Effect of recirculated air on air speeds at animal level:
Commercial-scale swine barn tests

J.A. DEURLOO^1, J.J.R. FEDDES^1, J.J. LEONARD^1 and D.E. DARBY^2

^1Department of Agricultural Engineering, University of Alberta, Edmonton, AB, Canada T6G 2H1; and ^2Engineering Services, Alberta Agriculture, Lethbridge, AB, Canada T1J 4C7. Received 7 May 1990; accepted 13 November 1990.

Deurloo, J.A., Feddes, J.J.R., Leonard, J.J. and Darby, D.E. 1990. Effect of recirculated air on air speeds at animal level: Commercial-scale swine barn tests. Can. Agric. Eng. 33:179-183. The effects of recirculated air on the air speed within the animal zone were studied in a commercial-scale swine barn. These results were compared with those found previously in an environmental chamber without pens and animals. The experimental room in the swine barn [6.7m(W) x 17.1m(L) x 3m(H)] had a larger floor area and a higher ceiling than the environmental chamber. Using similar recirculation rates per unit floor area, the mean air speed at animal level was lower in the swine barn. However, when similar recirculation rates per unit room volume (air changes per hour) were compared, the results were very similar. Air speed at animal level correlated most highly with the total of the inlet and recirculation air. With recirculation rates of 0-14 L/s per m^2, the mean air speed at animal level ranged between 0.15 and 0.4 m/s.

Les effets de la recirculation de l’air sur sa vitesse ont été étudiés dans une porcherie à échelle commerciale. Ces résultats furent comparés à ceux obtenus précédemment dans une chambre de simulation sans enclos et sans animaux. La chambre expérimentale de la porcherie [6.7 m de large x 17.1 m de long x 3 m de haut] avait une plus grande superficie et un plafond plus élevé que la chambre de simulation. En utilisant des taux de recirculation semblables par unité de superficie, la vitesse moyenne de l’air, au niveau des animaux, était inférieure dans la porcherie. Cependant, lorsqu’on a comparé des taux de recirculation semblables par volume unitaire (renouvellement d’air à l’heure), les résultats étaient très similaires. La vitesse de l’air correspondait très bien au total d’air frais et d’air de recirculation. Avec des taux de recirculation de 0 à 14 L/s par m^2, la vitesse moyenne de l’air variait de 0.15 à 0.4 m/s.

INTRODUCTION

Ventilation of livestock buildings in extremely cold weather requires that air exchange rates be kept at a minimum to conserve heat and yet supply the required fresh air uniformly throughout the animal space. The only source of fresh air is from the cold outdoors and thus must be heated or adequately mixed with resident warm air to avoid chilling of the housed animals.

Adjustable air inlets are intended to introduce fresh air to a room at velocities of 3-5 m/s so that it will mix well with the warm air inside the room. A significant pressure differential across the inlet is required to generate this velocity. It is difficult to construct a barn tight enough to create the required pressure differential at the low ventilation rates desired during cold weather conditions. Adding an air recirculation system below the fresh air inlets appears to be an effective means of ensuring that the cold air will be mixed well with warm air before coming into contact with the animals. The recirculation air provides the energy for mixing, so that a slower inlet air velocity is acceptable. If the recirculation duct is designed to provide adequate air jet throw length, the mixed air will travel near the ceiling to the other side of a room.

Cold air is obviously undesirable in the animal zone. Air velocities in excess of 0.3 m/s in the animal zone are considered undesirable, even though the air may be at an acceptable temperature (Riskowski and Bundy 1986). A properly designed recirculation system should be able to mix the cold air and warm air thoroughly without causing drafts in the animal zone. Ogilvie et al. (1988) suggest that air velocities at animal level should range between 0.2 and 0.4 m/s. Research is required to determine the factors which influence the relationship between recirculation system design and the air speeds at animal level. A recent study at the University of Alberta examined this problem under controlled environmental conditions (Deurloo et al. 1990a). This study was continued in a commercial-scale pig barn. Similar experimental procedures were used to verify the results of the earlier study.

