³ to 3.5 l/m³). The maximum volume flow V_{\max} for the summer period is calculated by the sensible heat production and the accepted temperature difference between indoor and outdoor to avoid heat stress. The accepted temperature difference is between 2 and 4 K (CIGR, 1984).

The latent heat balance (L) and the CO₂ mass balance (C) are calculated by taking into account the release of the animals and the transport due to the ventilation system:

$$L_A + L_B + L_V = 0 \quad (2)$$

$$C_A + C_B + C_V = 0 \quad (3)$$

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 (CIGR, 1984) and the sensible heat release S_A (Pedersen et al., 1998; Schaubberger and Pilati, 1998a and 1998b).

The odour release of 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 (OU/s) and the specific odour flow (OU/s LU) normalised by the livestock unit LU equivalent to 500 kg live mass. The specific odour flow (OU/s LU) 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 ($M = .12$ LU) are assumed. For the model calculation, no diurnal variation of the odour release was assumed (Schauberger et al., 1999b).

The model yields time series in the same temporal resolution as the input parameters of the model (outdoor air temperature, humidity, CO_2 concentration, and wind). Following indoor parameters were calculated: air temperature, humidity, CO_2 concentration, odour concentration, and dew point temperature of the inside surface of the building.

RESULTS

The thermal situation of the calculated livestock building is characterised by the indoor temperature as a function of the outdoor temperature (Fig. 1). Three subsets can be distinguished in relation to the indoor air temperature. (1) Below an indoor temperature of 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} . About 17% of the time the indoor temperature is lower than T_C . (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 (about 57% of the time). (3) Above $T_C + \Delta T_C$, the change of the indoor temperature is again proportional to the change of the outdoor temperature (27% of the time) caused by a constant volume flow (V_{\max}).

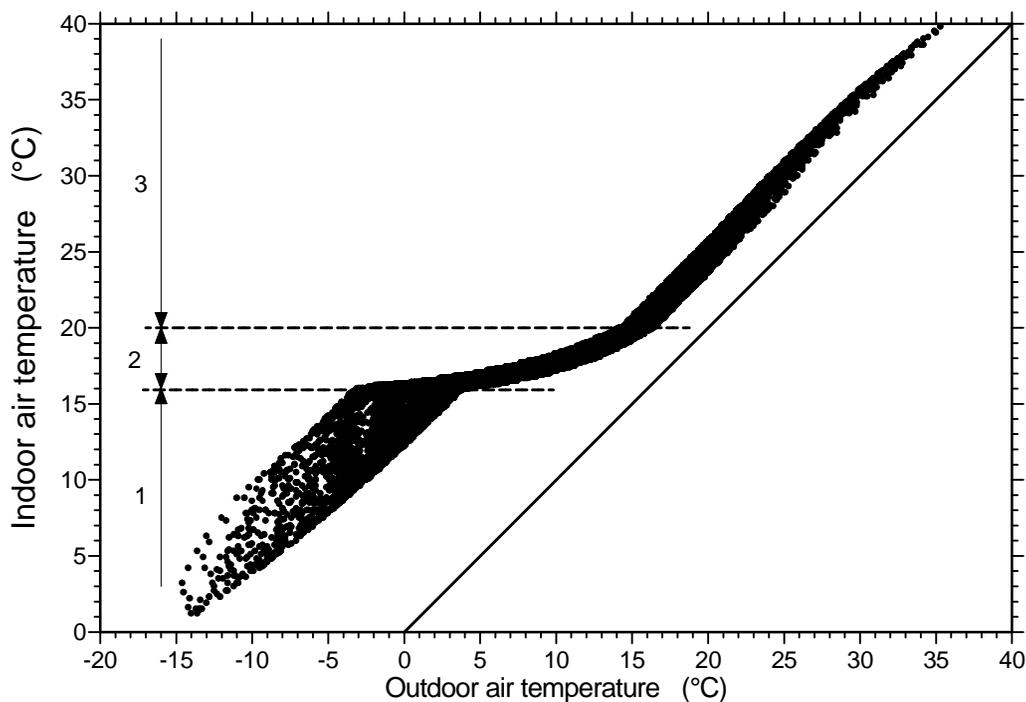


Figure 1. Indoor air temperature of the livestock building in relation to the outdoor temperature. The data set can be divided into three parts signed by arrows: (1) Indoor air temperature below the set point temperature T_C of the control unit, (2) the controllable range, and (3) indoor air temperature above $T_C + \Delta T_C$.

