# Assessing Air Infiltration Rates of Agricultural Use Ventilation Curtains

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**Abstract.** *Curtains commonly used in the agricultural ventilation industry were evaluated for air infiltration characteristics as a function of curtain material, closure overlap distance, and wind speed in a controlled and calibrated wind tunnel. Curtain material ranged from polypropylene to woven mesh with measured specific weights varying between 168 and 866 gm/m² (0.6 and 2.8 oz/ft²). Curtains classified as breathable allow as much as 1243 m³/h–m² (68 cfm/ft²) of infiltration air at wind speeds of 13.4 m/s (30 mph). For non–breathable curtains at wind speeds of 13.4 m/s, infiltration rates were reduced to 366 m³/h–m² (20 cfm/ft²) for single–layer low–density curtains to essentially 0 m³/h–m² for multi–layered insulated curtains. Curtain closure overlap distances of at least 5.1 cm (2 in.) were found to drastically reduce infiltration at the opening. A non–breathable curtain that just reaches the top of the opening (i.e., 0–cm curtain overlap) can allow nearly as much infiltration air to enter as a breathable curtain.*

*Keywords. Ventilation, Curtains, Infiltration, Wind tunnel.*

Fabric–based curtains are used extensively in the agricultural ventilation industry. Ventilation strategies from pure natural ventilation to tunnel ventilation use fabric curtains to provide closure control for major surface areas of the building. For most ventilation designs, fabric curtains encompass well over 50% of sidewall or endwall construction. Infiltration through curtains can occur through the curtain material itself, through the top seam of the curtain, or through the end–pocket closures designed (fig. 1). Small gaps between the curtain top and the building opening can allow excessive ventilation air to the building depending on the outside climatic conditions. During the heating season, controlling curtain infiltration is a major concern. In addition, if fans are used to deliver minimum fresh air to the building during the heating season, curtain sealing is critical if fans and inlets are to operate at desired balance points.

The objectives of this research project were to 1) investigate curtain infiltration characteristics of agricultural–use fabric curtains, and, 2) determine guidelines on proper curtain overlaps as a function of a perpendicular wind varying in magnitude.

## Materials and Methods

A wind tunnel capable of measuring operating conditions for fans and inlets (Shahan, 1985) was modified to accommodate fabric–based ventilation curtains. Figures 2 and 3 show the experimental setup. Square curtain sections of 0.76 × 0.76 m (2.5 × 2.5 ft) were tested for both infiltration rate through the fabric material itself and at the seal between the curtain and the wall opening.

The curtain test section was fitted with a 1.91–cm (0.75–in.) diameter hollow conduit typical of field–installed curtains (fig. 3). To prevent infiltration through the curtain sides during testing, a rigid seal was placed at the sides and bottom of the curtain test section as shown in figure 3. The wind tunnel was operated at static pressure differentials between 9 and 75 Pa (0.04 and 0.30 in w.g.). This static pressure developed by the wind tunnel was assumed to correspond to the actual pressure difference ($P_a$) exerted by wind. The actual pressure difference is related to the stagnation pressure ($P_{stagnation}$) by

$$P_a = C_p \, P_{stagnation} \qquad (1)$$

where

$C_p$ = wind pressure coefficient

The wind pressure coefficient for the windward surface of a gable–roofed building typical of animal confinement facilities is +0.70 (Albright, 1990). The stagnation pressure, $P_{stagnation}$, is further related to wind speed as

$$P_{stagnation} = 1/2 \; \rho \, V_{wind}^2 \qquad (2)$$

or

$$P_a = 0.70 \; 1/2 \; \rho \, V_{wind}^2 \qquad (3)$$

where

$V_{wind}$ = wind speed (m/s)

$\rho$ = air density [kg/m³ (assumed at 1.2 kg/m³)]

Solving equation 3 for $V_{wind}$ results in

$$V_{wind} = \{2 \times P_a / \rho \, C_p\}^{0.5} \qquad (4)$$

$$= 1.54 \, \{P_a\}^{0.5}$$

**(a)**



**Figure 2. Sidewall test section developed for curtain infiltration study (view as seen by wind tunnel exit).**

**(b)**

**Figure 1. Curtain leakage due to improper overlap at (a) sidewall and at (b) endwall pocket.**

and represents the wind speeds ($V_{wind}$) defined in this article relative to the static pressures developed in the wind tunnel ($P_a$). For clarity in communicating the results, wind speed in all tables and figures was converted to miles/h (mph) and all infiltration results were converted to ft³/min (cfm).

