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VENTILATION AND EMISSION RATES IN LIVESTOCK STRUCTURES WITH SIDEWALL OPENINGS

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SUMMARY

In animal production natural ventilation with sidewall openings is preferred to poultry houses. The air movement in such so-called Louisiana-stables is influenced by the ratio of the windward and leeward openings and by the geometry of the room.

From the theorectical point of view the same volumetric flow is obtainable with different loads of airborne materials from animal houses. The objectives for automatic control should be extended to the environmental aspect of minimization of emissions by means of special ratios of inlet and outlet openings.

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INTRODUCTION

Agricultural buildings may be ventilated in different ways. Economic aspects are responsible for the use of animal houses ventilated by natural forces produced by wind and temperature differences.

This kind of ventilation is preferred to poultry houses as so-called Louisiana-stables. Natural ventilation is the eldest way of air movement. Louisiana-stables provide venti-

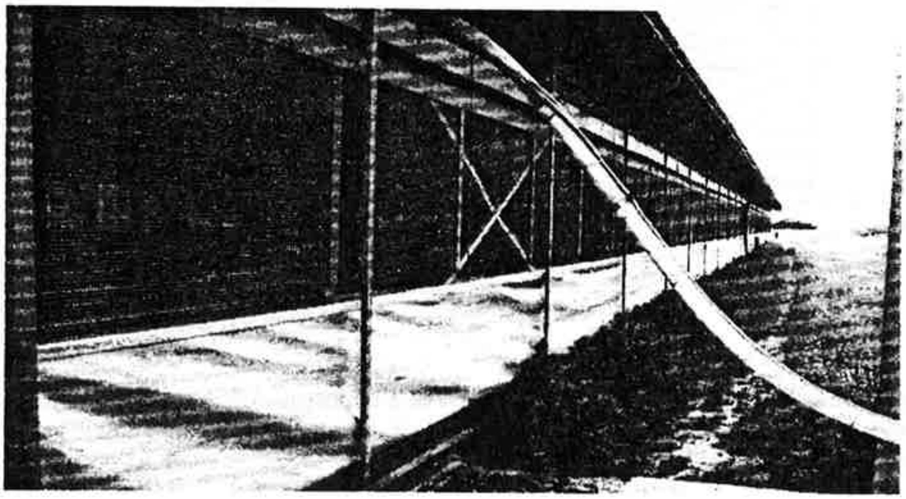

Fig. 1. Curtain wall of a so-called Louisian-stable. The maximum width of the opening amounts to 1 m. The length of the poultry house is 65 m.

lation openings by means of curtain walls. They are hinged a distance above ground. They open from the top down. Figure 1 shows the equipment for the curtain wall. During cold weather the incoming air is mixed with warm inside air before reaching the animals on the floor.

It is very difficult to measure the volumetric flow rate in real systems. Field studies around animal houses concern with odorant immissions. Simulating the frequency of odours perceptible in ambient air by means of dispersion models it is possible to determine the emissions indirectly. In order to determine the influence of special variations of the inlet and outlet conditions wind tunnel experiments - see reference [1] - and computer simulations are favoured. In the following we analyse and interpret some computer flow experiments with regard to their environmental importance[1].

