Air leakage through farm building envelopes in Eastern Ontario

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Massé, D.I., Munroe, J.A. and Jackson, H.A. 1994. **Air leakage through farm building envelopes in Eastern Ontario**. Can. Agric. Eng. **36**:159-163. A field study was conducted to measure air leakage in modern farm buildings of typical construction in order to evaluate the performance of their air barriers. A large capacity mobile fan was used to determine air leakage rates for inside-to-outside pressure differences of 10, 20, 40, 50, and 60 Pa. A total of 13 barns was tested including some built by owners and some built by contractors. Air leakage rates of 3 to 12 air changes per hour were measured at 15 Pa. These rates were much higher than those suggested using ASHRAE methodology. There was no apparent difference in air barrier performance according to being owner or contractor built.

Cet article décrit les résultats d'une étude sur la performance des enveloppes de bâtiments d'élevage. Un ventilateur mobile de grande capacité a été utilisé pour déterminer le taux d'infiltration d'air à travers les enveloppes des bâtiments. Les taux d'infiltration ont été obtenus pour des différences de pression statique entre l'intérieur et l'extérieur du bâtiments de 10, 20, 40, 50, et 60 pa. Au total 13 bâtiments ont été testés. Les données recueillies démontrent que les taux d'infiltration varient de 3 à 12 changements d'air par heure à une différence de pression statique de 15 pa. Ces taux d'infiltration sont considérablement supérieurs aux taux d'infiltration calculés par la méthode du ASHRAE. Les résultats démontrent aussi qu'il n'y a pas de différences significatives dans la performance de l'enveloppe des bâtiments construits par les producteurs agricoles ou les contracteurs.

INTRODUCTION

Air leakage through the building envelope in farm buildings occurs when air leaks in an uncontrolled fashion through cracks and spaces in the walls and ceiling and around windows and doors. The leaks occur when there is a pressure difference across the building envelope. This pressure difference can be induced by wind, stack effect, and ventilation exhaust fans.

When a room is being ventilated with exhaust fans there is a pressure difference developed between inside and outside against which the fans must work. Due to this same pressure difference, air will enter the building by leakage as well as through the air inlet normally provided to ventilate the building. The system will reach a balance wherein a pressure difference will develop such that the associated air flow rate of the fan matches the sum of the air leakage rate and the air flow rate through the air inlet. During the winter when ventilation rates are low, a leaky building can result in low inside-to-outside pressure differences. As a result, the air speed at the inlet will also be low, which can lead to poor air circulation within the room. Also, local cold drafts can result where the air leaks across the building envelope and enters the room. This can be detrimental to animal comfort and health.

Problems associated with air leakage in farm buildings are: (1) poor performance of negative pressure ventilation systems including incomplete air mixing and non-uniform air quality in the room; (2) water condensation on interior cladding, and (3) water accumulation in the walls and ceiling. The first problem can affect animal health, comfort, and performance. The last two problems can affect the durability of the structure (through wood rot and steel corrosion) and the energy efficiency of the building (loss of insulation value due to accumulation of water in the wall or ceiling).

OBJECTIVES

The objectives of this study were: (1) to determine the actual level of air leakage in typical farm buildings built in the Eastern Ontario region; (2) to quantify the variation that exists among farm buildings in terms of building style, builder, etc.; and (3) to develop recommendations for improved construction practices and future research work.

LITERATURE REVIEW

Air leakage can be measured using two different techniques. One technique involves injecting an inert tracer gas into the room and then measuring its rate of concentration decay. This technique is very weather dependent, therefore, several tests under different weather conditions must be carried out to obtain reliable results. The other technique is the fan pressurization method whereby a fan is used to develop a positive or negative pressure in the building in which all designed ventilation inlets are closed. The air flow rate through the fan is then measured, giving an indication of the air tightness of the building envelope. This technique is less weather dependent.

