VENTS, VENTILATION, AND MASONRY VENEER WALL SYSTEMS

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ABSTRACT

Vent openings in masonry veneers are commonly specified in modern Canadian wall systems. Several different products are available to screen these vent openings from insects and direct penetration by driving rain. While venting is considered good practise, there is little engineering basis for the size and spacing of vent openings.

With the support of a number of research partners, the role of venting in masonry veneer walls has been investigated. The importance of venting to pressure moderation and the control of rainwater, the removal of water vapour from behind the relatively vapour impermeable masonry veneer screen, and to the potential for ventilation drying were studied through a combination of theory, laboratory testing, and field monitoring.

Both theory and testing have confirmed the importance of sufficient venting. The four vent inserts tested in our program all restricted airflow to a very high degree; in fact, they practically negated most of the benefits of venting. It was shown that ventilation could remove significant quantities of water from both the back of the veneer and from the back-up wall so long as proper design and construction were provided. Field measurements confirmed that sufficient pressures act over most faces of a building for most of the time to drive ventilation air flow. It was also demonstrated that vent area and vent location are important variables that must be considered in design if the performance and durability benefits of venting and ventilation are to be realised in service.

INTRODUCTION

Moisture is one of the most important factors affecting building enclosure durability and performance, especially in cold climates. The design of moisture-tolerant enclosures should involve the consideration and balancing of the potentials for wetting, storage, and drying. Unfortunately, most design guidelines tend to focus on the avoidance of wetting, rather than the increase of safe moisture storage capacity or drying potential.

Drainage is often touted as the most important drying mechanism, and has received much attention of late with regard to drained screened wall systems such as brick veneer, EIFS, wood siding, stucco, etc. Drained screened systems are widely recommended as the best systems for all but the driest climates. This paper will demonstrate, however, that drainage, while critical, may not necessarily remove sufficient moisture to ensure proper enclosure performance -- other drying mechanisms must be provided. One drying mechanism that has not received the attention it is due is ventilation.

Vent openings in masonry veneers are often specified in modern Canadian wall systems. Several different products are available to screen these vent openings from insects and direct penetration by driving rain. While venting is considered good practise, there is little engineering basis for the size and spacing of vent openings and no information about the performance of vent inserts. The importance of venting to masonry wall performance and durability has also not been quantified.

Wetting and Drying

Enclosure systems constructed of hygroscopic porous materials (e.g., wood, stucco, masonry) can store very significant quantities of water. Capillary forces in a porous building material such as wood, stucco, and masonry will continue to absorb water until the material's moisture content reaches its capillary saturation moisture content. Therefore, it can be assumed that drainage cannot begin until either the saturation moisture content is reached, or the rate of wetting exceeds the rate of absorption.

It can be shown that most wetting mechanisms deposit water slowly enough that the majority of the water can be absorbed by many materials. For example, condensate tends to deposit moisture slowly and therefore often allows the material on which condensation occurs (e.g., masonry veneer, gypsum or OSB sheathing) sufficient time to absorb the deposited moisture. Driving rain deposition often occurs slowly enough that masonry veneers and many plasters can absorb a large proportion of the water. Therefore, it is reasonable to assume that in most common building enclosure wetting situations, a material must reach capillary saturation before sufficient volumes of water will bead on the surface and consequently allow drainage to occur. Our field studies have shown that drainage rarely occurs in masonry veneer walls because of their large moisture storage capacity.

Capillary saturated masonry is susceptible to freeze-thaw damage, and saturated sheathing such as OSB and gypsum, can also quickly deteriorate. Some means other than drainage must be provided to remove this stored moisture.

Moisture can be removed from a drained and vented masonry-veneer clad enclosure wall in a variety of ways (Figure 1):

1. drainage of free water, driven by gravity
2. capillary transport of bound liquid water to, and evaporation from, the outer surface of the screen
3. diffusion and/or convection of water vapour outward through the screen, and inward into the wall or building interior; and
4. convective flow of exterior air through the air space, (e.g., ventilation).

