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Drained and Vented Cavity Walls – Measured Ventilation Rates

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Drained and Vented Cavity Walls – Measured Ventilation Rates

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ABSTRACT

Ventilation drying is an effective way of removing moisture from drained and vented cavity walls. Wall designs with water managed cavities are being prescribed in greater numbers in New Zealand by Code documents recently revised to deal with the leaking buildings problem. The research described here used a tracer based method to measure ventilation rates in seven different walls in a test building at BRANZ. It is part of a larger programme developing a design path for the effective management of water in cavity walls. Carbon dioxide was used as the tracer because continuously reading non-dispersive gas analysers are readily available and because the gas is reasonably inert in walls not containing cement based products. In these measurements, tracer was injected at a constant rate into the water managed cavities and the concentration of tracer in the cavity interpreted in terms of a ventilation rate. Ventilation rates were found to be similar to theoretical estimates in drained and ventilated walls, but higher than expected for open rainscreen walls. The reason for this is thought to be due to natural infiltration paths in open rainscreen walls allowing similar ventilation processes, but on a smaller scale to those in drained and ventilated walls.

KEYWORDS: weathertightness, cavity ventilation, tracer methods

1. BACKGROUND – PREVIOUS RESULTS

It is becoming more common in New Zealand for wall designs to follow the 4 D's principles of water management proposed by Hazleden and Morris (1999). This paper deals with the third of the D's which requires walls to be able to "dry" water from the back of the cladding. The usual way to acquire this drying capability involves adding a ventilated cavity directly behind the cladding. Two ventilated wall cavity designs (drained and ventilated brick cavity walls and vented cavity stucco walls) have a lengthy track record of acceptable moisture performance in New Zealand. However, there is no established moisture design process that can be used to decide on the ventilation provisions that will work best with other wall claddings.

The theory of cavity ventilation has been developed by Burnett and Straube (1995) with equations that link ventilation rates with wind and buoyancy pressures and the geometry of the cavity. This theory has been interpreted for New Zealand wall styles and climate in a companion paper by Bassett and McNeil (2005). There have been few direct measurements of wall cavity ventilation rates, although air velocities have been measured with hot wire anemometry or inferred from pressure and air flow resistance measurements. TenWolde et al (1995) measured air pressure differences between the top and bottom vents of wall cavities and calculated ventilation rates from detailed airtightness measurements. These results were used to consider options for controlling moisture in timber-framed walls in cold climates. Air velocities in cavities have been measured on a number of occasions with hot wire anemometry. The results of these measurements have been summarised by Burnett and Straube (1995).

Direct measurements of cavity ventilation with tracer gasses has proved difficult in the confined dimensions of wall cavities, but a series of air flow rates have recently been measured in a ventilated wall cavity by Gudum (2003). These measurements continuously injected the tracer N_2O into the centre of the cavity and supported the results with hot wire air velocity results. The air velocity in the cavity was found to fluctuate in a way that was difficult to relate to wind and temperature data. In comparison, the tracer measured air flow rates were found to have a much longer time constant, but correlated reasonably well with wind pressures. The long time constant of the constant emission tracer method was considered to limit application to the measurement of long-term average ventilation rates.

2. A TRACER BASED METHOD AND EQUIPMENT

The results reported here used a Gascard II infra-red gas monitor (manufactured by Edinbrough Instruments Ltd) to measure the concentration of carbon dioxide used as a tracer gas. This duel wavelength sensor was calibrated in the 0 to 3% range and assembled together with gas lines and solenoid valves to sample and deliver tracer gas to a wall cavity. Figure 1 shows the main components in the system along with the layout of sampling and dosing points in the wall cavity. Air was sampled from four points on one side of the cavity and returned, along with the continuous supply of CO_2, to the opposite side of the cavity. Sampling flow rates were adjustable in the range 2 to 12 cc/s and the CO_2 dosing rate was similarly adjustable, taking values between 0.3 and 4 cc/s in the measurements reported here. Sampling airflow rates across the cavity were chosen primarily to minimise sampling transport delays and to minimise interference with ventilation flows up or down the cavity. Questions relating to mixing processes within the cavity are addressed later.

