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Wind Shelter Effects on Air Infiltration for a Row of Houses

D.J. Wilson and I.S. Walker
Department of Mechanical Engineering
University of Alberta
Edmonton, Alberta T6G 2G8

Synopsis

Once the flow-pressurization characteristics of a building are known, the largest uncertainty in predicting air infiltration is the effect of wind shelter from nearby buildings. To study the effects of wind sheltering a large data set of hourly air infiltration and meteorological measurements were made for a row of test houses located on an exposed rural site. This configuration produces strong variations in wind shelter as the wind direction shifts from along the row to perpendicular to it. A simple harmonic function is proposed for interpolating between highly sheltered and unsheltered wind directions for a building. Measurements show that the effect of strong wind shelter can change air infiltration rates by a factor of four, and strongly influence pressures that determine flow rates through passive ventilation intake and exhaust points. Measurements for buildings with varying leakage distributions are correlated to determine appropriate values for wind shelter coefficients.

Introduction

Most air infiltration models average infiltration rates over all wind directions. We have found that wind direction effects are a major source of variability in infiltration rates and are of similar magnitude to the weather effects (both windspeed and temperature difference). This has serious implications for passive ventilation for indoor air quality, making it difficult to provide an adequate minimum ventilation rate without over ventilating the building for some wind directions. Because wind shelter is very difficult to estimate accurately and has a significant effect on infiltration rates, estimates of wind shelter are one of the largest sources of uncertainty in a simple infiltration model.

Some detailed wind tunnel studies of local shielding have been made, notably Wiren (1984), and Lee, Hussian, and Soliman (1979). Only regular patterns of uniform sized obstructions were used in these studies because for more complicated configurations a systematic analysis of the results of the wind tunnel tests would be difficult. In reality, the obstructions around a building are of many sizes. Sherman (1980) produced a table of shielding coefficients to classify shielding effects. The values in Table 1 from Walker and Wilson (1990) are based on those of Sherman and are applied directly to the windspeed.

Test Site Description

The Alberta Home Heating Research Facility is made up of six permanent test houses with poured concrete basements. Their construction is described in Gilpin et al. (1980). The six unoccupied test houses have been continuously monitored since 1980 for building envelope energy losses and air infiltration and ventilation rates.

The flat exposed test site is located on rural agricultural farm land, with fields planted in forage and cereal crops in summer, becoming snow covered stubble in winter. Windbreaks of mixed poplar and spruce trees cross the landscape at intervals of a few kilometres. One of these windbreak rows with 20 meter high trees is located parallel to the line of the houses about 250 m to the north, and another windbreak lies 100m to the northeast. A low tree row with 3 meter height runs perpendicular to the line of the

Table 1. Estimates of Shelter Coefficient S_{wo} for No Flue

Shelter Coefficient	Description
1.00	No obstructions or local shielding
0.90	Light local shielding with few obstructions within two house heights
0.70	Heavy shielding, many large obstructions within two house heights
0.50	Very heavy shielding, many large obstructions within one house height
0.30	Complete shielding

buildings to the southwest. The houses are totally exposed to south and east winds. Wind shelter from man-made structures is dominated by two-storey storage and machinery buildings located about 50 m to the northeast.

The houses are situated in a closely-spaced, east-west line with about 2.6 m separation between their side walls. False end walls, with a height of 3.7 m but without roof gable peaks, were constructed beside the end houses of the line to provide wind shelter and solar shading similar to that experienced by interior houses in the row. Construction dimensions are given in more detail in Wilson and Walker (1991).

In addition to having a smaller floor area, the test modules differ from a standard house in that they have no plumbing or sewer drains, and no interior partition walls except for an entryway with an open interior doorway. The absence of interior walls promotes air mixing, and allows the house to be treated as a single air exchange zone. The houses are heated electrically with a centrifugal fan distributing air through under-floor ducts to the main-floor room. The fan in the electric heater operates continuously, recirculating 4.5 house interior volumes per hour to ensure complete mixing of air infiltration with indoor air tagged with SF_6 tracer gas. Air from the upstairs outlets returns to the basement through the large open stairwell. To avoid basement air stratification, a fan intake is located near the basement floor, and another intake is close to the ceiling.