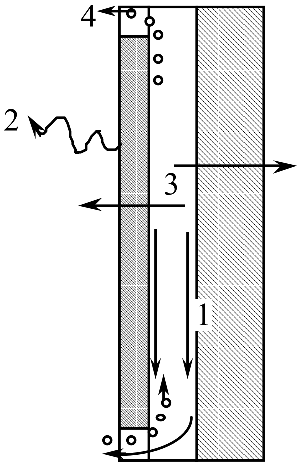


Figure 1: Drying Mechanisms in Masonry Walls with Vented Airspaces

Diffusive drying is fairly well understood and appreciated, although the precise calculation of such drying is still not very accurate because of our limited knowledge of moisture transport properties through porous materials. Drainage, although well understood, cannot remove moisture that is absorbed and stored in porous materials. One drying mechanism that can remove stored moisture is ventilation.

VENTILATION DRYING

Most cladding systems have relatively low vapour permeability and therefore tend to restrict diffusive drying. Moisture in or behind the cladding can be transported into the enclosure by solar-driven diffusion, especially in air-conditioned buildings. Rather than control vapour diffusion, a 6 mil vapour barrier close to the interior can, in many instances, exacerbate wetting and greatly retard drying. Ventilation of the space behind the cladding can be an important means of both drying and avoiding inward vapour drive wetting. In fact, a lack of ventilation may be the reason for previously noted inward vapour drive problems in filled-cavity walls (Straube and Burnett, 1997).

In theory, ventilating an air space behind the masonry veneer with outdoor air, offers two major benefits:

- convective drying of the inside face of the cladding and outside face of the inner wall layers, and
- water vapour diffusing through the inner wall layers can bypass the vapour diffusion resistance of the cladding and be carried directly outside.

Thus, ventilation could increase the drying potential of walls, especially in assemblies that either store significant amounts of water in the cladding or have claddings with high vapour resistance.

Note that the heat capacity of air is so limited that little heat can be carried out of the air space by ventilation (unless there are very large and fast air flows). Ventilation will not affect the insulation value of the air space for the majority of the time in most enclosure walls, so long as the insulation (e.g., insulating sheathing, batt) is protected from wind washing. Field measurements have shown that typical ventilation rates do not cool walls.

Very small air flows can, however, transport significant quantities of moisture if they act for long enough. Because the air space in many walls is usually warmer and contains more moisture than the outdoor air, even small ventilation flows over many days have the potential to remove useful amounts of moisture.

Most of the physics that lead to the above two conclusions are developed more fully in Straube (1998).

Forces Driving Ventilation Flow

Ventilation flow is driven by a combination of wind pressure differences, thermal buoyancy and moisture buoyancy. The provision of vent openings at both the top and bottom of the air space will generally allow the most ventilation because these vent locations take advantage of both buoyancy forces and wind pressures. This was demonstrated by field monitoring of a test building (see Straube and Burnett, 1995).

Wind pressure is the most important force driving ventilation flow. For most locations, the wind exceeds 1 m/s for 80 to 90% of the time, but the average wind velocity is generally quite low (3 to 4 m/s at 10 m above grade). Although low-rise houses are often protected from wind effects (both by neighbouring buildings and their location close to the ground), mid- and high-rise buildings are usually fully exposed to the wind. Measurements (Straube and Burnett, 1995) show that average wind pressures driving ventilation on low-rise buildings can be expected to be in the order of 1 Pascal, but the average will fall in a wide range between 0.1 and 10 Pascals, depending on the geometry and size of the building, the location and distance between vents, and wind speed and wind direction.

Increasing temperature and water vapour content decreases the density of air; these changes in density generate buoyancy effects that can drive ventilation air flow. Measurements of solar heating and outward heat flow in winter cause the air space of typical masonry veneer walls to be an average of at least 3 to 5 ºC above ambient over the entire year (Straube and Burnett, 1998). Daily variations of 10 to 30 ºC above ambient can be expected if the enclosure is exposed to the sun. Thermal buoyancy pressures can be found from:

$$\Delta P = 3465 \cdot \Delta h \cdot \left(\frac{1}{T_{amb}} - \frac{1}{T}\right) \tag{1}$$

where, ΔP is the pressure difference driving ventilation flow [Pa]

Δh is the difference in height between vents [m]

T_{amb} is the exterior ambient temperature [K]

T is the temperature in the air space [K]

Average pressures of the order of 1 to 2 Pascals can be expected due to the combined effects of moisture and temperature buoyancy.

Ventilation Flow

Given the driving pressures and the physical characteristics of the enclosure, the amount of ventilation air flow can be found using standard fluid mechanics. There are two major flow resisting mechanisms: friction with the sides of the air space and the restriction of air flow through the vents.