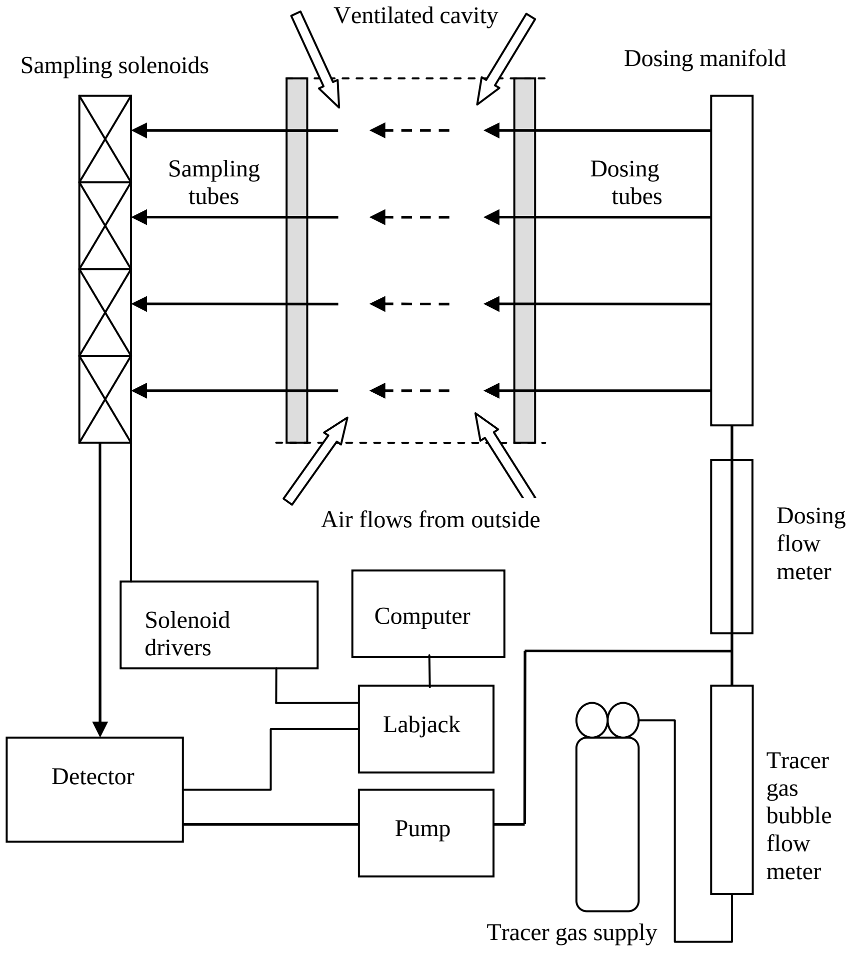

Figure 1: Configuration of tracer based equipment for measuring cavity ventilation rates.

3. ACCOUNTING FOR TRACER ABSORPTION IN BUILDING MATERIALS

There are a number of systematic issues that have to be dealt with when a tracer gas is used to measure a ventilation rate. One of these is possible absorption of tracer by building materials in the cavity. Carbon dioxide takes part in the carbonation process in cement based materials and is partially soluble in the moisture in damp materials. A series of absorption rate measurements were conducted to establish the limits of applicability of CO_2 as a tracer. These were carried out in a 1 m^3 non-absorbing plastic container, and the measured absorption rates are given in Table 1 along with the correction this would introduce into a cavity ventilation rate.

Table 1: Absorption of CO_2 in materials likely to be present in water managed wall cavities.

Material	**Approximate CO_2 absorption rate at a concentration of 0.02. Absorption rates below have units (mg/s.m^2)**	**CO_2 absorption expressed as a ventilation rate correction for a 20 mm deep cavity containing one face (or 2.4 m^2/m) of the absorbing material (l/s.m)**
Pinus radiata framing timber	< 0.02 Below measurement resolution	<0.002 Below measurement resolution
Fibre cement exterior cladding (type A)	0.5	0.1
Fibre cement exterior cladding (type B)	0.2	0.03
Fibre cement cladding with one coat of acrylic paint	< 0.02 Below measurement resolution	<0.002 Below measurement resolution
Paper faced gypsum interior lining (unpainted)	< 0.02 Below measurement resolution	<0.002 Below measurement resolution

