The Relative Merits of Zero-Cavity Brick Veneer Walls

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ABSTRACT

In a masonry veneer rainscreen wall system, the provision of both a clear cavity and effective drainage is essential for controlling water that penetrates the permeable masonry rainscreen. However, field surveys and experience have shown that the cavity, and hence drainage, is often obstructed by mortar dams, bridges, and droppings. Instead of an open space an alternative approach, one that is used extensively in some parts of the world, is to fill the cavity with an air and water permeable fibrous insulation to control the mortar and thus preserve the necessary drainage and air flow. However, this method is little used in North America and a project was proposed to evaluate the actual performance of a filled cavity wall relative to typical residential building practice.

This paper presents and compares the results of the field monitoring and testing of representative, i.e. 30 mm clear cavity, and zero-cavity brick veneer residential wood-frame wall systems exposed to the climate of S.W. Ontario for two years.

Testing and monitoring was conducted on pairs of identical full-scale panels mounted in the Beghut outdoor test and natural exposure facility. The results of monitoring temperature, humidity, wood moisture, and air pressure and testing for water penetration, air leakage, pressure equalization, and drainage are summarized and assessed. Some supplementary laboratory testing was also conducted. It was found that problems can arise in a zero cavity system especially for the climate of South-Central Canada. There is a need to take into account the effects of solar radiation, short-term diurnal effects and vapour flow characteristics within the wall system. However, with the proper materials and design, fibrous cavity fills can improve the performance of masonry rainscreen walls.

Keywords: brick veneer; rainscreen walls; solar effects; insulation

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1. INTRODUCTION

One of the most important and problematic functions of all types of walls is the control of moisture, especially rain. Various strategies are used to control rain in exterior walls. One strategy is to employ the mass of the exterior wythe to ensure that any water that does penetrate the exterior surface is fully absorbed and subsequently drained or evaporated without ever reaching the interior surface. A second strategy requires a perfect barrier to water at the exterior surface. A third strategy incorporates an imperfect screen and some other water control mechanisms to deal with the water that penetrates. A classification system of the various strategies used for rain control in exterior walls is presented in Figure 1.

In cold climates, multi-layer wall systems are almost mandatory if an effective building envelope is desired. Multi-layer wall systems, especially for North American residential buildings, often employ a brick veneer as the outermost screen against environmental factors such as rain and the sun. The common masonry veneer 'rainscreen' masonry wall system, shown highlighted in Figure 1, uses an exterior brick wythe as a screen and a cavity and water barrier to drain any water that penetrates the permeable masonry screen. Screened, drained, cavity walls often incorporate venting, ventilation and/or pressure moderation to improve or augment the wall's ability to control moisture from rain and other sources.

The primary physical elements of a wall system employing the so-called 'rainscreen principle' are:

1) the screen,
2) the cavity (capillary break),
3) the gravity drain,
4) the vents, and
5) the pressure moderation chamber.

This approach acknowledges that the brick screen is only an imperfect barrier and that water may penetrate the screen. It follows that one or more "secondary defense" mechanisms incorporating a capillary break (cavity), a drainage system, and some type of air and water barrier is essential.

The provision of a clear cavity and effective drainage in this form of construction is an important, if not the critical, issue for within wall moisture control. Unfortunately, field surveys and experience have shown that the draining and venting characteristics of the cavity are frequently compromised by the inadvertent creation of mortar bridges across the cavity, mortar dams and accumulations of mortar at the base of the cavity, and inadequate construction tolerances. Mortar dams and bridges can direct water running alongside the backside of the masonry screen across the cavity to wet the inner wythe. Accumulations of mortar droppings at the base of the air space can completely block the drainage path, i.e., the cavity and weep hole, allowing very little or no water to flow. The results can be damage to the building structure, envelope, and contents, water leakage, corrosion, moisture-related discolourations and deterioration, and a reduction in thermal performance. Ensuring a clear cavity presently depends largely on the mason and the level of quality control during construction. If this issue is to be resolved it is essential that the masons' job be made easier and that the quality control requirements be rendered feasible.