Friction with the sides of the air space is not very important to flow in most practical walls, but the partial blockage of the air space by mortar fins, strapping, bulging insulation, displaced building paper, etc. can be. Large air space widths are suggested as a means to overcome these potential blockages. In wall systems with discrete vents (e.g., masonry veneers), the vents impose the large majority of the resistance to air flow. Increasing the vent area will have a direct improvement on the air flow through the air space.

A review of the literature, simple calculations, and field measurements of ventilation pressures (Straube and Burnett, 1995) show that the flow generated by typical driving pressures (1 to 2 Pascals) can be expected to be in the order of 0.2 - 2 m^3/h per m^2 of cladding depending on the vent area and the depth and degree of blockage of the air space. Field measurements of well-vented wall systems (vent areas of more than 1% of wall area) typically experience flow velocities of 0.05 to 0.2 m/s (Jung 1985, Popp et al

1980, Kuenzel et al 1983) although Schwarz (1973) and Uvsløkk (1988) both found higher average velocities.

European codes are generally more specific regarding the size and location of vents and require much higher vent areas than North American code requirements. Most of the relevant wall cavity ventilation research has been conducted in Europe. Despite the extensive use of ventilated cladding systems in Europe, the benefits, drawbacks, and mechanics of ventilation flow have not been clearly defined. Moreover, very little work has been focused on masonry veneer wall systems.

Predicting Ventilation Drying

Given a knowledge of the quantity and quality (i.e., temperature and moisture content) of ventilating air, an estimate of the maximum drying capacity can be made. However, several simplifying assumptions need to be made:

1. the air in the space is well mixed, i.e., the moisture content is constant over the whole air space,

2. the rate of drying is controlled by the rate of ventilation flow not the rate of evaporation from the materials along the sides of the air space,

3. temperature conditions are not modified by the drying process.

Field monitoring of various wall systems has shown that the first assumption is quite accurate under most conditions. Because the vapour permeance of air is so high it is difficult for large gradients of air moisture content to form in clear air spaces. This assumption is no longer valid under high flow conditions near the inlet vent.

The second assumption is also valid provided that the ventilation flow rate is low and the sides of the air space are wet. When the materials drop below saturation, this assumption becomes progressively less accurate. Thus, calculations based on this assumption are maximum drying rates, or drying rates when the air space sides are saturated; however, it is precisely these conditions that one is trying to alleviate with ventilation drying.

The validity of the final assumption depends on the drying rate. At low ventilation rates, the specific heat capacity of air is too low to change the temperature conditions of the air space or its sides. At low drying rates, the amount of latent heat required to evaporate moisture is very small and has little effect on temperatures. Very high drying rates, such as would occur during a sunny period immediately after a rain event, will depress the temperature noticeably. This assumption limits the accuracy of calculations to ventilation drying during extreme events, i.e., most of the time the third assumption is valid.

In summary, the three assumptions listed above are valid for low ventilation flows (i.e., those typically experienced) and walls that have wet materials (i.e., walls requiring drying).

Example Calculation

Consider a well-built masonry veneer wall system with a 50 mm air space and open head joint vents spaced at 600 mm on centre, both at the top and bottom of the air space. Assume that a layer of 12.7 mm OSB sheathing (density 700 kg/m^3) has been saturated by exfiltration condensation.

If exterior conditions are 7 ºC and 85% RH (851 Pa), the outdoor air can store 6.6 g per m^3. If the sun shines on the wall, the air space temperature will rise to at least 20 ºC above the outdoors for 6 to 8 hours, and the air in the space will be nearly 100%RH (as it must be if the materials lining the sides of the air space are saturated or nearly so); this air can store 27.6 g per m^3. The difference of more than 20 g per m^3 is the amount that can be removed by ventilation. As discussed earlier, ventilation flows of 0.2 - 2 $m^3/m^2 \cdot h$ might be expected if such a wall were well vented. This flow rate is so small that it generates flow velocities of only 2.6 to 26 mm/s. Over an 8 hour period at a flow rate of 1 $m^3/m^2 \cdot h$, the moisture content of the materials lining the airspace can drop by 160 g; this would reduce the moisture content by almost 2%.

Diffusion drying of the sheathing through the veneer can be calculated in a similar manner. If the sheathing is at 27 ºC and 100%RH (3567 Pa) , drying by diffusion would be:

$$(3567-851)\text{Pa} \times 46\ \text{ng/Pa}\cdot\text{s}\cdot\text{m}^2 \times 3600\ \text{s/hr} \times 8\ \text{hrs} = 3.6\ \text{g}$$

In this realistic example, ventilation drying removed more than 40 times as much stored moisture than diffusion drying.