The change from outdoor to indoor air condition is shown as a psychrometric chart (1) in Fig. 2. For an increment of 2K and 1g/kg the vectors give the change of the temperature and humidity ratio. For low outdoor temperatures the endpoints of the vectors are below the saturation curve (10.5%), which means that inside the livestock building the relative humidity is 100% and the surplus of humidity is reduced by condensation.

Wet surfaces are one of the main problems during the cold period in the middle latitudes inside livestock buildings. The evaporation process can be assumed as adiabatic (Pedersen et al, 1998; Schauberger and Pilati, 1998a and 1998b). 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 inside the livestock building is a useful tool to evaluate this effect. The occurrence of condensation is calculated by the inside surface temperature and the dew point temperature. During 52.5% no condensation takes place, during 16.2% all surfaces are wet. A big contribution to wet surfaces is caused by the ceiling with 74% of the inside surface with a duration of 22.8%.

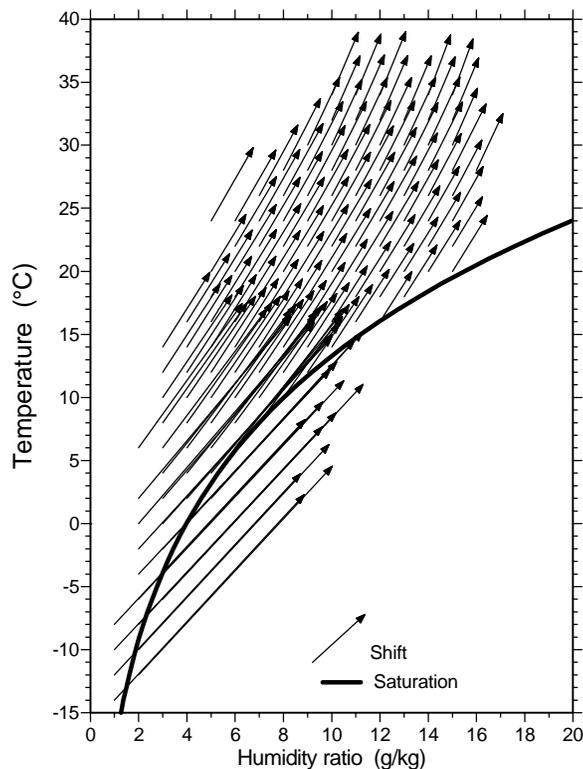


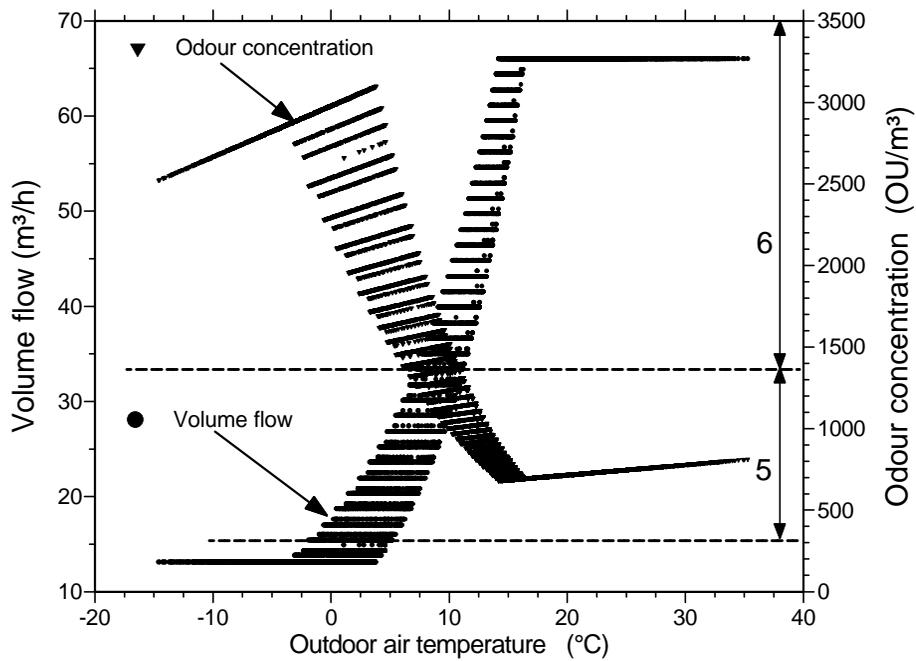