The CO_2 absorption characteristics in Table 1 show that very low ventilation rates measured in cavities containing new fibre cement materials might need a correction for tracer absorption, eg ventilation rates below about 0.5 l/s.m that might be measured in an open rainscreen wall cavity. It turns out though that the absorption rate for CO_2 declines as the carbonation process advances in the material so that absorption will be less of a problem in old material. Figure 2 shows the absorption process declining over a period of about 10 days in our chamber as repeated concentration decay measurements were completed. The CO_2 absorption rate is expressed for convenience as an equivalent ventilation rate in a 20 mm deep cavity with one wall of the cavity lined in the absorbing material (ie the cavity contains 2.4 m^2/m of material surface). If a ventilation rate was measured in such a cavity, it would be necessary to subtract the equivalent ventilation rate from the results. All of the measurements reported in this paper are in cavities containing non-absorbent materials (all of the fibre cement wall linings were painted). However, corrections for absorption are expected to be necessary when the CO_2 tracer methods are used in fibre cement clad houses.

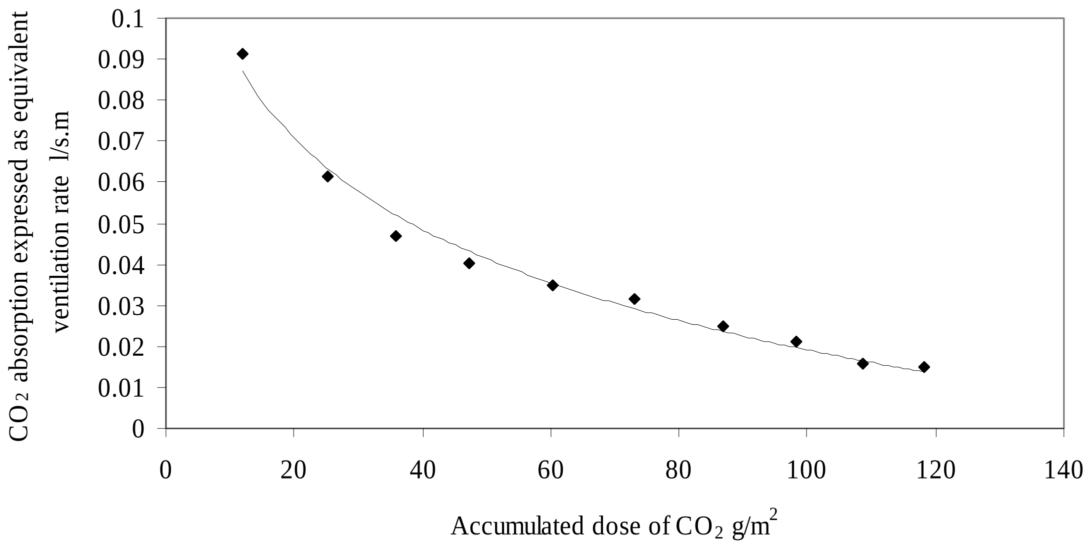

Figure 2: Absorption of CO_2 in fibre cement materials declining as the carbonation processes advances.

4. THEORETICAL VENTILATION RATES

The theory of ventilation has been applied to New Zealand wall cavities in a companion paper Bassett and McNeil (2005), and these methods have been used to compare predicted and measured ventilation rates in section 5. The comparison extends to open rainscreen walls (vented only at the bottom) and drained and ventilated cavities which have additional vents at the top.

4.1 Open rainscreen wall cavities

Ventilation rates in open rainscreen walls are difficult to estimate because it is likely that natural infiltration will dominate ventilation due to fluctuating wind pressures around the building. It has been estimated by Burnett and Straube that atmospheric pressure fluctuations (in time and space) might explain a ventilation rate in the range 0.01 - 0.1 l/s.m in an airtight wall cavity (excluding bottom vents), but the walls in New Zealand houses are not designed to meet airtightness targets. It has been shown by Bassett and McNeil (2005) that infiltration air flows through walls are likely to exceed ventilation due to fluctuating wind pressures. Another likely infiltration path might involve natural leakage openings in the head of the cavity, in effect turning the cavity into a drained and vented system with small top vents. These are more likely in the experimental walls used in this study than infiltration through the wall because these walls use a single sheet of internal lining and were detailed to be airtight. For this reason, theoretical ventilation rates for the open rainscreen walls have been calculated as though they were drained and ventilated cavities with a top vent. The size of the top vent was chosen somewhat arbitrarily as 100 mm^2, representing 18% of the bottom vent area.