VENT TESTS

Flow through deep orifices, cracks, or slots can be described by a general power law expression (Straube and Burnett, 1995):

$$Q = C_d \cdot A \cdot \left(\frac{2 \cdot \Delta P}{\rho}\right)^n \qquad (2)$$

where Q is the flow rate (m^3/s),

A is the area of the orifice (m^2),

ρ is the mass density of the air (about 1.2 kg/m^3),

ΔP is the air pressure difference (Pa),

C_d is a factor that accounts for friction and turbulence losses, and

n is a flow exponent.

A flow exponent of 0.5 indicates that the flow is completely turbulent, e.g. flow through sharp orifices and large openings. An exponent of 1.0 indicates that the flow is completely laminar, e.g., flow through small cracks.

The measurement of the flow characteristics of the various vent types over a range of steady-state flow rates were conducted to allow the more accurate assessment of ventilation air flow. The objective of the static vent flow experiments was to characterise a vent in terms of the discharge coefficient , Cd, and the flow exponent, n. These values can then be compared to other research and provide a full description of the volume of air flow that can be expected when a vent is under a given air pressure difference. The basic reference vent was a 65 mm high, 10 mm wide, and 90 mm deep open head joint. Four different commercially-available vent inserts were also tested (Figure 2).

Apparatus

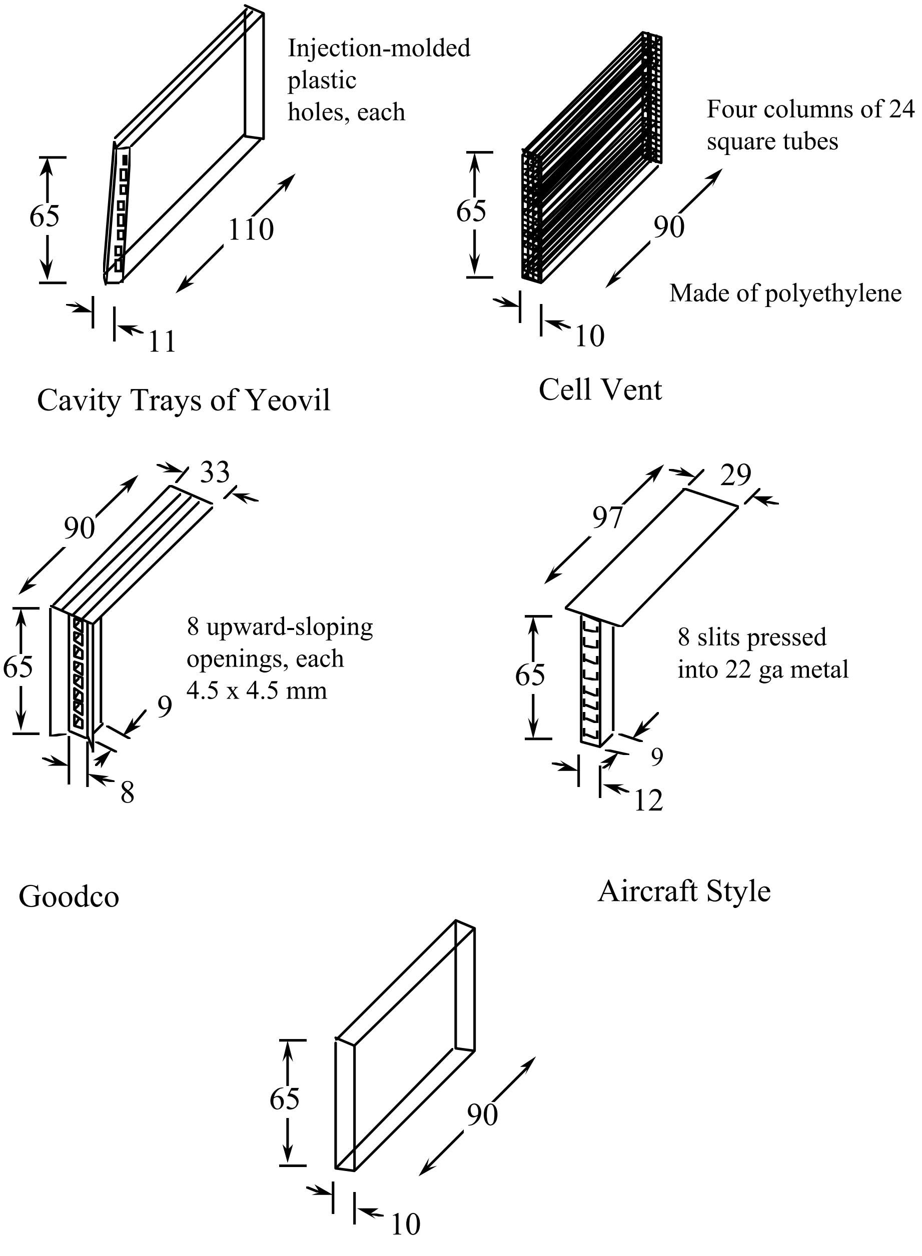
The apparatus developed to conduct the steady-state flow experiments consisted of a fan to produce the flow, 50 mm ducts to transfer the air flow, valves to regulate the flow, and a 1.2 m long, 250 mm diameter plexiglass pipe to which one of the vents could be attached. Instrumentation included a group of parallel flowmeters that could measure flows (from 0.02 l/min to 200 l/min), and pressure transducers or a Betz manometer to accurately measure the pressure drop (from 0.1 Pa to 3000 Pa) with better than 1% total accuracy.