The fan-pressurization test has been widely used. Shaw (1980), McIntyre and Newman (1975), Shaw and Jones (1979), Tamura (1975), Hunt et al. (1978), and Caffey (1979) used this method to pressurize full scale buildings. Persily (1982) measured the leakage of the same building 80 times over a year. He found that the coefficient of variation of the flow rate at 50 Pa was 1 to 2% for wind speeds less than 2.2 m/s. For higher wind speeds the coefficient of variation increased to as high as 15%. Therefore, it is important that the tests are carried out only during days of calm or low winds to get meaningful results.

Allen (1985) specified that air leakage is a function of building style, construction quality, and age. Because farm building construction practices change with geographical location and are carried out mainly by small contractors or farmers, there is a wide range in construction quality. Therefore, a large variation in leakage was anticipated.

METHODOLOGY

Building selection

Buildings selected for this project had to meet the following criteria: (1) recently constructed building; (2) building completely enclosed; (3) mechanically ventilated; and (4) empty at the time of testing. The fourth criteria was included to avoid stressing the animals or birds, or exposing them to drafts. Because of this criteria, no swine or poultry buildings were selected since none could be emptied for testing. It is likely, however, that results for swine and poultry barns would be similar to results for dairy barns, since construction techniques are similar. After thorough site inspection of 50 buildings, 13 buildings were found suitable for testing. These buildings are described in Table I.

Testing technique and procedures

The fan pressurization technique induces a pressure difference across the building envelope and the air flow through the envelope is estimated by a power law equation.

$$Q = a\,(\Delta p)^b \tag{1}$$

where:

Q = flow rate through the envelope (m^3/s),
Δp = pressure difference (Pa),
a = leakage coefficient, and
b = flow exponent.

The common practice (Hunt et al. 1978; Dumont et al. 1981) for small buildings (eg. residential houses) is to express air leakage in terms of air changes per hour at 50 Pa pressure difference. For large buildings (eg. schools, shopping centres, and warehouses) air leakage is expressed in terms of litres per second per square meter of building surface area at a pressure difference of 75 Pa (Shaw 1980). It is important to confirm these units when comparing results of various research studies.

A schematic diagram of the test apparatus is shown in Fig. 1 and the actual testing apparatus is shown in Fig. 2. The design, fabrication, and calibration of the test apparatus are described by Massé et al. (1994).

Prior to a test, the following steps were followed: (1) all interconnecting doors within the test area of the barn were secured open; (2) air inlets were sealed with duct tape and plastic film, (3) fan shutters were taped shut; and (4) data sheets concerning the physical characteristics of the building were completed. Complete details of each building were noted including: physical dimensions; sizes and construction details of doors and windows; wall and ceiling materials and construction style; number and type of lighting fixtures; number, size, and type of ventilation fans; and any other peculiarities that might affect air leakage.

After equipment warm up and calibration, the air leakage rate was measured at pressure differences of 10, 20, 40, 50, and 60 Pa. The air flow was measured using Pitot tubes and then corrected for temperature and barometric pressure. Only

Table I. Physical characteristics of farm buildings tested

Barn No.	Year of construction	Building type *	Built by **	Wall type ***	Roof type ***	Window Type ****	Window Total area (m^2)	Door Type *****	Door Total area (m^2)
1	1982	B,D	C	A,D,E,C	A,D,C	A,E,H,I	23.0	A,D,F	12.3
2	1987	B,D	F	A,D,E,C	A,D,C	A,E,G	29.8	A,C	20.0
3		C,D		A,D,E,C	A,D,C	C,E,H	15.9	A,C,D,F	17.2
4	1985	A	C, F	A,D,E,C	B,D,C	A,E,H	19.9	A,C,D,F	26.7
5	1988	B,D	C	A,D,E,C	A,D,F,C	A,D,E,F,H,I	14.9	A,C,D	17.2
6	1988	C,D	C	A,D,E,C	A,D,C	A,E,F,H	19.8	A,C,E,F	13.8
7	1988	C,D	F	A,D,E,C	A,D,C	A,D,E,F,H,J	16.1	A,C,D,E,F	11.0
8	1987	C,D	C	A,D,E,C	A,D,C	A,D,E,F,H,I	28.6	A,C,F	35.0
9	1988	A	C, F	A,D,E,C	B,D,C	A,E,F,H	17.3	A,C,D,F	28.5
10	1989	A	F	A,D,E,C	B,D,C	A,D,F,J	4.6	A,C,F	14.2
11	1984	B,D	F	A,D,E,C	A,D,C	A,D,G	17.3	A,C,D,F	18.5
12	1980	B,D	C	A,D,E,C	A,D,C	A,D,F,G,I	13.6	A,C,F	29.6
13	1987	B,D	C	A,D,E,C	A,D,C	C,E,F,H	18.7	A,C,D,F	14.2