Figure 2. Psychrometric chart of the indoor and outdoor air condition. The vectors show the change of air temperature and humidity ratio due to the livestock, the building and the ventilation system. For the endpoints of the vectors below the saturation curve a relative humidity of 100% and condensation of the surplus of humidity is assumed (Schauberger et al., 1999a).

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

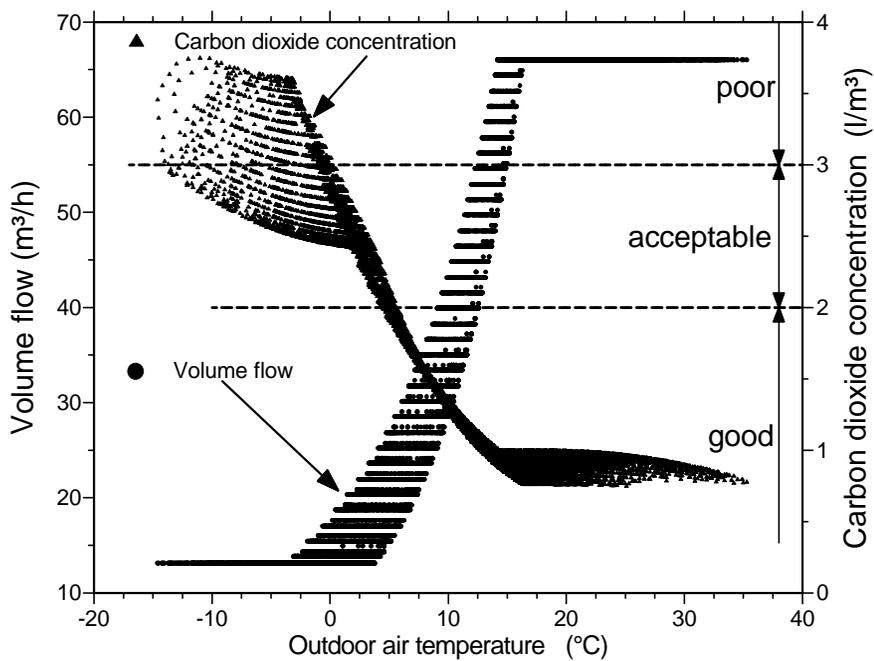
Construction element	U value (W/m ² K)	Duration (%)	Area (m ²)
Window	5.00	12.6	60
Window and door	3.00	12.1	70
Window, door, and ceiling	1.50	6.6	1070
Window, door, ceiling, and wall	.70	16.2	1350

The air quality is evaluated by the odour and CO₂ concentration. In Fig. 3 the correlation between the volume flow of the ventilation system and the two concentrations is shown as a function of the outdoor temperature. The contrary trend of the volume flow and the concentration

points out the importance of the ventilation system and its control unit, defined by the design values. The model calculation yields an odour duration of 52% of the time with an intensity of 5 (very strong) and 47% of 6 (extremely strong). The CO₂ concentration shows 66% of good air quality (below 2.0 l/m³), 29% acceptable and 5% poor air quality (above 3.0 l/m³).