4.2 Drained and ventilated wall cavities

The theory of ventilation in drained and ventilated cavities follows Burnett and Straube in solving for the ventilation rate Q in the following equation in terms of the pressure distribution across the various air flow resistances in the cavity. The total pressure driving the ventilation process ΔP_{total} can in turn be expressed in terms of wind and stack pressures.

$$\Delta P_{total} = \xi \frac{\rho}{2}\left(\frac{Q}{A_{vent1}}\right)^2 + \xi \frac{\rho}{2}\left(\frac{Q}{A_{vent2}}\right)^2 + \frac{Q\,h}{4611\,\gamma\, d^3\, b}$$

The applied pressure difference between the top and bottom vents $\Delta P_{total} = \Delta P_{stack} + \Delta P_{wind}$

Where : $\Delta P_{stack} = 3465\, h\left(\frac{1}{T_{cavity}} - \frac{1}{T_{outside}}\right)$ and $\Delta P_{wind} = \frac{\rho}{2} v^2 \left(C_p^{top\,vent} - C_p^{bottom\,vent}\right)$

Q	= air flow rate in cavity (m^3/s)
ρ	= density of air (kg/m^3)
ξ	= a lumped flow resistance taken as 0.5 at the entrance vent and 0.88 at the exit vent
A	= area of vent opening in (m^2)
h	= height of the cavity (m)
γ	= is a roughness factor taken as 0.8 for brick veneer and 1.0 for other walls
d	= depth of cavity (m)
b	= breadth of cavity – typically the gap between battens (m)
T	= temperature absolute (K)
v	= wind speed at roof height (m/s)
C_p	= wind pressure coefficient relative to wind speed at roof height

The cavity ventilation rates calculated in section 5 have used the wind pressure coefficients of Bowen (1976) re-presented by Liddament (1986), and all of the cavity and vent dimensions were as measured for each wall.

5. MEASURED VENTILATION RATES

5.1 The experimental walls

Ventilation rates were measured in the water managed cavities of wall specimens built into the experimental building shown in Figure 3. The north and south facing long walls each contain 10 wall panels 1.2 m wide by 2.4 m high and there are two panels on the east and west sides. The building has been constructed to study drying rates and how these depend on provisions for water management, but it also provided a wide range of cavities in which to measure ventilation rates.

Figure 3: Experimental building at BRANZ used for ventilation measurements.

Ventilation rates were measured in seven wall panels, three of which were open rainscreen designs (ORS) and four contained drained and ventilated cavities (D&V). Table 2 gives the cavity and vent dimensions for each of these walls along with the materials used in the claddings. All of the walls have the same frame, building wrap, insulation and internal lining that follow common practice in New Zealand. Note that the open rainscreen walls have been allocated an arbitrary 100 mm^2 top vent opening. Top vents were not designed into these walls, but the claddings were not sealed to the frames and there will be an infiltration path at the head of the vented cavity.

Table 2: Measured wall cavity and vent dimensions and cladding materials except for the top vent areas for walls 1, 2 and 3 which were assigned.

	Wall 1	**Wall 2**	**Wall 3**	**Wall 11**	**Wall 12**	**Wall 15**	**Wall 16**
Cavity vent type	ORS	ORS	ORS	D&V	D&V	D&V	D&V
Cavity depth mm	20	20	20	20	40	40	20
Cavity width mm	550	550	550	550	1200	1200	550
Top vent area mm^2	100	100	100	560	1650	1220	560
Bottom vent area mm^2	560	560	560	560	1970	3150	560
Cladding type	F cement	F cement	F cement	F cement	brick	brick	F cement

The sizes of most purpose-built vents were carefully measured during construction, but there was no easy way to control vent sizes in the two brick veneer walls. In this case, the vent air leakage characteristics were measured as an effective leakage area. This involved pressurising the cavity with a metered air flow *Q* and fitting data to the following relationship:

$$Q = ACd\left(\frac{2\Delta P}{\rho}\right)^n$$

Because the vents are large slot openings between bricks, Burnett and Straube have been followed in setting the discharge coefficient Cd = 0.61 and the flow exponent n = 0.5. The effective leakage areas for top and bottom vents in walls 12 and 15 measured by this method were similar to areas estimated geometrically and are given in Table 2.