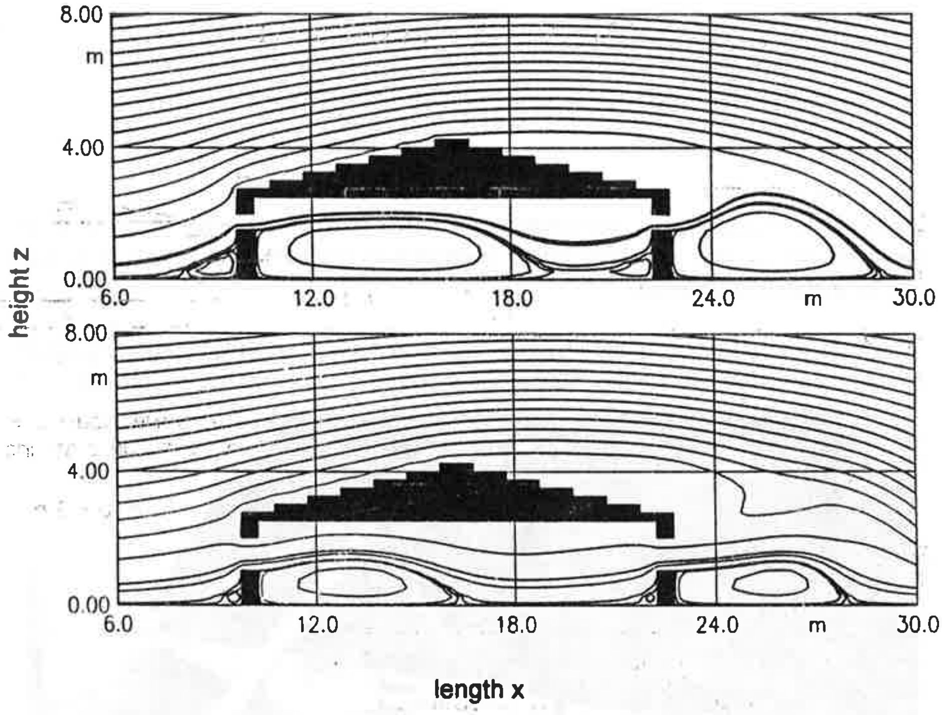

Fig. 2. Streamlines in the vertical cross section of a Louisiana-stable. In the upper part of this figure the inlet and outlet openings are half-open in contrast to the lower part. The scaling of the x-axis differs from the z-axis.

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1 I am very much obliged to Mr. Hake, Mr. Mack and Mr. Pardylla for their support.

OBJECTIVES

The minimization of odour, dust, ammonia and germ emission from animal houses is the main objective - without neglecting the animal welfare, see reference [5]. The flow and concentration field within and around the animal house is simulated by methods of computational fluid mechanics. The velocity field is the solution of the system of differential equations for the balances of mass and momentum. The system is solved by a finite difference technique, called Marker-and-Cell (MAC) computing method, see reference [7].

The wind flow over a Louisiana-stable causes a flow pattern in and around the animal building, see figure 2. The parabolic wind profile shows an horizontal component $u = 2$ m/s at $x = 0$ m in the height of $z = 10$ m. The streamlines show different recirculation zones in the animal house depending on the width of the opening.

The ratio of the velocity in the windward opening to the undisturbed flow is 0,66.

VOLUMETRIC FLOW RATES

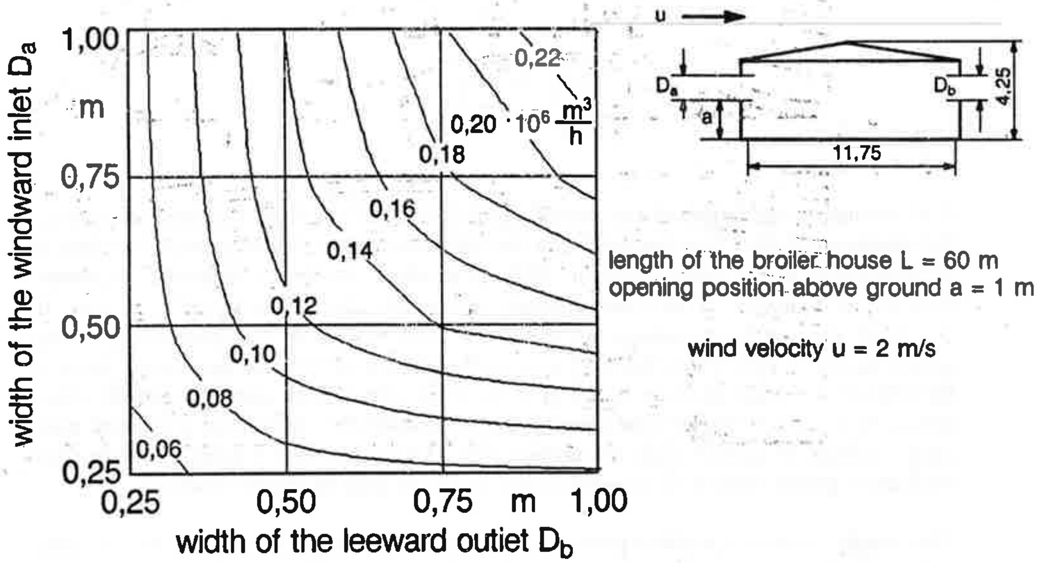

Fig. 3. Volumetric flow rate $\dot{V}_0$ depending on the windward (D_a) and leeward (D_b) openings.