Curtains were tested at 0–, 2.5–, 5.1–, and 7.6–cm (0–, 1–, 2–, and 3–in.) curtain overlap. A 0–cm curtain overlap implies that the curtain top is in–line with the top opening position of the sidewall. Two replications of curtain, curtain overlap, and pressure differential were investigated with the averages presented for analysis.
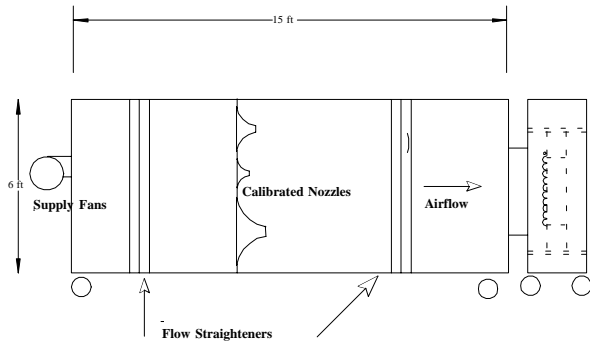
## CURTAINS TESTED

Nine fabric–based curtains were tested as listed in table 1. Curtains C1 to C9 varied in curtain density, surface coating, and primary construction material. Curtain density ranged from a manufacturer's listed 2 oz/yd³ (measured specific weight = 168 gm/m²) to a seven–layer insulated curtain with a listed density of 20 oz/yd³ (measured specific weight = 866 gm/m²). Polyethylene films covering the inside and outside surfaces of the primary fabric were present on curtains C2 to C9. Curtain C1 had no such film coating and was manufactured to be a breathable curtain. Primary fabric material consisted of either polypropylene, polyester, or polyethylene. Curtain C6 was manufactured as a two–layer version of C3. All curtains, except for curtains C6 and C9, were classified as single–layer curtains. All curtains tested were purchased from a local distributor (Farmtek, Inc., Dubuque, Iowa).

## RESULTS AND DISCUSSION

Infiltration results for all curtain combinations tested at stagnation pressures exerted by wind speeds of 10, 21, and 30 mph (4.5, 9.4, 13.4 m/s) are listed in table 2. The results summarize infiltration rates at 0–, 1–, 2–, and 3–in. (0–, 2.5–, 5.1–, 7.6–cm) curtain overlaps. All results are summarized as total test section infiltration rates (cfm). A plot of all curtains as a function of each wind speed tested is given in figure 4.

Clearly, breathable curtains (C1) are very porous, providing a large amount of infiltration no matter how much curtain overlap is used, a result clearly shown in figure 5. At curtain overlaps of 1, 2, and 3 in. (2.5, 5.1, 7.6 cm), the infiltration rates were nearly constant at each wind speed tested. At stagnation pressures representing 10 mph (4.5 m/s), the infiltration rate was at about 100 cfm (170 m³/h). At stagnation pressures resulting from a 30 mph (13.4 m/s) wind, infiltration rates rose to about 300 cfm (510 m³/h). This result implies that the majority of air

**Figure 3. Test section fitted with curtain material and mating to wind tunnel test chamber. (a) Curtain test section mating with wind tunnel. (b) Back side of test section showing 2.5– × 2.5–ft (0.76– × 0.76–m) test section.**