5.2 Measured and calculated cavity ventilation rates

Continuous records of the CO_2 concentration in each wall cavity were recorded over a period of at 5 to 20 days along with the measured tracer delivery rate which remained constant throughout the measurements. It was always necessary to adjust the tracer delivery rate for each wall in the early stages to ensure the tracer concentrations stayed within the 0 to 3% calibrated range of the detector. The average ventilation rate was determined from the 15 minute averaged tracer concentration at the four measurement points in the cavity using the following relationship:

$$q = \frac{g}{b(C-c)}$$

Where q = flow rate in cavity (l/s.m)
g = tracer emission rate cc/s
C = measured average tracer concentration in the cavity
c = atmospheric concentration of tracer
b = breadth of the cavity (gap between battens in mm)

The temperatures inside the water managed cavity and outside were measured at 15 minute intervals and average wind speed and direction results were recorded 10 m above ground at minute intervals and averaged over 15 minutes.

The day average ventilation rates in Figure 4 were measured in the open rainscreen walls 1, 2 and 3. These have been plotted against a theoretical ventilation rate calculated using the methods in section 4, measured temperatures and wind speed and direction, and the data in Table 2.

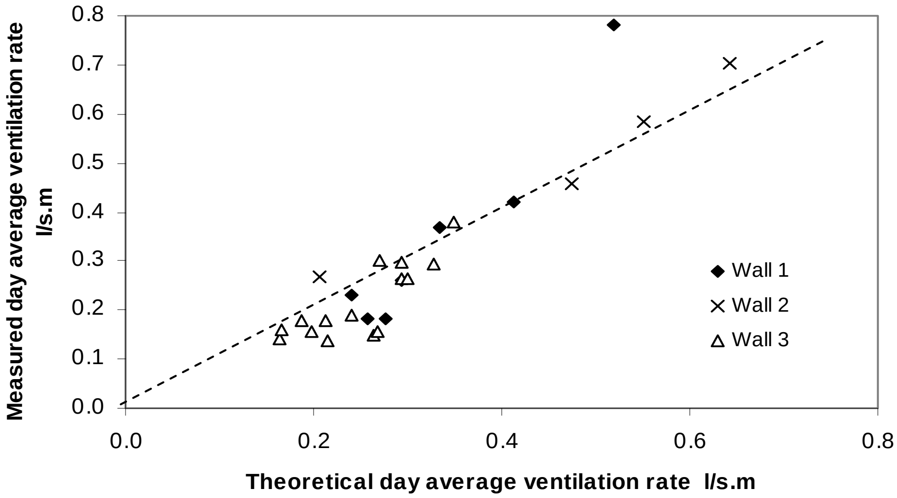

Figure 4: Day average ventilation rates in open rainscreen wall cavities.

These average ventilation rates in the open rainscreen walls were generally higher than can be explained in terms of pressure fluctuations, so a theoretical model involving infiltration paths in the wall has been trialled. Although the theoretical ventilation rates calculated in Figure 4 involve an arbitrary air leakage area of 100 mm^2 at the head of each cavity, it is a plausible leakage area for an infiltration path and the ventilation rates agree reasonably well with measured data for the three walls.

The tracer method is considered to have a reasonably long time constant (typically around 10 minutes) and therefore can not be used to measure ventilation changes on a short time scale. Calculated and measured ventilation rates are shown in Figure 5 as hour averages. As expected, the data is more scattered around the line of agreement than the day averages in Figure 4.