A number of approaches can be taken to resolve the mortar problem. One is to ensure that mortar dams, bridges and droppings are avoided by careful construction. Alternatively, an appropriate filler with both drainage and venting capabilities could be developed and used in lieu of an air cavity.
Figure 1: Wall Classification

Notes: The system classifies walls based on actual behaviour, not design intent or construction method. The classification is dependent on the definitions below.
Drained: the majority of free, liquid water that penetrates the screen is removed by gravity forces.
Cavity: a clear unobstructed space that acts as a capillary break, provides a drainage path, and permits ventilation air flow movement
Vented: significant water vapour diffusion and mixing of air occurs via openings
Ventilated: significant air flows which may aid in cooling and/or drying
Pressure-Moderated: moderates pressure differences across the screen i.e. partially pressure equalized
Canada Mortgage and Housing Corporation (CMHC) initiated a project to study the full-scale, field assessment of both of these strategies for ensuring a clear cavity. In particular, the practical feasibility, the extent of pressure equalization (pressure moderation), the effect on thermal gradients, and the ability of the walls to drain and dry were to be studied.

2. OBJECTIVE AND SCOPE

The Building Engineering Group at the University of Waterloo conducted this two-year study. This paper is a summary of some of the results from this project. The objective is to present some of the significant findings from the study. The full details of the experimental set-up, panel materials and construction, instrumentation and data acquisition, and results are documented in a report prepared for CMHC. A supplementary study of the importance and role of venting, ventilation, drainage, and pressure moderation in walls screened with brick veneer and the development of the pressure moderation measurement methods have been presented elsewhere. It should be noted that this overall project turned out to be somewhat more ambitious and instructive than initially intended. The findings go well beyond the issue of mortar blockage and clear cavities.

3. EXPERIMENTAL PROGRAM

The experimental program involved the construction, testing, and field monitoring of two pairs of test panels and the evaluation of their performance. To represent the more common approach to ensuring a clear cavity, a pair of test panels (called the Datum panels) were built using current, accepted practices for wood frame housing. The brick veneer of the Datum panels was built with great care to ensure that the 30 mm wide cavity was kept clear of mortar dams, bridges, and droppings. A second pair of panels (called the Zero-Cavity panels) were built with a cavity filler consisting of high-density (52 kg/m³) fibreglass board insulation.

The four full-scale panels were installed in the Building Engineering Group's (BEG) natural exposure test facility (Beghut) located on the University of Waterloo campus. Two views of the Beghut and panel dimensions, locations, and orientations are shown in Figure 2. Common to all panels was a gypsum board interior sheathing, a 6 mil polyethylene vapour retarder, and a 2x4 wood stud frame filled with fiberglass batt insulation. Rigid fibreglass insulating sheathing and Tyvek™ housewrap was used in both pairs of panels. All the panels were clad with a face brick veneer. Figure 2 presents a horizontal cross section of each of the two panel types.

Each panel was typically instrumented with 12 to 15 thermocouples for sensing temperature, 4 pairs of Delmhorst pins for measuring the wood moisture content of the framing, 4 to 6 relative humidity transducers, and 7 to 9 pressure taps for sampling air pressures (Figure 3). A special base detail allowed cavity drainage to be intercepted and measured. The panels were installed in July of 1991, one of each panel pair facing east and the other facing west, and exposed to the environment of South-Western Ontario. After acclimatization, the panels and their environments were continuously monitored for fourteen months from November 1, 1991. The sensors were read every 5 minutes and the calculated hourly averages stored for later analysis. The interior conditions were maintained at 50% relative humidity and 21°C.

To establish specific characteristics of the performance of each panel, air leakage, water penetration, and pressure moderation tests were conducted using standard ASTM and CGSB procedures, where ever possible. The drainage of water within the wall assembly after it had penetrated the brickwork was studied in laboratory mockup
Panel Locations in Test Hut

Datum Wall Section

Zero-Cavity Wall Section

Figure 2: Test Panels

Note: All dimensions in mm unless otherwise stated.
Figure 3: Panel Instrumentation (Composite of Datum and Zero Cavity)
tests. More than two years after their installation, the panels were opened and their condition physically inspected.