A thermostat located on the room side of the entryway wall maintained the interior temperature at 22C ± 0.5C during the heating season. In summer, the fan continues to circulate through the house, and room temperature is governed by ventilation and heat gains through the walls and windows. Summer indoor temperature rarely differs by more than ±5C from the outdoor air.

In addition to intentional passive ventilation leakage sites each house had a leakage distribution of small cracks and holes created unintentionally during construction. The major unintentional leakage sites are: the crack between the wall sill plate and the top of the concrete basement wall; vapour barrier penetrations by electrical conduits and outlet boxes, flue pipes and plumbing vents; and cracks around the frames of windows and doors.

In addition to pressure differences of 10 Pa to 70 Pa required to meet the ASTM (1982) and CGSB (1986) fan pressurization test requirements, the pressure-flow characteristic of the house envelope was measured at low pressures of 1 Pa to 10 Pa that are typical of actual wind and stack effects. The results from over 2500 pressurization tests are summarized in Table 2, where the pressure-flow characteristic of each house has been fitted to the power law

$$Q = C(\Delta P)^n \tag{1}$$

where C is a flow coefficient dependent on leakage flow area and n is an exponent that characterizes the type of leak and ΔP is the pressure difference across the building envelope. The exponent n must lie between n = 0.5 for flow through sharp edged holes to n = 1.0 for laminar flow through long, thin, straight cracks. Because the ensemble of cracks and holes that make up a leakage distribution usually vary widely in their size and shape, the value of n lies between the limits $0.5 \le n \le 1.0$. Measurements for short pipes by Kreith and Eisenstadt (1957) suggest n = 0.67 for laminar flow in short cracks typical of envelope construction leakage sites. The values in Table 2 are from tests with windows closed and the flue and passive intake sealed to leave only distributed "background" leakage.

Table 2

Distributed Background Envelope Leakage from Fan Pressurization Tests With Flue and Passive Vent Intake Sealed, Windows Closed
$Q = C(\Delta P)^n$

House	PRESSURIZATION			DEPRESSURIZATION		
	Flow Coefficient C $m^3/(s{\cdot}Pa^n)$	Flow Exponent n	Leakage Area A_L cm^2 at 4 Pa	Flow Coefficient C $m^3/(s{\cdot}Pa^n)$	Flow Exponent n	Leakage Area A_L cm^2 at 4 Pa
4	0.00684	0.712	71.0	0.00592	0.742	64.1
5	0.00937	0.625	86.3	0.00970	0.661	93.6

Air Exchange Measurements

The total amount of outside air brought in by combining natural infiltration, passive ventilation, and fan exhaust was measured using a tracer gas system that injected sulphur hexafluoride, SF_6, to maintain a constant concentration in each of the test houses. The total volume of tracer gas, injected eight times each hour, is proportional to the amount of outside air that enters the house and is brought up to the 5.0 ppm setpoint. The gradual decrease of concentration in each of the 7.5 min periods between injections was accounted for in the data analysis to determine a true hourly average concentration, typically 4.8 ppm. The calibration and operating techniques applied to the gas analyzers is described in more detail in Wilson and Walker (1991).

Measurement uncertainty was much smaller than the hour-to-hour natural variability of the air infiltration rate. An uncertainty analysis of the injection and concentration measuring systems indicated that the standard deviation in measured infiltration rate was ±2.5% of the air exchange rate, added to an absolute error of ± 0.0025 ACH. This corresponds to a measurement uncertainty standard deviation of about ±3% at typical air exchange rate of 0.3 ACH. For random variations this implies a range of about ±6% to encompass 95% of data scatter due to uncertainty.

The wind speed and direction at 10 m height was measured with low-friction cup anemometers and rotating direction vanes. Wind speeds and directions were measured at 2.5 minute intervals and averaged to produce one hour average values. Both the mean and standard deviation of these 24 readings for wind speed and direction were recorded. In addition, east and north vector components of each of the 24 readings were calculated, and stored as mean-squared averages over the hour. These mean-square values were then be used to compute the standard deviation of wind speed, and to calculate a true average wind-run direction.