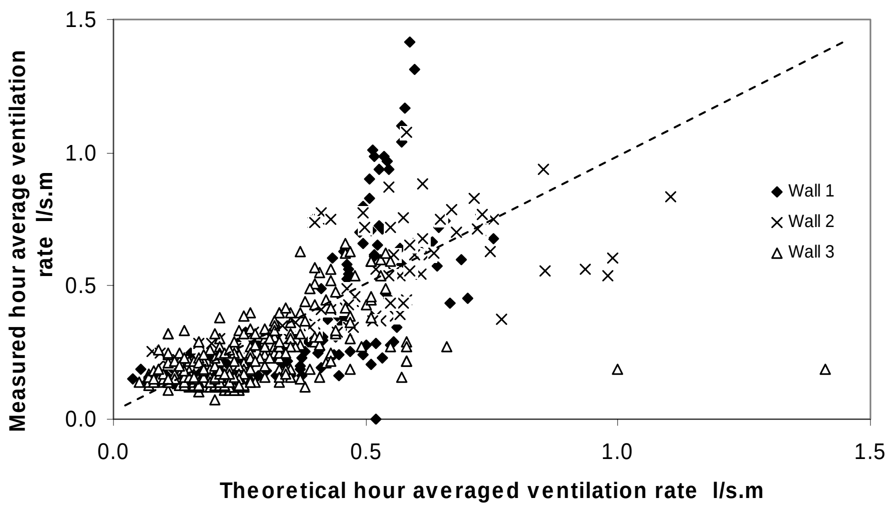

Figure 5: Hour averaged ventilation rates in open rainscreen wall cavities.

Day averaged theoretical and measured ventilation rates for the four drained and ventilated cavities are given in Figure 6. Perhaps surprisingly, the agreement between measured and theoretical results is less clear than for the open rainscreen cavities. The authors think that some of this scatter could be reduced using measured wind pressure coefficients instead of those taken from the reference data of Liddament (1986). The average measured and theoretical ventilation rates though are similar for each wall as indicated in Table 3, and this suggests a reasonable theoretical basis has been established for calculating average cavity ventilation rates. For open rainscreen walls, it is suggested that a more detailed study of the infiltration paths may be rewarding. It is likely that ventilation rates in open rainscreen walls will be rather closer to the ventilation performance of drained and ventilated walls than previously thought.

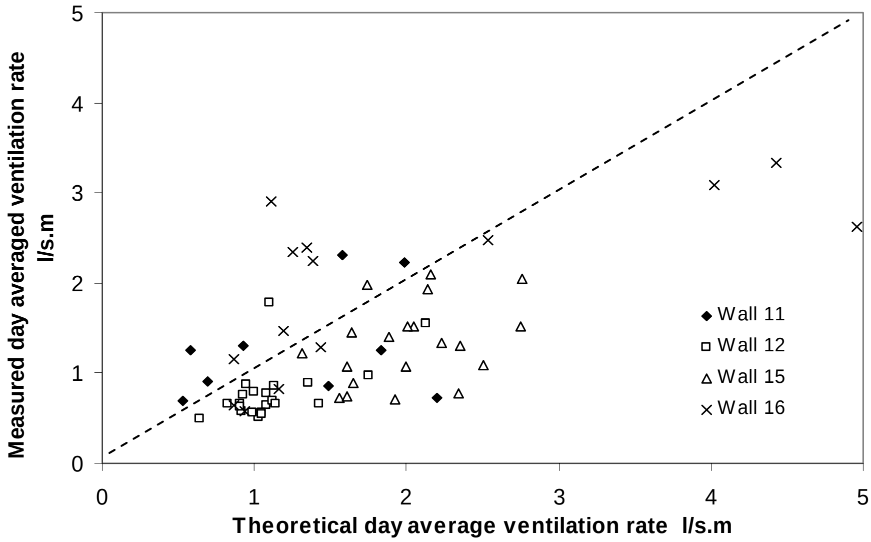

Figure 6: Day averaged ventilation rates in drained and ventilated wall cavities with line of agreement.

Table 3: Average measured and calculated ventilation rates in the cavities of seven walls.

Data	Wall 1	Wall 2	Wall 3	Wall 11	Wall 12	Wall 15	Wall 16
Cavity vent type	ORS	ORS	ORS	D&V	D&V	D&V	D&V
Duration of measurement (h)	175	136	360	171	472	453	307
Measured ventilation rate (l/s.m)	0.35	0.52	0.22	1.38	0.75	1.32	1.90
Calculated ventilation rate (l/s.m)	0.33	0.49	0.25	1.25	1.13	1.99	1.85
Average calculated driving pressure (Pa)	1.5	2.9	0.9	1.5	0.6	1.8	3.2
Average wind speed at 10 height (m/s)	2.7	4.8	2.0	2.4	2.1	2.9	3.8

5.3 Discussion on experimental method

Any application of tracer methods raises a number of system related questions. The first of these concerns possible losses of tracer by absorption in building materials and this has been dealt with in section 3. There were no wall cavities in this study containing unpainted fibre cement cladding materials, although the two brick veneer cavities in walls 12 and 15 contain some mortar jointing that is potentially absorbing.