The first objective was to verify the findings of the laboratory project, that air speed at animal level increases as the recirculation rate increases, in an actual barn situation. Animal level was considered to be within 300 mm of the floor. Six recirculation rates, from 0 to 11.2 L/s per m^2 of floor area were used, and each recirculation rate was replicated three times (Table 1). When there was no air from this recirculation duct, mixing was due only to fresh air entering through the inlet.

The second objective of the project was to compare air speeds at animal level in a large room with those measured in the smaller room used in the earlier project (Deurloo et al. 1990a). The two rooms had very different ceiling heights. Assuming that the contents of the room have no significant effect on the correlation between recirculation rate and air speed at animal level, comparing the results of the two projects would indicate on what basis recirculation rates should be expressed, floor or room volume.

EXPERIMENTAL FACILITIES

Experimental data were collected at the University of Alberta Swine Research Unit in Edmonton. The room used was a grower-finisher room, 6.7 m x 17.1 m, with a 3.0 m high ceil-
Table I. Parameters used in project.

<table>
<thead>
<tr>
<th>Recirculation rate L/s</th>
<th>Recirculation rate L/s per m²</th>
<th>Recirculation rate air changes/hour</th>
<th>Outlet area m²</th>
<th>Jet exit velocity m/s</th>
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</thead>
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<td>0</td>
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<td>0.0</td>
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<td>6.1</td>
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<td>8.3</td>
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<td>11.2</td>
<td>13.5</td>
<td>0.282</td>
<td>4.6</td>
</tr>
</tbody>
</table>

ing, which is higher than ceilings normally found in commercial pig barns. The room contained 12 pens, each measuring 1.2 m x 4.2 m with fully slatted floors and pen partitions constructed of vertical steel bars. The room had a capacity of 70 to 100 pigs, depending on the size of the animals. Ventilation was provided by two exhaust fans located in the ceiling, and discharging via a duct system through the attic. The minimum ventilation fan had an airflow rate of 260 L/s. The large ventilation fan was disabled during the test runs.

Fresh air was introduced to the room from a duct system located in the attic via five counterbalanced baffle inlets, each 2.4 m long and located above the recirculation duct. The recirculation duct was 245 mm x 540 mm in cross-section, and 15.0 m in length with 72 holes of 50 mm diameter spaced evenly along its length.

To provide sufficient capacity for higher-than-normal recirculation rates to be studied, and to ensure that the recirculation rates were being measured accurately, the existing recirculation fan was removed from the recirculation duct, and an airflow measuring duct, with dimensions of 560 mm x 560 mm x 3.6 m long was installed in place of the fan. A 556 mm diameter variable-speed fan (maximum output 1300 L/s) was attached to the end of the airflow measuring duct. To maintain a recirculation jet exit velocity of 5 m/s at the maximum recirculation rate of 1300 L/s, extra holes were cut in the recirculation duct. At lower recirculation rates holes were blocked off with duct tape as required, to maintain the recirculation jet exit velocity of 5 m/s. Recirculation jet exit velocities were calculated from the measured fan capacity and the total hole opening area (Table I). The airflow measuring duct was left in place while the air speeds at animal level were being measured, to ensure that the recirculation rate was being measured accurately.

EXPERIMENTAL PROCEDURE

The airflow rates through the recirculation duct were determined by a hot-wire anemometer traverse (Kurtz Instruments, Redlands, CA) in the airflow measuring duct, at different settings of the fan speed controller (Jorgenson 1983). In all cases, the airflow rate was measured before measuring the air speeds at animal level.

The air speed at animal level was determined by filming the response of smoke puffs to the moving air with a video camera. The smoke generator contained titanium tetrachloride, which reacts with water vapor to produce a very fine precipitate which can be used as a smoke tracer. The smoke was released near the floor in a vertical direction. The video camera was mounted 2 m above the floor of the pen, pointing down, so that the horizontal distance travelled by the smoke could be measured. A 50 mm grid of steel mesh, with a black paper background, was laid on the floor of each pen to provide a reference by which to measure the direction and distance travelled by the smoke puffs. Elapsed time was determined by counting the number of frames exposed by the video camera, knowing that the speed of the camera was 30 frames per second.