The plexiglass pipe served several functions. Its length ensured that flow from the fan was stabilised before reaching the vent test section. Its diameter was chosen so that the vent would be exposed to an approaching flow very similar to that in actual wall vent (i.e., the diameter of the pipe was very large in relation to the diameter of the vent). The transparent pipe also permitted the nature of the flow to be observed, i.e., smoke could be added to the air flow and the nature of the flow could be clearly observed.

Vent Test Results

The discharge coefficient and flow exponent of the vent inserts are presented in Table 1. The brick vent (C_d=0.63, n=0.56), despite its rectangular aspect ratio and depth, behaved in a very similar manner to a large orifice. The discharge coefficient for the brick vent inserts was not calculated because measuring the area of the openings in the inserts is difficult. Instead, an equivalent discharge coefficient was calculated based on the full area of the vent (10 x 65 mm). This method of presentation is also more useful for comparing the venting efficiency of the different products to each other and to an open head joint. The flow exponent calculated from the results of the open brick vent tests indicates that flow begins to diverge slightly from perfect turbulent flow, almost certainly because of the vent's depth. It is expected that, a very low pressure differences (much less than 0.1 Pa), the flow exponent will be higher because the flow will reattach to the sides of the vents.

Not surprisingly, the Cell-Vent (n=0.72), essentially a series of 1 mm square pipes 90 mm long, behaves in a manner much closer to laminar flow than any other configuration. The other vent inserts did not modify the *nature* of the flow significantly.


Cavity Trays of Yeovil

Cell Vent

Goodco

Aircraft Style

Open Head Joint

Figure 2: Head Joint Vent and Vent Inserts Tested

Figure 3 plots the pressure-flow relationship of the masonry vents. The commercially available inserts severely restricted the flow of air. The Cell-Vent restricted flow least, but still reduced flow to less than 15% of that through an open head joint. The Goodco, Yeovil, and aircraft-style inserts all restricted flow to between 5 and 8% of the flow through an unobstructed vent. Clearly, the flow restriction of all the vent inserts may have serious negative implications for both ventilation and pressure-moderation performance.

Masonry Vent Type (10 x 65 mm head joint)	Discharge Coefficient (Cd)	Flow Exponent (n)
Open	0.626	0.56
Cell-Vent	0.089	0.72
Goodco	0.047	0.52
Yeovil	0.056	0.56
Aircraft	0.030	0.50

Note: Linear regression best-fit to flow equation $Q = C_d \cdot A \cdot (\Delta P)^n$. Area based on an open head joint.