Data Reduction and Normalization

To minimize stack effects, the data was sorted to include only temperature differences less than 10°C and relatively high windspeeds of 3 to 10 m/s. The ventilation rates are normalized by dividing by U^{2n} to remove the variation due to windspeed, U, (where n is from fan pressurization test results, in Table 2) and then binned every 30° of wind direction (θ). The final normalization is performed by dividing by the average ventilation rate for winds from the south (θ = 180° ± 15°). This is done because the building has no shelter from winds from the south and the shielding factor for southerly winds will be unity. There is a relationship between the shielding factor, S_w, and the normalized air exchange rate, Q_{normal} as follows:

$$Q_{normal} = S_w^{2n} \tag{2}$$

Wind Shelter Effects for a House with Uniform Leakage Distribution

When wind shelter effects on test house #5 with a 0.15 m I.D. flue were examined by Wilson and Dale (1985) they found very little variation of ventilation rate with wind angle. Figure 1 shows data for this house configuration in both unbinned and binned form. The unbinned data shows the large number (975) of data points used, their uneven distribution with wind angle and the scatter present in the data. To reduce these effects and to make for clearer data analysis the binned data is also shown, where the central square is the mean value and the error bars are ± one standard deviation for each bin. Figure 1 shows that the shelter of the row of buildings only changes the ventilation rates by less than 17%. This small effect of changing wind shelter is due mainly to the large flue (about 60% of total leakage) that is unsheltered from wind effects.