Other researchers have measured air speed at animal level with a hot-wire anemometer or a thermistor bead unit (Yao et al. 1986; Ogilvie et al. 1988). These units enable a large amount of data to be collected easily, but the accuracy of an anemometer appears questionable at very low air speeds. The smoke puff and video camera technique is more laborious but better suited to these very low air speeds and it has the added benefit of providing directional data. This technique is accurate to within 15% at an air speed of 0.20 m/s (based on a distance travelled by the smoke puff of 13 cm (±1 cm) during which 20 video frames (±1 frame) were exposed at a camera speed of 30 frames per second). The errors associated with this technique tend to be random errors, as opposed to the systematic calibration errors of the hot-wire anemometer technique. Results from the smoke puff technique are enhanced by good lighting, small but dense smoke puffs, a flat black background, and a minimum of air turbulence. The smoke puff technique is not as suitable for air speeds in excess of 1 m/s.

In the room studied at the swine barn, four test points were used to determine the mean air speed at animal level. Twenty smoke puffs were released at each test point, for a total of 80 measurements for each room average. The effects of the different recirculation rates upon the air speed at animal level were compared on the basis of the room average, i.e., mean of the 80 air speeds measured. Pigs were present in all pens except the pens in which the test points were located. The video camera technique requires that the smoke puffs be visible to the camera, and the presence of animals in the immediate measurement location would obstruct the view of the camera.

RESULTS AND DISCUSSION

Observations of airflow patterns

Figures 1 and 2 show the locations of the test points. The shaded circle sectors indicate the dominant airflow directions observed at a given point. The expected airflow pattern at
animal level would be in a direction towards the recirculation duct, with a slight angle towards the recirculation fan (Deurloo et al. 1990a). Figure 1 shows the airflow pattern at high recirculation rates (6.1 air changes per hour). At low recirculation rates (2.7 air changes per hour) the observed airflow patterns near the floor were not stable, but varied widely, sometimes being opposite to the expected direction (Fig. 2). The airflow pattern at low recirculation rates could be considered to have two zones: a well-defined high velocity zone in the vicinity of the air jet, which became more unpredictable as the jet momentum dissipated, and a low velocity zone in the remainder of the room, where the airflow pattern was very unstable and dominated by localized eddies, particularly near the floor (Fig. 3). These observations agree with those of Jin and Ogilvie (1990). They found that, under low inlet velocities, rotary flow did not occur throughout the entire room volume and that intermediate zones near the floor included both rotary and stagnant air flow.

The effect of recirculation rate on air speed

Figures 4, 5, and 6 combine the data obtained in the laboratory (Deurloo et al. 1990a) with the data obtained in the barn (Deurloo et al. 1990b). These data are presented as air speed at animal level plotted against:

(a) recirculation rate, in L/s per unit floor area (Fig. 4),
(b) recirculation rate, in air changes per hour (Fig. 5), and

\[ T = 0.182 + 0.005X + 0.0028X^2 \]

\[ R^2 = 0.66 \]
(c) total of recirculation and inlet air, in air changes per hour (Fig. 6).

As was found in the earlier study, increasing the recirculation rate in the room caused an increase in the mean air speed at animal level.

Current recirculation system design criteria suggest that the recirculation fan capacity be based on 2 - 3 times the minimum ventilation rate, or 6 - 7 L/s per m² of floor area (Darby and Dill 1988). Recently, some engineers have suggested that the recirculation rate should be based on room volume (Dill 1987). This would seem to be a logical approach, since an increase in room volume would result in an increase in air mass that must be kept in motion.