The second possibility is that sampling and dosing process actually drive the ventilation process in some way. This has been minimised in these measurements by arranging for the dosing and sampling flow to be perpendicular to the ventilation flows in the cavity. Furthermore, the sampling and dosing flows were always small compared with the measured ventilation rate. To confirm that the measured ventilation rates do represent air flows through the vents, the vents in walls 16 and 15 were temporarily blocked, during which time average ventilation rates were measured over four days in each case. The average ventilation rates measured were 0.1 l/s.m and 0.27 l/s.m respectively or 5% and 20% of the open vent measurements. These residual ventilation rates are thought to be due to infiltration paths which were shown by airtightness measurements to be significant in the brick veneer walls, but they indicate that most of the ventilation measured in the cavities involved air flowing through the vents.

The final question concerns the uniformity of tracer in the cavity and whether or not tracer was short circuited from the cavity. This question is normally addressed by rearranging the locations of dosing sampling points and showing that the ventilation result is insensitive to these changes. Several alternative dosing and sampling arrangements were found to have no influence on the results presented in this paper, but the question of dosing small cavities is going to be investigated further in the context of drainage plane cavities.

6. CONCLUSIONS

A tracer based method has been developed to measure average ventilation rates in water managed wall cavities. The automated system injects the tracer gas carbon dioxide into the wall cavity at four points and samples air from another four points. It was deployed in seven specimen walls built into an experimental building at BRANZ. Measured ventilation rates have been compared with ventilation rates calculated for the same wall cavities from measured wind and temperature data. The following conclusions are drawn:

1. We expected to measure between 0.01 and 0.1 l/s.m of ventilation in the three experimental open rainscreen walls caused by atmospheric pressure fluctuations. The average measured ventilation rate was significantly higher (0.4 l/s.m), indicating that infiltration paths present in the structure contribute to the ventilation process.
2. An arbitrary infiltration path of 100 mm^2 was added to the head of the three open rainscreen walls to allow ventilation rates to be calculated as though the cavities were drained and ventilated. With this assumption in place, the calculated ventilation rates for all three walls agree well with measured data.
3. The average ventilation rate (over 60 days of measurement) in the four drained and ventilated walls was 1.4 l/s.m compared with 1.5 l/s.m predicted from the climate data. The ventilation rates were higher than in the cavities of open rainscreen walls, but the difference between the two wall types was less than expected.

7. ACKNOWLEDGEMENTS

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8. REFERENCES

Bassett, M.R. & McNeil, S. 2005. *The theory of ventilation drying applied to New Zealand cavity walls*. Proceedings of the IRHACE Conference, Nelson.

Bowen, J.J. 1976. *A wind tunnel investigation using simple building models to obtain mean surface wind pressure coefficients for air infiltration estimates*. NRC Report LTR-LA-209, National Research Council of Canada.

Burnett, E. & Straube, J. 1995. *Vents, ventilation drying, and pressure moderation*. Canada Mortgage and Housing Corporation Research Report, Ottawa.

Gudum, C. 2003. *Moisture transport and convection in building envelopes – Ventilation in light weight outer walls*. PhD Thesis, Technical University of Denmark. http://www.byg.dtu.dk/ under Publications R 047.

Hazleden, D.G. & Morris, P.I. 1999. *Designing for durable wood construction: the 4D's*. 8th. International Conference on Durability of Building Materials and Components, Vancouver, Canada.

Liddament, M.W. 1986. *Air infiltration calculation techniques – An applications guide*. Air Infiltration and Ventilation Centre, Bracknell.

TenWolde, A., Carll, C. & Malinauskas, V. 1995. *Airflows and moisture conditions in walls of manufactured homes*. ASTM STP 1255: Airflow performance of building envelopes, components and systems. American Society for Testing and Materials, Philadelphia.