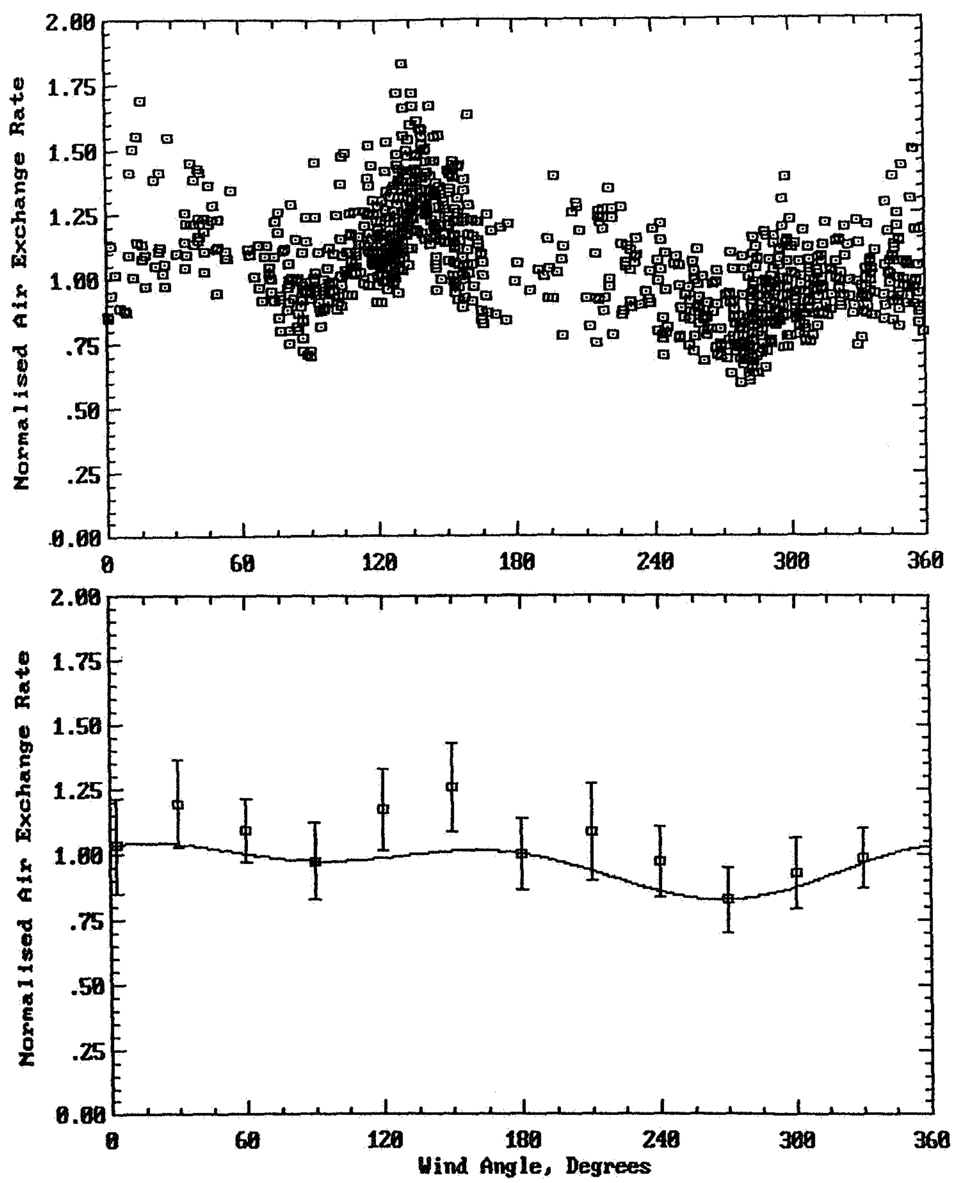

Figure 1. Measured wind shelter for House #5 with an open 0.15 m I.D. flue (975 hours)

The line shown in all the figures is generated by an empirical equation for estimating S_w as a function of wind angle, proposed by Walker (1989), and used in the single zone air infiltration model AIM-2, Walker and Wilson, (1990):

$$S_w = \frac{1}{2}\left[(S_1+S_3)\cos^2\theta + (S_1-S_3)\cos\theta + (S_2+S_4)\sin^2\theta + (S_2-S_4)\sin\theta\right] \qquad (3)$$

where S_1 through S_4 are the S_w values for winds normal to sides 1 through 4 of the building, numbered clockwise from side 1, and θ is the wind angle measured clockwise (looking down) from the normal of side one. The shielding values for S_1, S_2, S_3 and S_4 for the theoretical lines in the figures were calculated from the measured data by averaging the normalized data in the bins at $\theta = 0°$, $\theta = 90°$, $\theta = 180°$, $\theta = 270°$, (North, East, South and West directions).

In Figure 2 the data shown is for house #5 with the flue blocked. As expected this data shows stronger sheltering with air exchange rates reduced by 23% for east winds and 34% for west winds. These correspond to a windspeed reduction factor, S_w, of 0.82 and 0.73 respectively (with n = 0.65). Note that the reduction in effective windspeed is less than the reduction in infiltration rate (see equation 2).