**Table 1. Tested curtain material specifications.**

| Curtain I.D. | Manufacturer's Listed Density (oz/yd$^3$) | Measured Specific Weight gm/m$^2$ (oz/ft$^2$) | Construction Material |
|---|---|---|---|
| C1 | 2 (breathable) | 168 (0.6) | polypropylene |
| C2 | 4.5 | 208 (0.7) | polyethylene |
| C3 | 5.2 | 185 (0.6) | polyethylene |
| C4 | 6.0 | 211 (0.7) | polyethylene |
| C5 | 9.5 | 292 (1.0) | polyester |
| C6 | 10.4 (two–layers of C3) | 369 (1.2) | polyethylene |
| C7 | 13.0 | 371 (1.2) | polyester |
| C8 | 18.0 | 593 (1.9) | polyester |
| C9 | 20 (seven–layer insulated) | 866 (2.8) | vinyl, polyethylene |

infiltration is through the curtain fabric itself and not through the top seam. Breathable curtains are effective in allowing a relatively large amount of fresh air to enter a building even at relatively low wind speeds of 10 mph (4.5 m/s).

Adding two layers of a medium–density curtain is marginally effective in infiltration control as shown in figure 6. Curtain C6, representing a two–layer version of curtain C3, provided little additional infiltration control at a curtain overlap of 2 in. (5.1 cm). Curtain C3 had a maximum infiltration rate for the test section of no more than 20 cfm (34 m$^3$/h). This trend was the same when the single–layered curtain C3 was compared with the seven–layer curtain C9, as shown in figure 7.

The major criterion in infiltration control as found with this study is the level of curtain overlap provided. A non–breathable curtain (C2 to C9) that just encompasses the building opening (i.e., 0–cm curtain overlap) provides a point for high infiltration regardless of the density or number of layers used. This trend is shown for curtain C5 (fig. 8). For curtain C5, subjected to a 10–, 21–, and 30–mph (4.5–, 9.4–, and 13.4–m/s) wind, providing a 1–in. (2.5–cm) curtain over-lap reduced the infiltration rate by 55, 59, and 66%, respectively, compared to a 0–in. curtain closure. Providing a 2–in. (5.1–cm) curtain overlap reduced the infiltration rate by another 30, 62, and 72%, respectively. Further curtain closure to 3 in. (7.6 cm) provided little additional infiltration control.

Comparing single–layer curtains, increasing curtain density has a positive effect on infiltration control, especially as the curtain overlap is increased (fig. 9). However, single–layer polypropylene versus single–layer polyester

**Table 2. Curtain infiltration (cfm)[a] for the 2.5– × 2.5– ft (0.76– × 0.76–m) test section as a function of curtain overlap (CO) and wind speed (WS).**

| WS mph (m/s) | CO in. (cm) | Curtain Tested C1 | C2 | C3 | C4 | C5 | C6 | C7 | C8 | C9 |
|---|---|---|---|---|---|---|---|---|---|---|
| 10 (4.5) | 0 | 117.1 | 37.3 | 27.9 | 52.2 | 58.1 | 44.5 | 66.9 | 40.3 | 39.1 |
|  | 1 (2.5) | 82.3 | 11.5 | 21.7 | <10 | 26.3 | <10 | 16.5 | <10 | <10 |
|  | 2 (5.1) | 112.0 | <10 | <10 | <10 | 18.3 | <10 | 11.6 | <10 | <10 |
|  | 3 (7.6) | 75 | <10 | <10 | <10 | <10 | <10 | <10 | <10 | <10 |
| 21 (9.4) | 0 | 296.4 | 77.4 | 79.4 | 91.5 | 114.9 | 91.7 | 107.5 | 78.9 | 86.8 |
|  | 1 (2.5) | 215.7 | 23.4 | 38.1 | <10 | 46.9 | <10 | 26.4 | <10 | <10 |
|  | 2 (5.1) | 221.1 | 21.8 | 16.2 | <10 | 17.9 | <10 | 18.5 | <10 | <10 |
|  | 3 (7.6) | 215.7 | <10 | <10 | <10 | <10 | <10 | <10 | <10 | <10 |
| 30 (13.4) | 0 | 425.0 | 113.5 | 124.4 | 131.7 | 159.9 | 123.8 | 148.7 | 109.8 | 127.7 |
|  | 1 (2.5) | 312.1 | 26.2 | 46.4 | 11.4 | 54.8 | 11.6 | 27.7 | 11.6 | <10 |
|  | 2 (5.1) | 312.1 | 23.4 | 18.2 | 14.1 | 15.3 | <10 | 22.0 | <10 | <10 |
|  | 3 (7.6) | 290.5 | <10 | <10 | <10 | 10.6 | <10 | <10 | <10 | <10 |