The room of the volume V is supplied by fresh air through openings in the sidewall. According to the wind direction and wind speed natural ventilation of the room takes place.

In figure 3 the windward opening D_a is of reverse proportionality to the leeward opening D_b, at least in the region up to $D_b = 0.5$ for all D_a and up to $D_a = 0.5$ for all D_b. The flow chart is a result of interpolation between several simulation results for different ratios of windward and leeward openings.

The approach of stream thread theory to the air flow through buildings gives the following description of the volume rate, see reference [3]:

$$\dot{V}_0 = ab\, D_a L u \tag{1}$$

The dimensionless factor a refers to the pressure distribution around the building ($0 < k_b < 1$)

$$a = \sqrt{1 + k_b} \tag{2}$$

and the dimensionless factor b takes into consideration the flow resistance of the system:

$$b = \sqrt{\frac{1}{\left(\frac{D_a}{D_b}\right)^2 + \left(1 - \frac{D_a}{H}\right)^2 + \zeta}} \tag{3}$$

L characterizes the length of the animal house (60 m), H the height of the room and ς the resistance factor. It is assumed that the ridge direction of the livestock building is perpendicular to the wind direction. Without artifical ventilation support ς is greater than 0. For example: if the mean velocity in the windward opening of $D_a = 1$ m is $u = 2$ m/s the maximum volume rate may be $\dot{V}_0 = 432.000$ m^3/h. The inner height of the animal house is $H = 2.5$ m. Since k_b is in the magnitude of 0.5, we find for the factor a the relation $a = 1.22$. Because of the validity of the law of mass conservation the volumetric flow rate at the leeward opening can not exceed the rate in the windward opening - effects of compression are neglectable. That means that b must be lower than 0.82 and ς greater than 0.12. In practice the last value may be greater than 0.5.

This rough estimation predicts great volume rates of Louisiana-stables. We have to prove how the local areas within the livestock building are supplied with fresh air.

VENTILATION EFFICIENCY

For quantification of air distribution in rooms the age distribution theory is used. The volume of the animal room is nearly 1.800 m³. From this we can deduce a global renewal rate of $\dot{V}_0/V > 200\ h^{-1}$ with regard to the data mentioned above. The renewal rate in animal houses with forced ventilation is in the range of $20\ h^{-1}$.

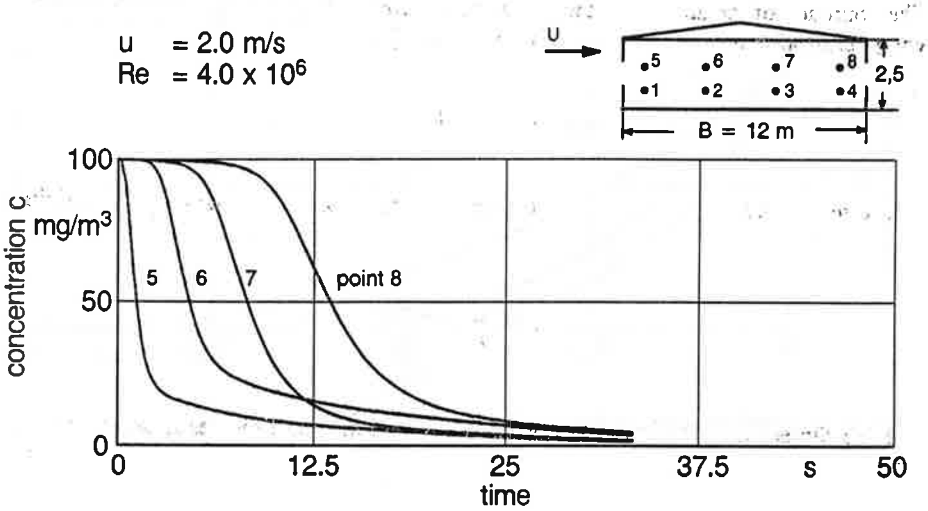

Fig. 4. Local concentration curves at points in the opening area.