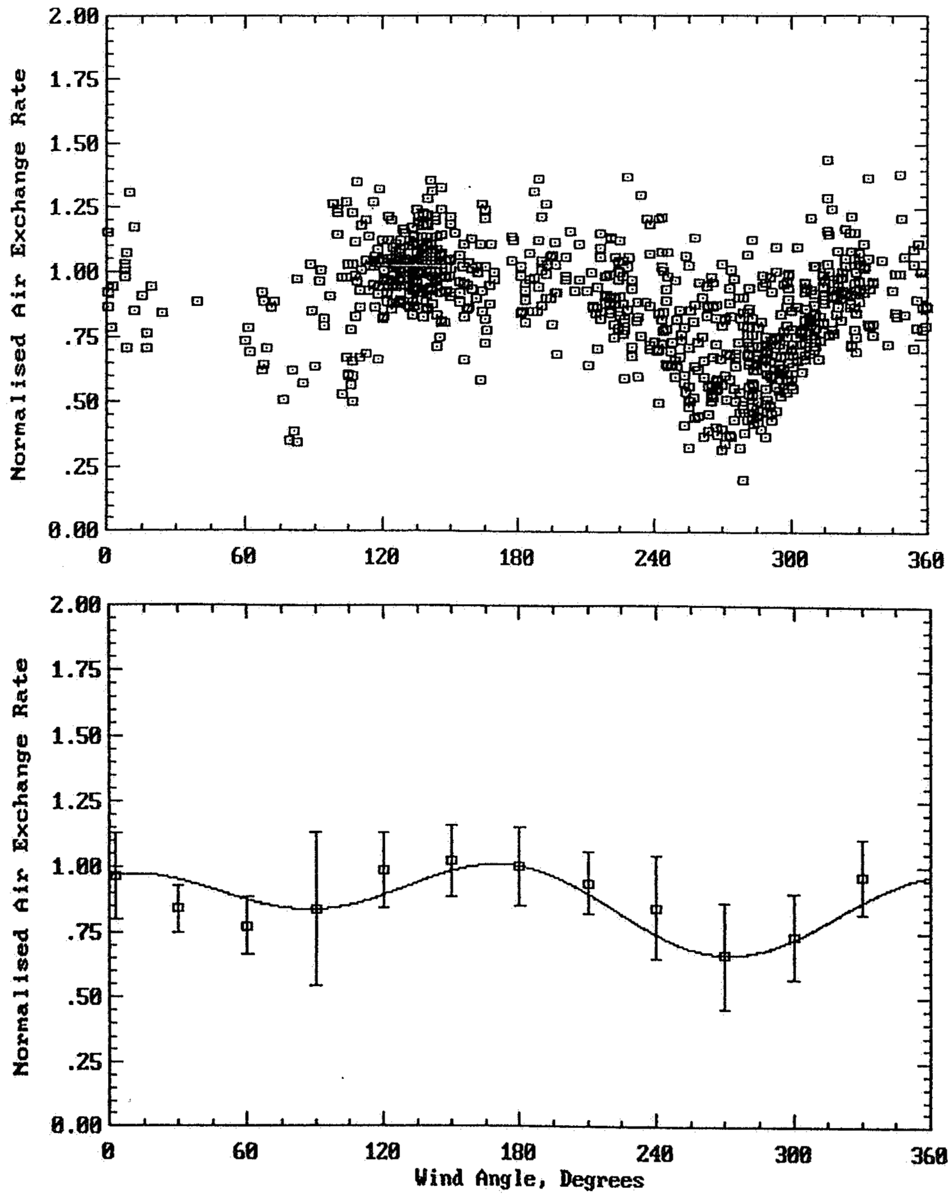

Figure 2. Measured wind shelter for House #5 with no flue (823 hours)

Effect of Varying Leakage Distribution

Most houses in rows have windows and doors concentrated on their exposed sides. House #4 has large south facing windows and is thus more typical of row house construction than house #5 with its evenly distributed leakage. Figure 3 shows how this concentration of leakage in one wall makes the ventilation rate much more sensitive to wind direction. Because most leakage is concentrated in the south-side windows, and the north wall is blank, the infiltration rate when the wind is from the north is only 41% of that for south winds.