4. RESULTS

Graphs, tables, and the appropriate statistical measures of the daily average temperature, relative humidity and moisture content over the entire monitoring period, over representative winter and summer periods, and the hourly averages over specific winter and summer days were developed. Analysis of the monitored data combined with the field and laboratory test results provided a great deal of information regarding panel performance. Some of the results of this analysis are reviewed below.

4.1 Thermal

In all four panels the brick screen, wood framing, batt insulation, drywall, and poly generally performed in a similar manner. The daily average temperatures varied sinusoidally over the year and the hourly average temperatures varied sinusoidally over a day.

Solar radiation increased the average daily temperature of the brickwork above the ambient air temperature by about 6.5 °C in summer and 4 °C in winter. A daily peak difference between the outside air and brick temperature of 15 °C was common on sunny days and differences as large as 35 °C were measured. This solar-induced temperature difference has a dramatic influence on the inner layers of each wall and affects condensation potential, moisture storage and transmission, energy consumption, material durability, and thermal conditions. The number of freeze-thaw and thermal movement cycles would be greater than those registered by climatic records.

The hourly average temperatures are graphically presented in Figure 4 for six of the temperature sensors in the west-facing Zero-Cavity panel over a representative summer day. The average temperature for this day is the same as the average over a 10 week period in the summer of 1992. The ambient exterior temperature is below the interior temperature for the entire day; however, the effect of the sun drives the exterior brickwork temperature to a maximum of 18 °C above the interior temperature. In particular the solar-induced variation in temperature at the inside face of the brickwork and the sheathing (cavity fill) and even the studspace should be noted. The behaviour of shaded and north-facing walls could be expected to be significantly different because of their different solar exposure.

There were some differences in the thermal performance of the two pairs of panels. Because the Tyvek™ housewrap was located behind the sheathing in the Zero-Cavity panels, it experienced much warmer (by an average of over 7 °C in the winter) and more stable temperatures than did the Tyvek™ in the Datum panels. In the winter, the temperature in the middle of the fibreglass sheathing was consistently colder in the Zero-Cavity panels than in the Datum panels (by about 5 °C) but the temperature gradient was otherwise similar (that is, the brick veneer was neither colder nor warmer).

4.2 Moisture

Water penetration testing (using a modified ASTM standard) confirmed that the brick veneer screen on all six panels was water permeable with or without an applied air pressure difference. A uniform static air pressure difference of 100 Pascals applied across the walls did not have any measurable effect on the nature or volume of water
Figure 4: Hourly Average Temperatures in Zero-Cavity Panel

Figure 5: Hourly Average Vapour Pressures in Zero-Cavity Panel
penetration. Drainage of water both outside and within the panels appeared to function well. In spite of the fact that all panels were supposedly pressure-equalized rainscreen systems, significant amounts of water penetrated the brick veneer, likely through the many small interfacial cracks between the brick and mortar. Additional water penetration tests indicated that penetration through the vent holes did not make a disproportionate contribution to the total. In these tests, the presence of the fibreglass cavity fill did not appear to affect the drainage of water in the Zero-Cavity panels.

Controlled laboratory mockup testing also showed that the fibreglass cavity fill in the Zero-Cavity wall drained the large majority of the water at a high rate. However, after testing, 50 to 75 mm of water remained in the base of the fibreglass board held by capillary attraction to the glass fibres. It took some time for this retained water to be removed by evaporation. Thus, in these Zero-Cavity panels, there was a potential for some moisture to be stored in the base of the cavity fill.

In the field, wood moisture content and relative humidity values indicated that rain water which penetrated the screen tended to be stored in the base of the fibreglass filling the Zero-Cavity panels. Within all panels, moisture could be transported from the cavity to the stud space by evaporation and subsequent vapour diffusion through the water-vapour-permeable Tyvek™. Figure 5 presents a plot of the hourly average vapour pressures for the same day as in Figure 4. It can be seen that while there is a small and stable outward vapour drive based on interior and exterior ambient conditions, there is a very large vapour drive within the wall from the cavity to the studspace of the wall. This occurred for about 8 to 12 hours on each sunny day in the spring and summer. Such reversals of vapour flow because of solar radiation have previously been reported by other researchers.