[a]  To convert cfm of infiltration air to m$^3$/h, multiply by 1.7003.
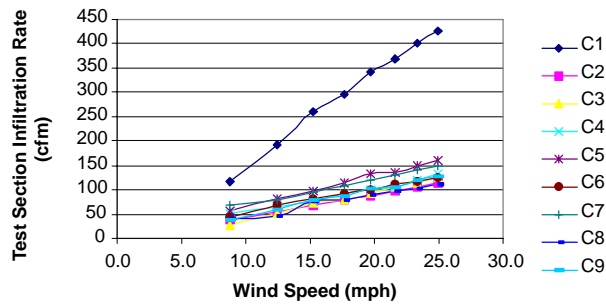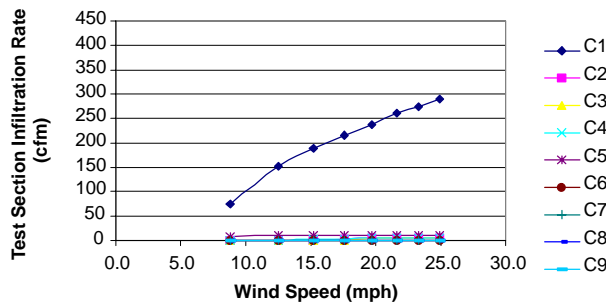
**(a)**
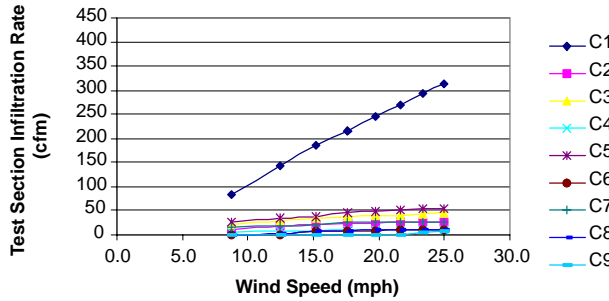


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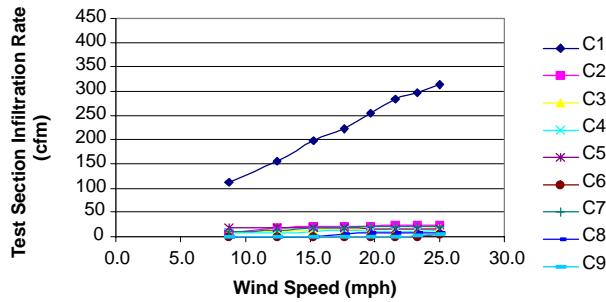


**(c)**



**(d)**

**Figure 4. Test section infiltration rates for 0–, 1–, 2–, and 3–in. curtain overlaps, respectively.**

curtains have very little infiltration control differences at comparable curtain overlaps (fig. 10).

### PRACTICAL INTERPRETATION OF THE RESULTS

Infiltration through ventilation curtains can be a troublesome design feature that is frequently the culprit causing a much larger problem. For example, wean–to–finish pig facilities often use fabric curtains on both sidewalls, encompassing 50% or more of the sidewall. For wean–to–finish facilities, the cold–weather ventilation rate is
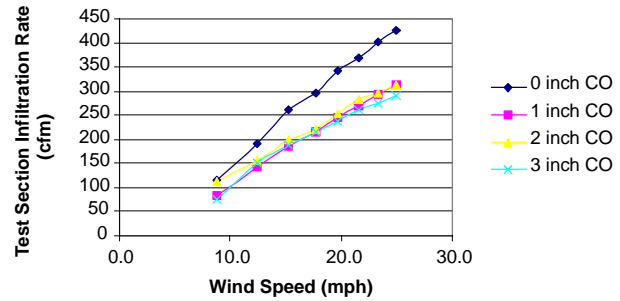