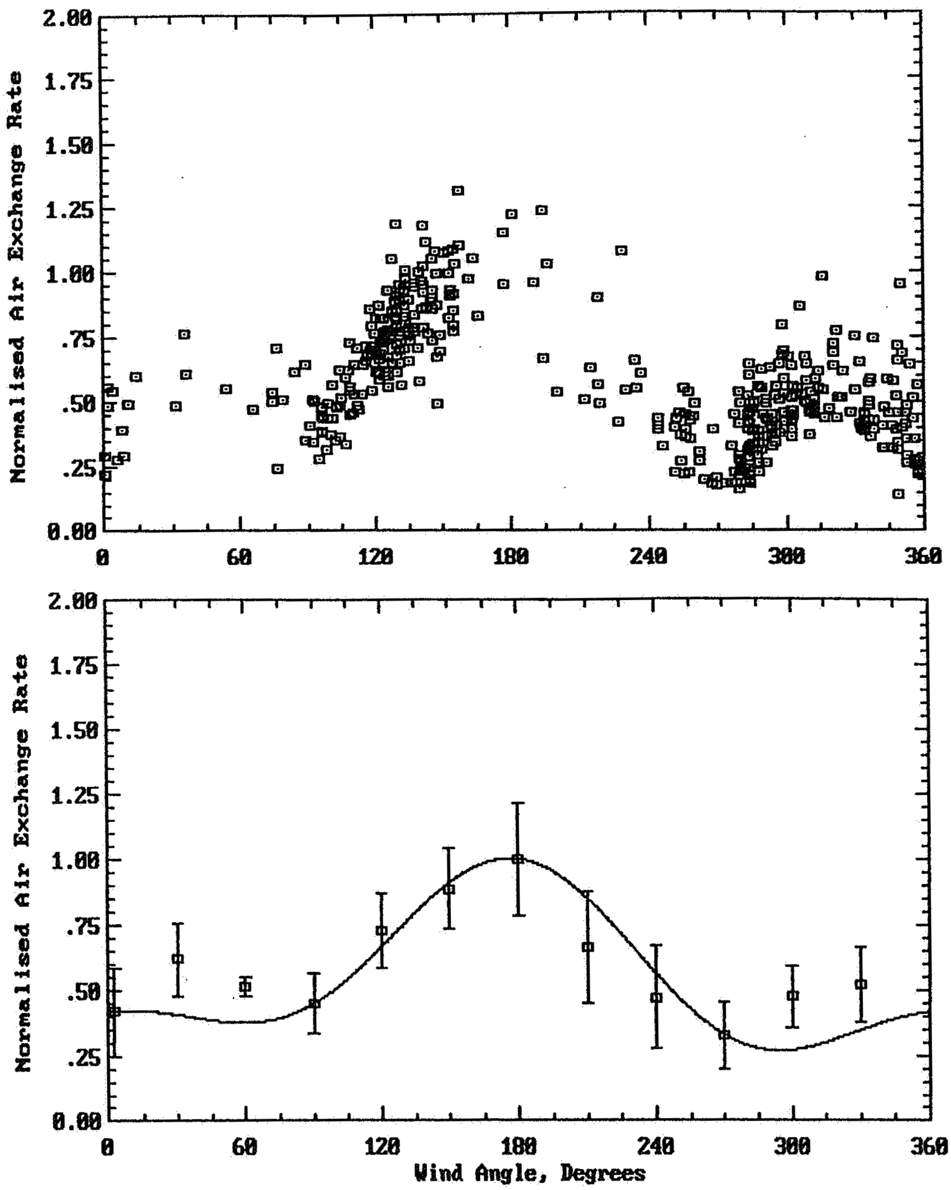

Figure 3. Measured wind shelter for House #4 with no flue (427 hours)

The effects of the row shelter are much greater than in house #5. The air exchange rates are reduced by 55% and 68% for east and west winds respectively. Thus S_w = 0.57 and 0.46, i.e. about a factor of 2 reduction in effective windspeed. A total of 427 points are shown in Figure 3. The individual points and the standard deviation bars in the binned data show that for a narrow wind angle ranges about west (270°) the air exchange rate is reduced by 80% (S_w = 0.32) indicating a factor of 5 difference between shielded and unshielded ventilation rates.

Figure 4 shows that opening a furnace flue that is about one third of the total leakage area of house #4 reduces the variation in ventilation rates to a reduction of 27% and 41% for east and west winds (S_w = 0.79 and 0.67). This is greater variation than in house #5 with the flue blocked which indicates that large influence the asymmetric leakage distribution. Warren and Webb (1980) found a similar variation in shielding effects for a house in the middle of line of common-wall row houses.