In the Zero-Cavity panels this solar-induced warm weather vapour pressure differential resulted in the transportation of the moisture stored in the fibreglass cavity fill, especially that at the base, to the wood framing during the spring and summer months. In all four panels the inward water vapour drive was higher in the summer than the outward drive in winter and this resulted in increased wood moisture contents in the framing. In general, the wood framing in all of the walls (including most of the wood in the Zero-Cavity panels) dried to an equilibrium value of 11 to 15% moisture content over the winter.

During spring and summer the moisture content of the framing generally increased. The framing lumber in the base of the Zero-Cavity panels developed elevated and often saturated moisture levels for about seven months starting at the end of April (see Figure 6). Throughout the summer, the lower cavity fill was often moist or had a very high amount of water vapour. The retained moisture was transferred to the stud space and this resulted in high relative humidity values in the stud space during the summer. Consequently the wood moisture level, particularly in the bottom plate, increased through the summer and dried during the late fall and winter. Confirmation of the monitored moisture and RH measurements was provided when the panels were opened for inspection in September 1993. The lower portions of the wood framing and the adjacent batt insulation were found to be saturated and extensive microbiological growth (mould and staining) had occurred in the Zero-Cavity panel.

The physical inspection established that the Datum panels were in very good condition except for some slight mould growth discovered in one panel. This was clearly due to peak late-summer moisture content levels of more than 20%.
4.3 Ventilation

All panels were constructed with two vent holes in open head joints (10 by 67 mm) top and bottom at 600 mm intervals. Although airflow in the cavity was not monitored, the temperature and relative humidity measurements in the cavities permitted some indirect observations of ventilation performance.

It was found that the cavity in all panels seemed to behave in a manner very similar to an unvented airspace; the temperature and relative humidity conditions seemed to be largely decoupled from the exterior conditions. No consistent vertical temperature or humidity stratification was observed. By inference little, if any, buoyancy- or wind-driven ventilation occurred in any of the four test panels.

4.4 Pressure Moderation

At present pressure-equalization testing is not governed by any standard. Field monitoring of pressure conditions outside and inside the wall under natural conditions is, in fact, difficult largely because of the nature of the wind (i.e. wind-induced pressures on a building are low and variable). Nonetheless, pressure and wind records were obtained and this permitted some important conclusions to be made. A frequency-domain method of measuring the percent pressure-equalization as a function of the speed of the external pressure variation was developed to allow for comparable, repeatable, and quantitative field tests.

As others have found, the day-to-day wind pressures experienced by low-rise walls are generally quite low (less than 20 Pa) and higher pressures (greater than 30 Pa) occur rarely. Moreover, for low-rise construction, the variation in mean pressure with
height, even over a height of one-storey, has a relatively significant effect on pressures and pressure differences.

Simultaneous cavity and exterior pressure measurements at the center of the brick screen were recorded at 16 Hz when the wind was blowing approximately perpendicular (± 15°) to the wall at speeds over 25 km/h. The extent and incidence of pressure-equalization, or more precisely, pressure-moderation, across the screen for all of these screened panels was found to be highly dependent on the frequency of the wind pressure variations. Our analysis considered wind to be composed of mean quasi-static pressures as well as a highly variable component. The magnitude of mean wind pressures close to the ground are similar to the standard deviation.

None of the panels developed full pressure equalization for any record irrespective of frequency. In all panels, the moderation of the pressure difference across the screen based on one minute mean pressure values was better than 90% for wind blowing perpendicular to the wall. However, all panels moderated only 20 to 50% of the pressure differences across the screen due to wind pressure variations less than 10 seconds long. The Zero-Cavity panel had measurably better performance than the Datum under both mean and variable wind pressures. Thus from a pressure moderation perspective, the Zero-Cavity panels were superior.