* A) Steel frame single storey; B) Wood frame single storey; C) Wood frame two-storey; D) Ceiling;
** C) Contractor; F) Farmer.
*** A)38x140 mm stud or rafter; B) 38x140 mm girts; C) polystyrene sheathing; D) Exterior steel cladding; E) Interior steel cladding; F) Interior plywood cladding.
**** A) Wood frame; B) Metal frame; C) Plastic frame; D) Single glazing; E) Double glazing; F) Weather stripped; G) Pivot type; H) Sliding type ; I) Casement; J) Fixed type.
***** A) Wood frame; B) Metal frame; C) Casement; D) Sliding; E) Roll up; F) Weather stripped.

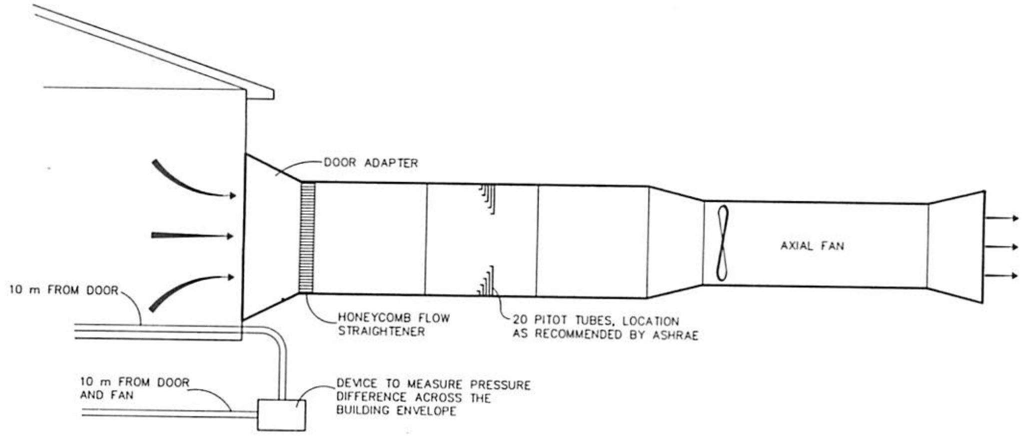

Fig. 1. Schematic diagram of the testing system.