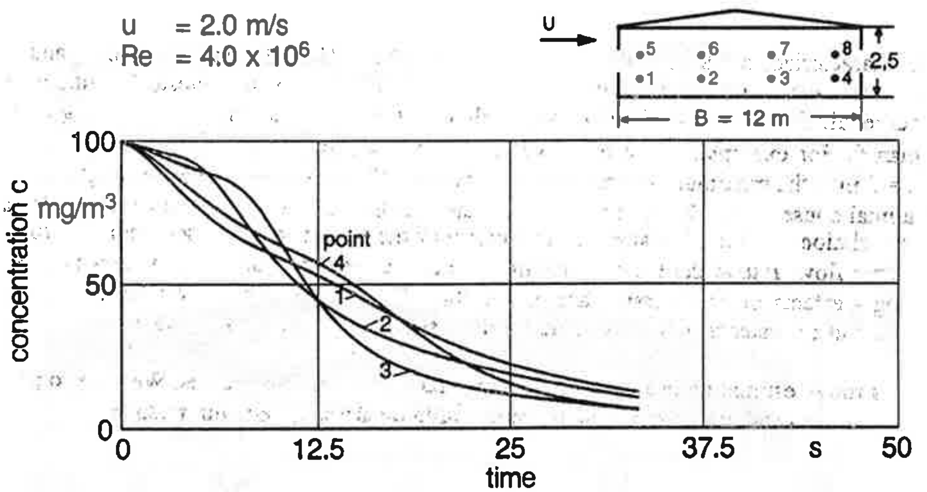

Fig. 5. Local concentration curves at points nearby floor.

Different contents of air are defined to characterize the air flow in a confined space, see reference [4]. We look at the tracer mass content of fluid elements at special points and at the total tracer mass content of all fluid elements of air within the room. The whole room is filled with a tracer gas. The gas concentration is 100 mg/m³; then at the time t = 0 the natural ventilation causes an extraction of the gas from the animal house.

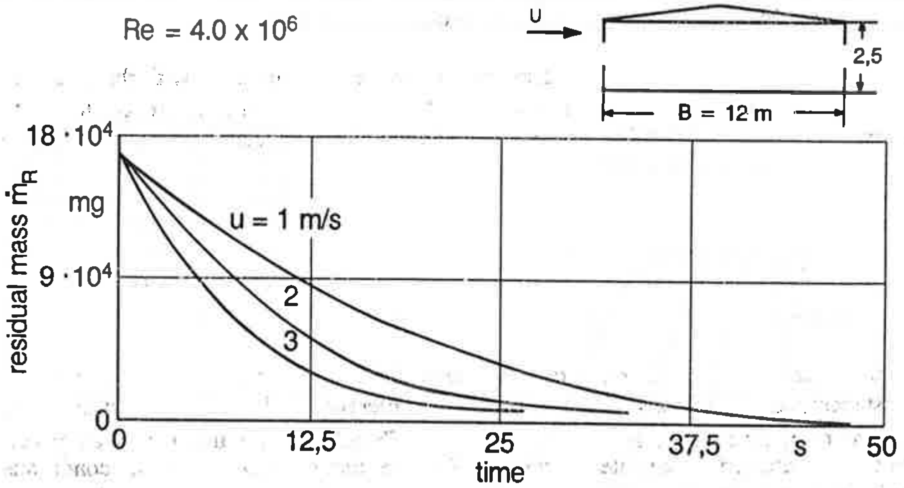

Fig. 6. Residual mass decay versus time.

In figure 4 and figure 5 the concentration decay with time differs from the area between the windward and leeward openings (point 5, 6, 7, 8) to the floor (point 1, 2, 3, 4). In