**Figure 5. Test section infiltration rates of the breathable curtain (C1) for 0–, 1–, 2–, and 3–in. curtain overlaps as a function of wind speed (mph).**
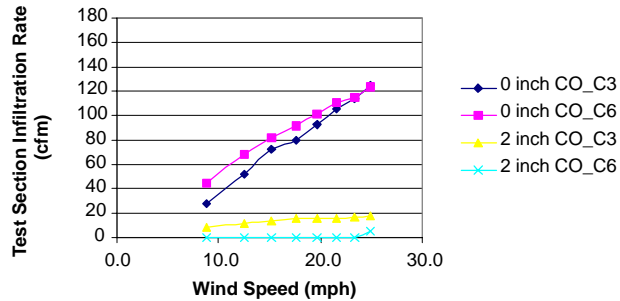


**Figure 6. Test section infiltration rates for a single– versus two–layer curtain of the same composition (C3 vs. C6) for 0– and 2–in. curtain overlaps as a function of wind speed (mph).**
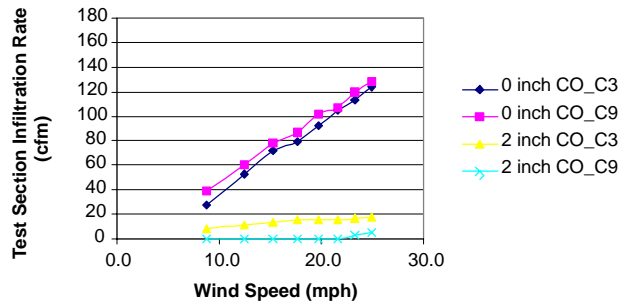


**Figure 7. Test section infiltration rates for a single–layer curtain of medium density (C3) versus a seven–layer insulated curtain (C9) for 0– and 2– in. curtain overlaps as a function of wind speed (mph).**

recommended to be about 1 cfm/pig (1.7 $m^3$/h–pig) (MWPS, 1997). In a single–stocked wean–to–finish facility, roughly 7.5 $ft^2$/pig (0.70 $m^2$/pig) is allowed. If a barn width of 60 ft (18.3 m) is used, then eight pigs will be housed in each 1 ft (0.3–m) of building length. The ventilation rate requirements at the weaning stage would be 8 cfm/ft (45 $m^3$/h–m) of building length. For all non–breathable curtains tested (C2 to C9), and assuming that all leakage is through the top seam, this ventilation rate would be exceeded for all curtains with a 0–in. curtain overlap, and exceeded for curtains C2, C3, C5, and C7 at a 1–in. (2.5–cm) curtain overlap for a wind speed of 30 mph (13.4 m/s). At a wind speed of 30 mph (13.4 m/s), a 3–in. (7.6–cm) curtain overlap is required to prevent curtain infiltration from being the primary source of ventilation air.

These results point out the futility in using a ceiling inlet distribution system, along with sidewall or endwall curtains for mechanically ventilated barns that house young animals in cold climates. Often the infiltration through improperly
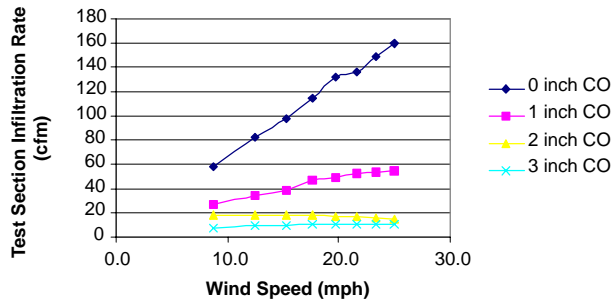
**Figure 8. Test section infiltration rates for a single–layer curtain of medium density (C5) as a function of curtain overlap and wind speed (mph).**
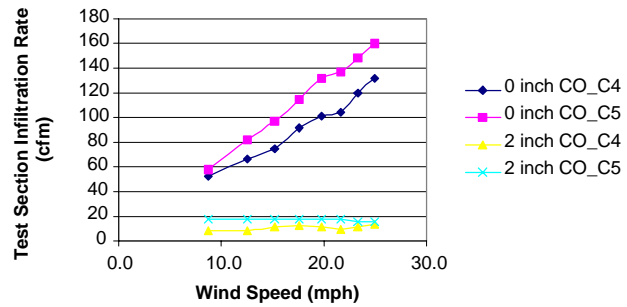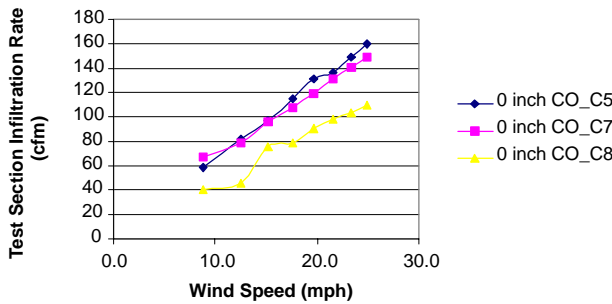