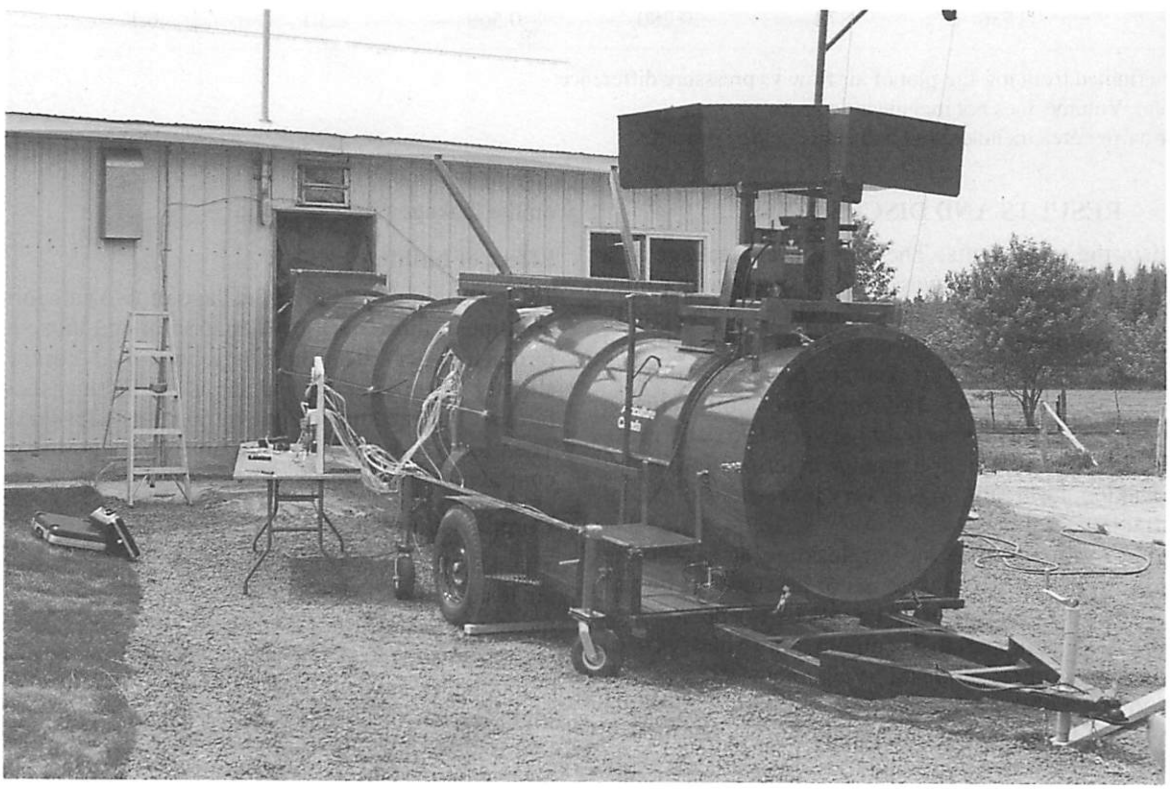

Fig. 2. Test apparatus in place at barn door.

depressurization tests (room under negative pressure) were used as the buildings were ventilated with exhaust fans.

To avoid wind effects, this study only reports results of tests carried out during periods with no or low winds. Specific wind speeds were not recorded.

For each barn tested, the air flow versus the pressure difference across the building envelope was plotted on log-log paper. A regression analysis of the log of air flow versus the log of pressure difference was also carried out. A typical plot of test data complete with regression analysis results is shown in Fig. 3. This plot, which represents the air leakage characteristics of Barn 8, is typical of all the buildings tested. The leakage coefficient a and the flow exponent b were determined for each farm building tested and are listed in Table II.

This study followed the common practices of determining air leakage in terms of air changes per hour at a pressure difference of 50 Pa and air flow (L/s) per unit of area (m^2) of the building envelope at a pressure difference of 75 Pa. Another parameter determined in this study was air changes per hour at a pressure difference of 15 Pa. A pressure difference in the order of 15 Pa or greater across the building envelope of a farm building is recommended for winter ventilation in order to get high enough velocities at air inlets to promote good air mixing (Munroe 1988). The air leakage rate at this pressure difference indicates the portion of the ventilation air that will enter the room due to leakage as opposed to through the air inlet, assuming the room operates at this pressure.

Table II. Farm building air leakage test results

Barn No.	Internal** volume (m^3)	Air *** barrier area (m^3)	Leakage* coeff. a	Flow* expon. b	Air change per hour at 15 Pa	Air change per hour at 50 Pa	Air leakage at 75 Pa L/s per m^2
1	1329	923	1.133	0.475	11.1	19.7	9.6
2	1783	1083	1.391	0.366	7.6	11.8	6.2
3	1129	675	0.348	0.761	8.7	21.8	13.8
4	1244	759	0.993	0.489	10.8	19.5	10.8
5	1232	766	0.629	0.602	9.4	19.3	11.0
6	2147	1202	0.112	0.916	2.3	6.8	4.9
7	1238	761	0.261	0.789	6.4	16.6	10.3
8	2305	1187	0.637	0.526	4.1	7.8	5.2
9	1976	819	0.830	0.484	5.6	10.1	8.2
10	1206	625	0.446	0.648	7.7	16.8	11.7
11	916	582	1.037	0.415	12.6	20.7	10.7
12	1830	1048	1.375	0.420	8.4	14.0	8.0
13	1536	878	0.280	0.569	3.1	6.1	3.7

* Determined from log-log plot of air flow vs presssure difference.
** Note: Volume does not include attic space.
*** Air barrier area includes wall and either ceiling or roof.