Comparing Figs. 4 and 5 supports the concept of using room volume rather than floor area for determining an optimum recirculation rate. The data obtained in the barn fit smoothly with the data obtained in the laboratory in Figs. 5 and 6, but not as well when expressed in terms of floor area (Fig. 4). The coefficient of determination ($R^2$) for the best fit line shown in Fig. 4 is 0.66, while the $R^2$ value for Fig. 5 is 0.78. Summing the recirculation and inlet air gives a better correlation with the air speed at the animal level (Fig. 6, $R^2=0.79$). These figures suggest that air speeds at animal level vary non-linearly with the total of recirculation rate and ventilation rate. A change in low recirculation rates does not affect air speeds at animal level as much as a change at higher recirculation rates. Jin and Ogilvie (1990) attributed this to the transition from partial to fully rotary airflow.

Darby and Dill (1988) suggested that recirculation rate should be based on 6 - 7 L/s per m² of floor area. Assuming a ceiling height of 2.4 m, this is equivalent to 8.8 to 10.3 air changes per hour. Dill (1987) suggested a recirculation rate of 1/6 of room volume per minute, which is equivalent to 10 air changes per hour. Assuming that a maximum air speed of 0.30 m/s in the animal zone is desirable, Fig. 6 indicates that the total of the recirculation rate and the winter ventilation rate should not be greater than 11 air changes per hour.

Jet momentum function

The jet momentum function ($J_i$) has been defined (Kaul et al. 1975) as:

$$J_i = \rho QU/V$$  \hspace{1cm} (1)

where:

$\rho$ = air density (kg/m³),
$Q$ = airflow rate (m³/s),
$U$ = jet velocity (m/s), and
$V$ = room volume (m³).

The jet velocity is calculated from:

$$U = Q/(AC_d)$$  \hspace{1cm} (2)

where:

$A$ = total outlet area (m²), and
$C_d$ = coefficient of discharge (assumed to be 0.74 from Deurloo et al. 1990a).

Since $J_i$ includes the volumetric air exchange rate ($Q/V$), the possibility of using it to define optimum recirculation rates was explored. Jet momentum can be calculated for the recirculated air and the inlet (fresh) air. These two values can be combined into a total jet momentum ($J_t$) by:

$$J_t = (\rho i Q_i + \rho r Q_r)(U_{i/r}/V$$  \hspace{1cm} (3)

where:

$\rho_i$ = inlet air density (1.2 kg/m³ at 0°C, 670 m altitude),
$\rho r$ = recirculated air density (1.1 kg/m³ at 20°C, 670 m altitude),
$Q_i$ = inlet airflow rate (m³/s),
$Q_r$ = recirculation airflow rate (m³/s), and

$$U_{i/r} = (Q_i + Q_r)/((A_i + A_r)C_d)$$  \hspace{1cm} (4)

where:

$U_{i/r}$ = resultant velocity from recirculation and inlet jets (m/s),
$A_i$ = total fresh air inlet area (m²), and
$A_r$ = total recirculation duct outlet area (m²).

As in Figs. 4, 5, and 6, the mean air speed at animal level increases as the value of $J_t$ increases (Fig. 7). The data from both projects appear to support a continuous function for the two sets
Fig. 7: Relationship between jet momentum and mean air speed at animal level (X = jet momentum, Y = air speed).

of data. This suggests that the contents of the barn did not affect the air speed at animal level since there was not an abrupt change in jet momentum values between the two projects.

The results indicate that \( J_1 \) is not as good at predicting air speed at animal level as recirculation rate (R² for Fig. 7 is 0.59, whereas R² for Fig. 6 is 0.79). The jet momentum concept includes the value of the air jet velocity, but as was found in the earlier study, the air speed at animal level did not change significantly with air jet velocities between 3 and 5 m/s.

CONCLUSIONS

1. Air speed at animal level increases as the recirculation rate increases.

2. For recirculation system design, the recirculation rate should be selected on the basis of room volume, rather than floor area. There is a better correlation between recirculation rate/room volume with air speed at the animal level (R² = 0.79) than expressed per floor area (R² = 0.66).

3. Air speed at animal level increases as the jet momentum function (I) increases, but the correlation is not as good (R² = 0.59) as the correlation between air speed at animal level and the recirculation rate.

REFERENCES