Table 1: Orifice Flow Coefficients from Masonry Vent Insert Tests

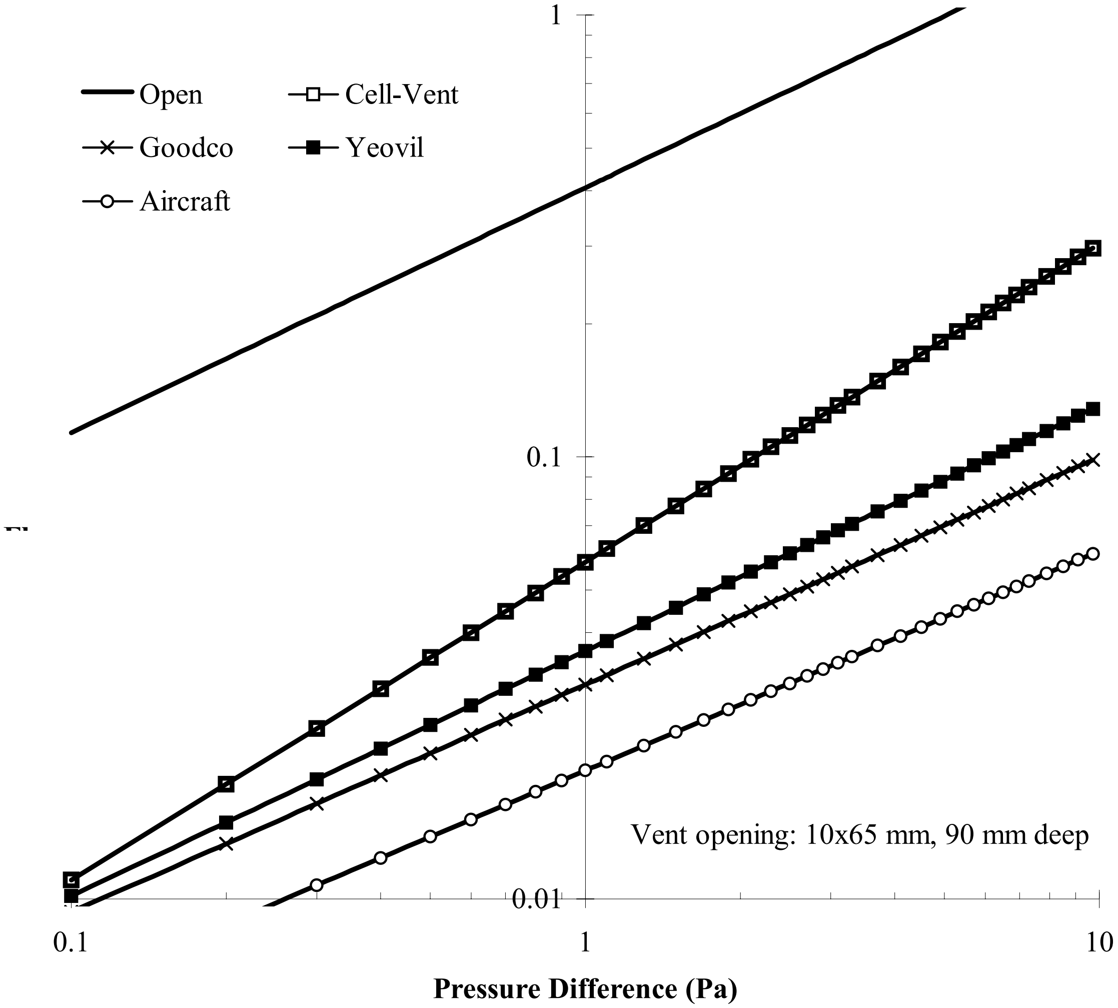


Figure 3: Pressure vs. Flow Relationship for Masonry Vents and Vent Inserts

FIELD MONITORING PROGRAM

As part of a much larger multi-year research project, the response of several claddings exposed to the south-western Ontario environment have been continuously monitored for over two years. Twenty-six test 1.2 m wide and 2.4 m high panels were installed in the University of Waterloo's natural exposure and test facility, the Beghut, in the summer of 1995. Results from the monitoring of a single east-facing panel will be discussed here to demonstrate the potential role of ventilation in wall performance.

The exterior temperature, humidity, windspeed and direction, and driving rain deposition were measured with meteorological-quality instruments at the standard height of 10 m above grade. Interior conditions were tightly controlled to 50±5% relative humidity and 21±1 ºC.

The panel was instrumented with temperature sensors, Delmhorst pins (for measuring wood moisture content), and relative humidity transducers. A special base detail allowed cavity drainage to be intercepted and measured. The panels were installed in July and exposed to the environment over at least two winters. Readings were taken every five minutes for two years.