RESULTS AND DISCUSSIONS

Table II lists the test results. The average air leakage at a pressure difference of 50 Pa was 14.7 air changes per hour and varied from about 6 to 22 (Table II). This is substantially higher than that found by Dumont et al. (1981), who reported a mean leakage rate of 10.35 air changes per hour for Canadian houses built before 1945, 4.55 for houses built between 1946-1960, and 3.57 for houses built between 1961 and 1980. This shows that the construction quality in terms of air tightness for Canadian farm buildings is very low when compared to residential housing.

Table II also shows that the air leakage at a pressure difference of 75 Pa expressed in terms of air flow per unit of envelope surface area ranged from 4.8 to 13.7 L/s per m^2 with an average of 8.7 L/s per m^2. Tamura and Shaw (1976) classified large building air leakage characteristics as follows: less than 0.51 L/s per m^2 is a tight building, 1.5 L/s per m^2 is an average building, and more than 3.1 L/s per m^2 is a loose building. When farm buildings are compared to these criteria, it appears that farm building envelopes perform very poorly. Table II also lists the air changes per hour measured at a pressure difference of 15 Pa, which is in the pressure difference range expected for farm buildings ventilated by exhaust fans during winter. This parameter ranged from 2.3 to 12.6 air changes per hour with a mean value of 7.5. For comparison, typical ventilation rates for poultry or feeder pig barns in winter are in the 1-5 air changes per hour range.

Effect of building style

As shown in Table III, three of the buildings tested were steel frame single storey, six were wood frame single storey, and four were wood frame two-storey. Table III gives the number of buildings tested and the mean and standard deviation of air leakage rates at 50 Pa for each building style. The means are quite similar but the standard deviations are high. From this table, there is no evidence that the building style had an effect on the leakage rate.

Effect of builder

Table IV compares the air leakage of two categories of farm buildings: those built by a contractor and those built by the farmer (owner). The buildings built by a contractor had a slightly lower average leakage at 50 Pa than those built by farmers but the standard deviation was substantially larger. Therefore, it is not obvious that farm buildings built by contractors are more air tight.

Comparison with ASHRAE prediction

The ASHRAE (1985) methodology was used to predict the air leakage rate in one of the buildings as a comparison to measured values. Barn 2 was arbitrarily selected for this case and equivalent leakage areas were estimated for different components such as doors, windows, and wall-to-ceiling joints. Following ASHRAE guidelines, the predicted infiltration rate at 15 Pa pressure difference was estimated to be 1.8 air changes per hour. From Table II, the measured rate was 7.6. It is possible that cracks are generally larger in barn construction as opposed to residential construction for which

Table III: Air leakage versus building style

Building style	No. of buildings tested	Average air change per hour at 50 Pa	Standard deviation
Steel frame, single storey	3	15.46	4.83
Wood frame, single storey	6	15.26	5.71
Wood frame, two-storey	4	13.20	7.20

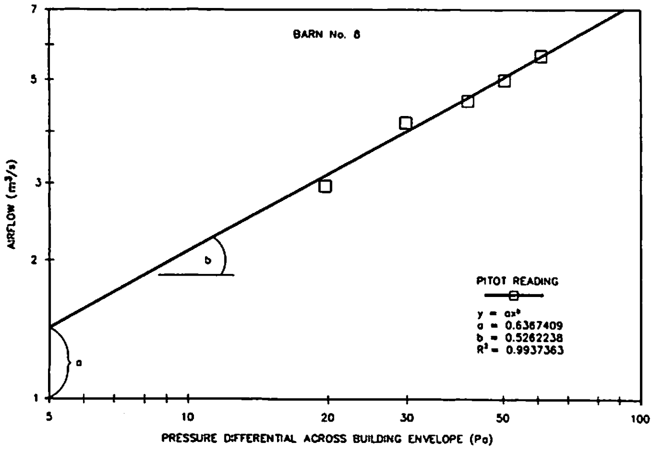

Fig. 3. Typical log-log plot of air flow versus pressure difference across the building envelope for a farm building.