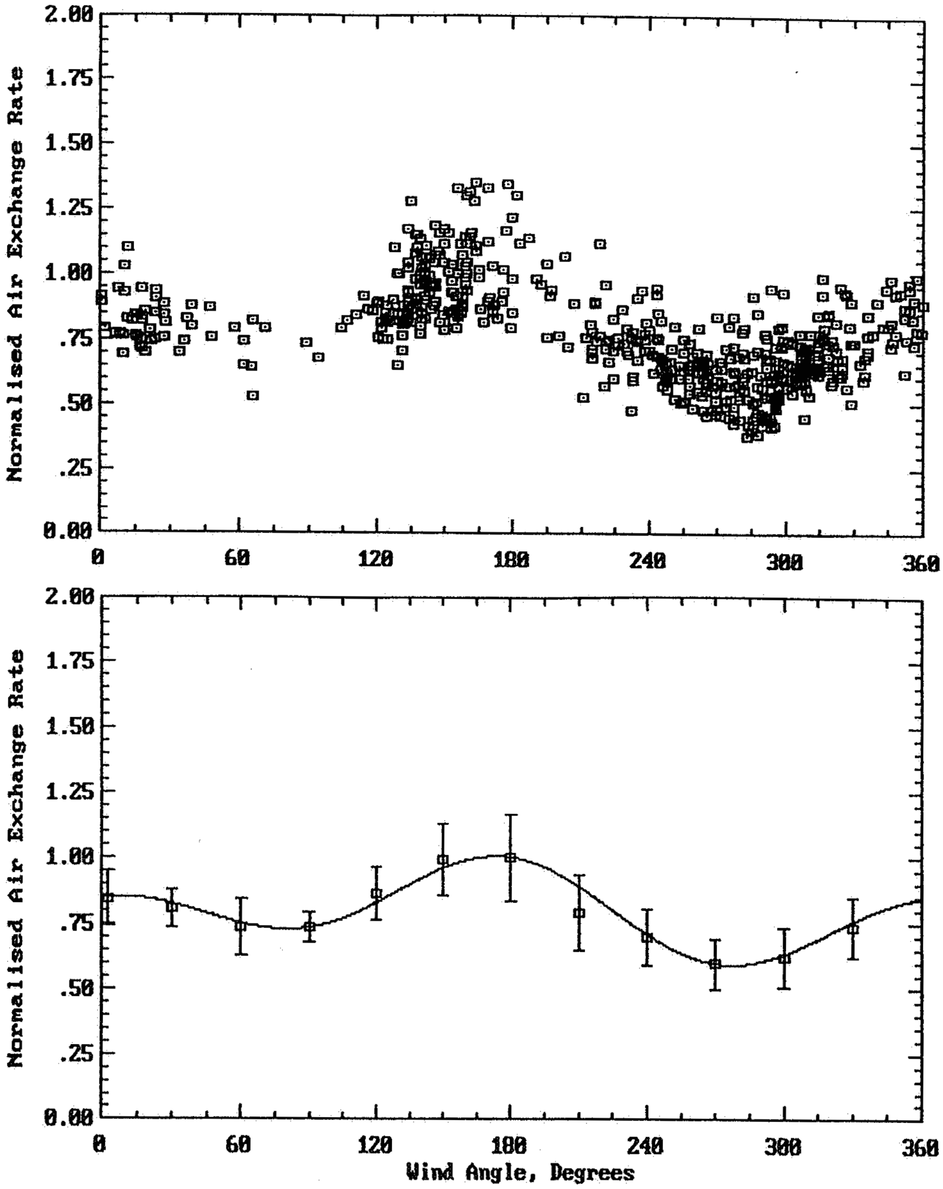

Figure 4. Measured wind shelter for House #4 with 0.075 m restriction orifice in 0.15 m I.D. flue (580 hours)

Accounting for Furnace Flue Contribution to Shelter

To find a shielding factor, S_w, that can be used to correct the windspeed used in simple infiltration models the following simple linear empirical relationship may be used. This relationship allows the flue to experience different shelter effects than the rest of the house (usually the flue is unsheltered and $S_{wf} = 1.0$).

$$S_w = (1-Y)S_{wo} + Y\,S_{wf} \qquad (4)$$

where S_{wo} = wind shielding factor for building
S_{wf} = wind shielding factor for flue
Y = fraction of total building leakage in flue

Measured values of shelter factor for a house with a flue and those calculated using equation (4) are compared in Table 3. This shows that equation (4) is a good rough approximation but does not always give adequate predictions, however it is hard to justify using a more sophisticated method, given the uncertainty in estimating building shelter.

Table 3. Furnace Flue Contribution to Shelter

House #	Wind Direction	S_w		
		No Flue Measured, S_w	With Flue Measured	With Flue Predicted
5	East	0.86	0.98	0.94
	West	0.70	0.85	0.88
4	East	0.57	0.78	0.71
	West	0.46	0.68	0.63
1	East	0.68	0.66	0.87
	West	0.48	0.64	0.79

Summary and Conclusions

A detailed set of air infiltration measurements using a constant concentration tracer gas system in a row of houses have been used to examine the variation in residential building infiltration rate with wind direction. The results of this testing give rise to the following points.

- Wind shelter can change ventilation rates by up to a factor of five for houses in a closely-spaced row.
- Changes in shelter produce changes in ventilation rates that are as important as the wind and stack driving forces.

- A simple harmonic function effectively interpolate between sheltered and unsheltered wind directions.
- Shelter is less effective in buildings with uniformly distributed leakage sites.
- An unsheltered furnace flue reduces wind shelter effects. A simple empirical relationship has been found to account for this effect.

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