The test panel (Figure 4) was built following the current accepted practice for masonry-clad, framed wall systems. The 85 mm clay brick veneer was built with great care to ensure that the 30 mm wide air space (slightly larger than the nominal 25 mm typically provided) was kept clear of mortar dams, bridges, and droppings. Mineral fibre board insulation (48 kg/m^3 density) on exterior gypsum sheathing was applied over the steel framing.

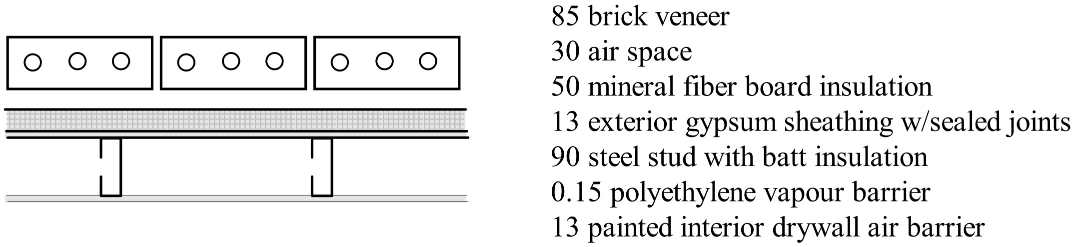


Figure 4: Simplified Test Panel Cross Section

Venting of the air space was provided by open head joints at 600 mm on centre, top and bottom. Framing was 38x89 mm steel framing (single top and bottom plates with studs at 400 mm on centre) filled with low-density batt insulation, a 0.15 mm polyethylene vapour retarder ($M = 3.4$ ng/Pa·s·m^2) and painted gypsum board interior finish. Pieces of wood were used to measure the moisture content within the studspace. The interior drywall/poly layer was confirmed to be airtight by testing. The gypsum sheathing was vapour permeable ($M > 2000$ ng/Pa·s·m^2).

The panel was monitored for one year with its vents open, and for one summer with the vents sealed air tight. Drainage from the weep holes was intercepted, collected, and measured. The weather conditions were not significantly different, and the amount of driving rain deposited on the wall was measured to be approximately the same, in both years.

FIELD MONITORING RESULTS

The moisture content of the air in the air space of the test wall was calculated using the the temperature and relative humidity measurements. Over the summer period, the average moisture content of the exterior air in 1996 was 9.6 g/m^3. Over the summer period in 1997, the average exterior air content was 9.1 g/m^3, i.e. drier. The average moisture content of the air in the airspace of the well-vented wall was 10.9 g/m^3: about 1.3 g/m^3 higher than the exterior. During the following summer, when wall was unvented, the moisture content in the airspace was 13.1 g/m^3, 4 g/m^3 or 44% above the exterior. Another well-vented east-facing wall monitored during 1997 exhibited an air space moisture content of 1.0 g/m^3 (11%) above the exterior, demonstrating that weather conditions were similar both years.