Table IV: Air leakage versus builder

Builder	No. of buildings tested	Average air change per hour at 50 Pa	Standard deviation
Contractors	7	13.6	6.74
Farmer	6	15.8	4.24

leakage estimates were tabled in ASHRAE; however, further work would be required to confirm this or identify other reasons for the difference.

CONCLUSIONS

Based on the air leakage tests performed on several actual farm buildings in this study, it can be concluded that:

1. Air leakage in farm buildings was in general much greater than that predicted using methodology and leakage estimates contained in ASHRAE.
2. At a pressure difference of 15 Pa, the infiltration rates measured ranged from 3 to 12 air changes per hour which is generally well above the recommended minimum winter ventilation rates for most livestock operations which are in the order of four air changes per hour.
3. There were no apparent differences in air leakage due to building style or due to being farmer rather than contractor built.
4. The air leakage rates found in this study should be further compared with the air leakage rates predicted using the ASHRAE methodology and procedures. This will indicate if the ASHRAE crack method is suitable for farm buildings.
5. Because of the high leakage rates noted with farm buildings, component testing is required to develop better construction practices.

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REFERENCES

Allen, C. 1985. Leakage distribution in buildings. Technical Note AIC 16. Air Infiltration Centre, Bracknell, Berkshire, United Kingdom, RG12 4AH.

ASHRAE. 1985. Measurement and instruments. In *Handbook of Fundamentals*, Chapter 13. American Society of Heating, Refrigeration, and Air Conditioning Engineers, Atlanta, GA.

Caffey, G.E., 1979. Residential air infiltration. *ASHRAE Transactions* 85(1):41-57.

Dumont, R.S., H.W. Orr and D.A. Figley. 1981. Air tightness measurements of detached houses in the Saskatoon area. Building Research Note No. 178. Division of Building Research, National Research Council of Canada, Ottawa, ON.

Hunt, C.M., J.M. Porterfield and P. Ondris. 1978. Air leakage measurements in three apartment houses in the Chicago area. Interagency Report NBSIR 78-1475. National Bureau of Standards, U.S. Department of Commerce, Washington, D.C.

Massé, D.I., J.A. Munroe and H.A. Jackson. 1994. A mobile test rig for determining the air leakage characteristics of farm buildings. *Canadian Agricultural Engineering 36:181-184.*

McIntyre, I.S. and C.J. Newman. 1975. The testing of whole houses for air leakage. Building Research Establishment Note AIC No. 69. National Research Council of Canada, Ottawa, ON.

Munroe, J.A. (ed.) 1988. *Canadian Farm Buildings Handbook*, Part 6. Canadian Government Publishing Centre, Hull, QC.

Persily, A. 1982. Repeatability and accuracy of pressurization testing. *In Proceedings of ASHRAE/DOE Conference on Thermal Performance of the Exterior Envelope of the Building*, 11:380-390. American Society of Heating, Refrigeration, and Air Conditioning Engineers, Atlanta, GA.

Shaw, C.Y. 1980. Methods for conducting small-scale pressurization tests and air leakage data of multi-storey apartment buildings. *ASHRAE Transactions* 86(1):241-250.

Shaw, C.Y. and L. Jones. 1979. Air tightness and infiltration. *ASHRAE Journal* 21(4):40-45.

Tamura, G. 1975. Measurement of air leakage characteristics of house enclosures. *ASHRAE Transactions* 81(1):202-208.

Tamura, G.T. and C.Y. Shaw. 1976. Studies on exterior wall air tightness and air infiltration of tall buildings. *ASHRAE Transactions* 82(1):122.