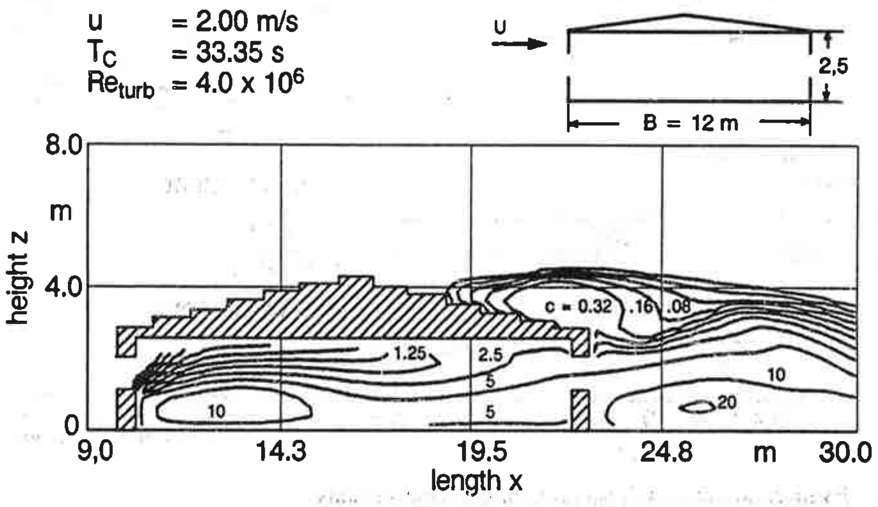

Fig. 7. Local concentration distribution for a residual mass of 5 % of the initial mass.

the first case the renewal rate is nearly 400 h^{-1}, in the second case 200 h^{-1}. The differences are small behind the windward opening and great nearby the leeward opening.

The total tracer mass content of contaminated air is shown in figure 6. The residual mass in the whole system is considered with respect to time for different wind velocities u. The renewal rate is 195 h^{-1} for u = 3 m/s.

A combination of local and time dependent concentrations is given with the results in figure 7. The residual mass is reduced to 5 % of the initial mass. The greatest concentrations are nearby the floor and in the recirculation zone behind the animal house.

CONCENTRATION OF AIRBORNE SUBSTANCES

At the floor within the animal house we have sources for internal emission of odour substances, dust, ammonia and germs, see reference [2]. The concentration of 100 mg/m³ is a fictive value for simulation only. There is straw at the floor to absorb all the manure and urine deposited in the pen. Poor ventilation results in humid conditions giving rise to the production of unpleasant smells, high levels of ammonia and poor animal health. This is known from controlled ventilation systems. But it is also known that the higher the outlet the greater the dilution factor by air movement.

In the following we assume that the mass transfer of the mentioned substances is proportional to the air velocity, see reference [6] and figure 8. The concentration nearby the floor is constant; figure 9 shows real conditions by growing animals and altering production of urine.

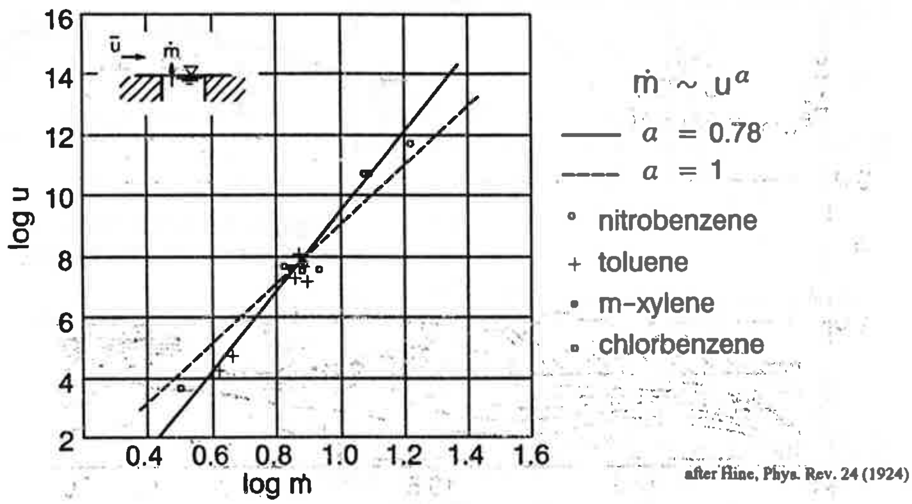

Fig. 8. Evaporation rate ṁ depending on the wind velocity u.