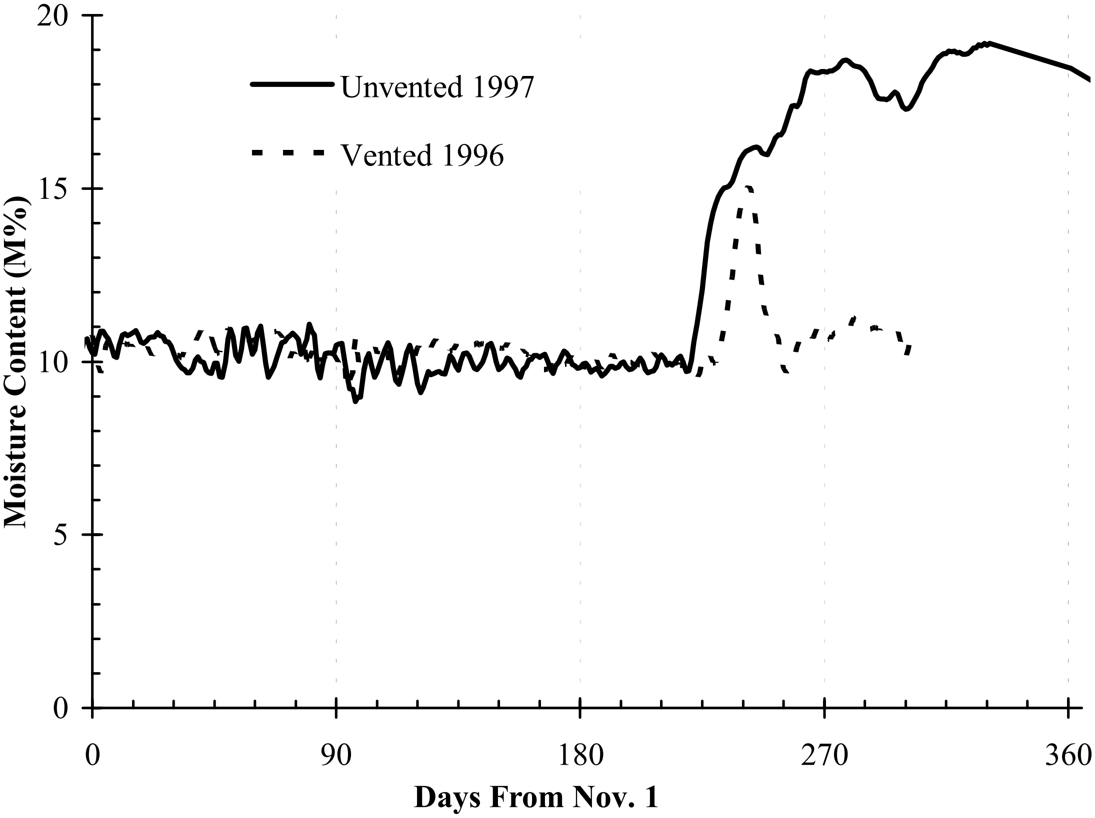


Figure 5: Framing Moisture Content Vs Time

Figure 5 plots the framing moisture content of the panel over a year. During the summer of 1996 the moisture content of the vented wall climbed to almost 15% for a short time. This is not a dangerous level, but clearly shows that this type of assembly is sensitive to inward vapour drives. Sealing the vent openings on June 1, 1997 (Day 211), however, had a significant impact on the moisture content driving the moisture content to a dangerous level. The relative humidity in the studpsace of the unvented wall also exceeded 80% (the threshold for corrosion and mould growth) for several months.

Much more detailed analysis of the moisture conditions in the air space of this and other walls, both vented and non-vented, can be found in Straube (1998).

CONCLUSIONS AND IMPLICATIONS FOR DESIGN

Several important conclusions can be drawn from the information reported.

Ventilation is primarily driven by a combination of wind pressures and thermal buoyancy. The provision of vent openings at the top and bottom of the cavity will generally allow the most ventilation by these mechanisms. Field monitoring shows that wind pressures driving ventilation can be expected to be in the order of 1 Pascal. The flow behind masonry veneers generated by these pressures will be in the order of 0.1 to 1.0 litre per second per m^2. Masonry veneer systems can achieve useful levels of ventilation flow if sufficient venting and reasonably clear cavities are provided. Normal amounts of ventilation will not cool masonry veneer walls.

In normal walls, the ventilation drying rate will be governed by the ventilation flow rate, not the ability for wet materials to evaporate moisture into the air space. Solar heating greatly affects the potential for ventilation drying, both by increasing thermal buoyancy and by increasing the moisture carrying capacity of the air.

Full-scale testing has shown that standard (10 x 65 x 90 deep) open head joints in masonry veneers can be considered to behave as orifices with a flow coefficient of 0.65 and a flow exponent of 0.55. All of the commercially available masonry veneer vent inserts tested greatly restricted flow to from 5 to 15% of that through an open head joint.

Although ventilation drying can be recommended as a design strategy, the current practise for masonry veneers does not reliably ensure a significant amount of ventilation. To achieve the full benefit of ventilation drying, more vent area and clear air spaces must be specified. Commercially available vent inserts provide too much flow resistance to be practical, and air space widths of 40 to 50 mm are likely required to ensure flow. The use of open head joints at 600 mm centres, top and bottom, and air spaces of over 40 mm should be considered the minimum level of venting required to provide measurable benefit to masonry veneer walls.

ACKNOWLEDGEMENTS

This research is part of the In-Service Performance of Enclosure Walls Project and was also supported Canada Mortgage and Housing Corporation. The assistance and technical review of CMHC's project manager, Pierre-Michel Busque was most helpful. The support, technical input and funding of the seven corporate partners (Brampton Brick, Canada Brick, Celfortec, Durisol Materials, Owens-Corning Canada, Roxul Insulations, and Sto Corporation), has been invaluable and is gratefully acknowledged. The Ontario Government also provided funding through the University Research Initiative Fund.

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