a



b

Figure 3. Volume flow and odour concentration (a) and volume flow and carbon dioxide concentration (b) as a function of outdoor temperature. Odour and CO₂ concentration are used to classify the indoor air quality (odour intensity: 5 very strong 53%, 6 extremely strong 47%; CO₂: good 66%, acceptable 29%, poor 5%) [limit values according to CIGR (1984), CIGR (1994), Wathes (1994), and Misselbrook (1993)].

DISCUSSION

The model presented here describes mechanically ventilated livestock buildings. In Austria about 20% of cattle houses and 39% of pig houses (63% of fattening units) are mechanically ventilated (Schauberger et al., 1993). Especially for pigs and poultry, which are mostly housed in environment-controlled buildings, appropriate models are necessary to investigate the system behaviour of the indoor climate, whereas sheep and cattle are often housed in naturally ventilated buildings, in which the volume flow is caused by buoyancy and wind pressure.

The validation of the steady-state balance model used is done for a wide range of input parameters like the livestock, the insulation of the building, and the ventilation system. For beef cattle, Schaubberger and Pilati (1998a and 1998b) propose the following improvements: (1) diurnal variation of the total heat release due to the animal activity, (2) the evaporation on wet surfaces by a temperature depending 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 modification of the basic equations given in CIGR (1984) are used here to improve the balance model especially for the portion of the total heat which appears as latent heat. The constant value of 61% of sensible heat of the total energy release of the animals by Pedersen et al. (1998) is in good agreement with Webster (1994) arguing that pigs and poultry have only limited feasibility to adapt to the sensible heat loss (sweating) with temperature.

Nevertheless, the assessment of the evaporation on wet surfaces is a big issue for the energy balance of the livestock building (CIGR, 1984; Schaubberger and Pilati, 1998b; Økland, 1980; Zappavigna and Liberati, 1997). A principal problem is the fact that transpiration by animals cannot be separated from the evaporation of wet surfaces by measurements of the different heat fluxes of a livestock building in housing level. Whether it is appropriate to improve the model by a modification of the latent heat loss of the animals (Pedersen et al., 1998) or by an additional term, describing evaporation, is still an open question.

Odour is a relevant pollution concerning the indoor air quality for stockmen and farmers as well as an airborne emission in the vicinity of livestock buildings. The potential health effects of odour are discussed by Schiffman (1998). For the UK, Skinner et al. (1997) report that about a quarter of the complaints received by the Environmental Health Officers are related to odour. Inside the livestock building, the odour intensity is in level 5 (very strong) or 6 (extremely strong) all the time. Such high concentrations could have health effects described by Schiffman et al. (1998) like respiratory problems to nausea, fatigue, headaches and plugged ears as well as psychological symptoms. Indoor carbon dioxide concentration is mainly selected as a key parameter to evaluate the indoor air quality in relation to animals (Schauberger et al., 1993), because the maximum concentration in workspace is 5 l/m³ compared with 3 l/m³ as criteria for poor air quality (Fig. 3).

For design purposes, sensitivity studies for various system parameters are helpful. Schaubberger (1988) used a static model for animal density, insulation of the livestock building, and the ventilation rate. Model calculations are also a useful tool for herd management decisions. By comparing model calculations with measurements of the thermal environment inside animal buildings over longer times (eg fattening period of pigs of about 3 months), the design values of the ventilation system, the quality of the control unit and the influence of livestock management (eg feeding time) can be investigated (Schauberger et al., 1995).

Besides the indoor climate, the emission characteristics of livestock buildings can be described by such a model. In addition to gases like CO₂, NH₃ and N₂O, 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. Schaubberger 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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