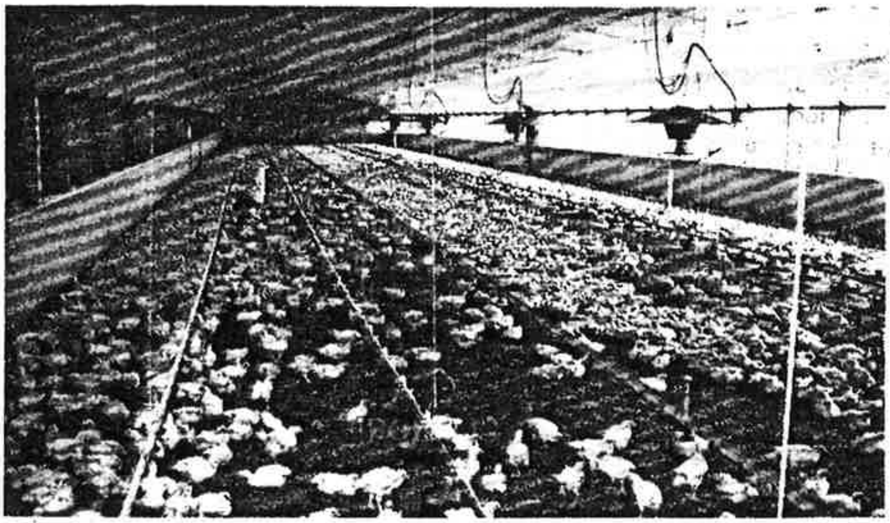

Fig. 9. Variable emission rate by the growing of the animals - variable inner sources.

EMISSION OF AIRBORNE SUBSTANCES

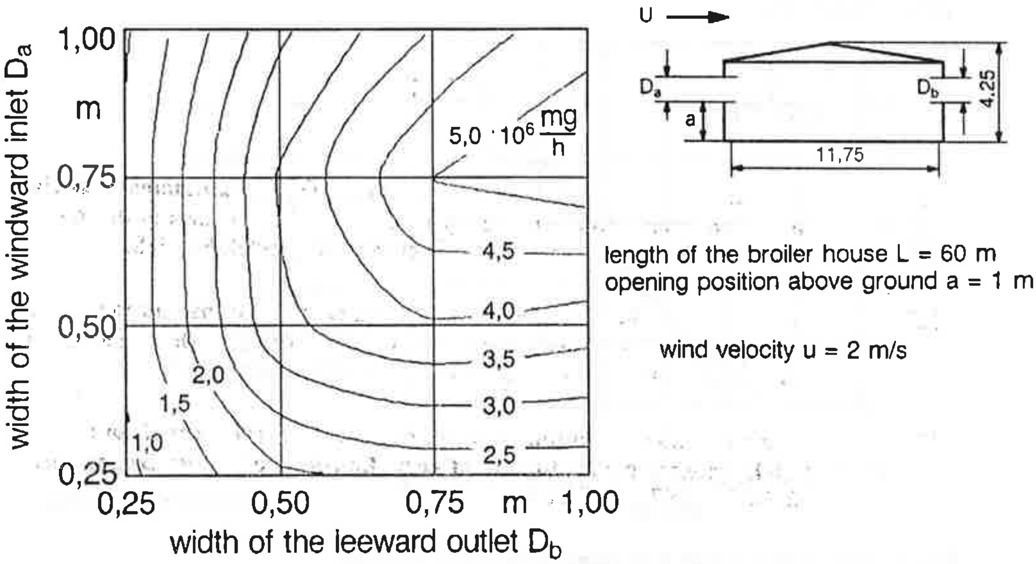

Fig. 10. Mass flow rate $\dot{m}_0$ depending on the windward (D_a) and leeward (D_b) openings.

The results of several simulations concerning the emission rate are given in figure 10. In contrast to the isolines of volume rate in figure 3 we have an ambiguous mass flow for great widths in the opening. From figure 3 it is known that special volume rates are produced for little windward openings in combination with great leeward openings and opposite holds true for little leeward openings with great windward openings.

Figure 10 shows that in general it is better to prefer constellations with great windward openings and small leeward openings than small windward openings with great leeward openings. There are several open questions, so the influence of the width of the cross section and the effect of temperature distribution on the inner sources.

CONCLUSION

In so-called Louisiana-stables an ammonia emission rate of 1 kg/h is possible. A reduction is always desirable.

Automatic control for natural ventilation systems is mainly based on temperature measurements. If a special volume rate is needed under given environmental conditions the curtains can be opened or closed.

The volume rate depends on the ratio of the windward and leeward openings. The higher the volume rate the higher the produced airborne materials. The emission of airborne material - like odour substances, ammonia, dust and germs - are to be controlled by inlet and outlet openings. This study is a first step for such a flow controlled system.

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