(a)



(b)



(c)

**Figure 9. Test section infiltration rates for a single–layer polyester curtain of low (C5), medium (C7), and high (C8) density as a function of curtain overlap and wind speed (mph).**

secured curtains provides excessive ventilation air, preventing the fan/inlet system from developing proper operating static pressures. Practically, limit switches on curtain machines should be set to permit a 4–in. (10.2–cm) curtain overlap to allow for imperfections in curtain installation procedures. Additionally, curtain cabling will expand and
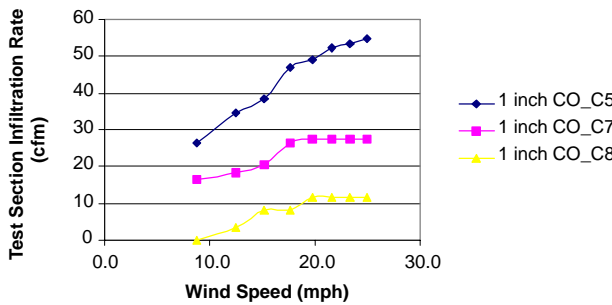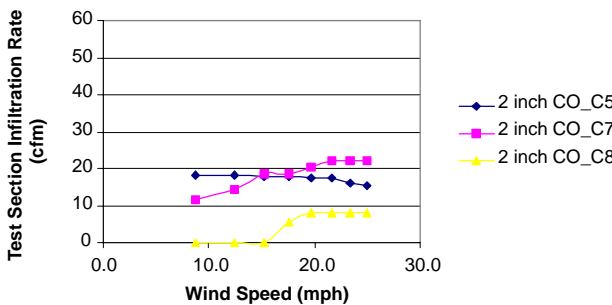


**Figure 10. Test section infiltration rates for a single–layer polypropylene (C4) and polyester (C5) curtain at comparable densities as a function of curtain overlap and wind speed (mph).**

contract with time making periodic checks on curtain overlaps imperative.

## CONCLUSIONS

Breathable curtains are designed to allow infiltration air to enter through the fabric material. Results from this research indicate that breathable curtains, at curtain overlaps of 1 in. (2.5 cm) or greater, allow between 16 cfm/ft$^2$ (293 m$^3$/h–m$^2$) at 10 mph (4.5 m/s) and 48 cfm/ft$^2$ (878 m$^3$/h–m$^2$) at 30 mph (13.4 m/s) of infiltration air to enter.

For those curtains classified as non–breathable, a curtain overlap of at least 2 in. (5.1 cm) is required. For these curtains, no differences were found in curtain leakage between single–, two–, and seven–layer curtains if a curtain overlap of at least 2 in. (5.1 cm) was provided. A seven–layer insulated curtain provides no additional infiltration control as compared with low–density single–layer curtains. However, insulated curtains will provide some inside surface temperature tempering during cold winter months that will provide other thermal environment benefits, especially for young animals.

The key to infiltration control through the curtain fabric is the integrity of the polyethylene film coating on the curtain. For example, breathable curtains use no surface polyethylene treatment and provide ready access to infiltration air entering through the fabric itself. Curtains will have a tendency to crack upon repeated use, rendering the polyethylene film coating useless, and this will promote increased infiltration. A regular maintenance schedule on curtains is critical, especially when curtains are used along with mechanical ventilation.

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