Our investigations suggest that wind directions other than that perpendicular to the wall and pressure gradients near building edges have a significant negative effect on the pressure-moderation of mean and gust pressure variations.

4.5 Air Leakage Testing

Bearing in mind that the drywall/poly layer is the primary air barrier in the wall assemblies (this layer was confirmed to be airtight by testing), some interesting air leakage testing of that portion of the wall assemblies downstream of the airtight drywall/poly layer found that the Tyvek™ housewrap (attached to the framing by plastic-headed nails) was the only significant plane of air flow resistance. It was established that in the Datum panel this Tyvek™ layer provided less, nearly an order of magnitude less, resistance to airflow than in the Zero-Cavity panels. The placement of the flexible air barrier behind the insulating sheathing in the Zero-Cavity panels contributed structural support and confinement to the Tyvek™; this resulted in significant tightening of this portion of the wall. In the Zero-Cavity panels the downstream assembly was initially relatively air tight and remained so throughout the testing.

4.6 Panel Inspection

Opening up of the panels and the subsequent inspection conducted in September 1993, some two years after installation, found that the base of the Zero Cavity panels was completely clean of mortar droppings and would allow unhindered drainage of any water reaching the base flashing of the panel. Despite the extraordinary precautions taken during construction, mortar projections occurred and mortar droppings were found at the base of the Datum panel cavities. While in this case the impaired drainage caused by the mortar blockage did not cause damage to the wall, it did highlight how difficult it is to provide a clear clean cavity in normal wall construction.
5. CONCLUSIONS AND RECOMMENDATIONS

In this project, the Zero-Cavity panels performed poorly. Reversed spring and summer diffusion of moisture from the fiberglass-filled cavity resulted in wet wood framing at the bottom of the stud space. However, this was largely due to the combination of the water permeability of the brick screen, the moisture retention characteristics of the fiberglass cavity fill, the vapour permeability of the Tyvek™, and the solar-induced inward vapour drive. Two of these factors can be easily resolved, for example by using a hydrophobic coating on the fiberglass fill and a more vapour resistant housewrap. Otherwise this work confirmed that the basic zero-cavity concept is essentially sound and offers benefits such as better assurance of drainage, thinner wall sections, support and protection of the air barrier, and possibly better pressure moderation. Decades of use and the popularity of this form of construction in some Scandinavian countries provides some assurance that, with proper materials and construction, fibrous cavity fills can improve the field performance of multi-wythe rainscreen walls.

The performance of the Datum panels was often dominated by solar effects although the results (in terms of vapour pressures and damage) were much less dramatic than in the Zero-Cavity panels. Solar-induced vapour drive from the cavity through the Tyvek™ to the stud space created high wood moisture levels in late summer. Drying occurred throughout the fall and winter. The vapour permeable Tyvek™ caused the wall to perform quite differently than would a less vapour permeable material such as normal building paper would. If not mounted between two stiff elements, Tyvek™ should only be used when well adhered to a stiff substrate and fully taped. It is strongly recommended that the use of fiberglass board insulation and, especially, the use of Tyvek™, in particular its location and intended purpose, be carefully considered in the future.

The efficacy of pressure moderation in low and high-rise construction needs further study. Many more pressure moderation measurements using repeatable, quantitative test procedures are necessary. It was established that, for wind perpendicular to the face of the wall, all of the panels moderated less than 50% of the wind pressure variations over the frequency range measured. It also appears that the measurement of mean pressures or mean pressure differences has limited relevance to the actual response of the cavity pressure to the wind. Both the water permeability of brick veneer screens, especially under dynamically-varying, low-pressure differences, and the incidence and coincidence of rain and wind effects need to be given more study and attention.

Daily solar-induced warming and the dynamic heat and moisture transfer that was observed in all panels clearly demonstrates that mean ambient environmental conditions are not sufficient to predict envelope performance. It is very important that the daily as well as the seasonal effect of the exterior environment be taken into consideration in the design of wall systems and that less reliance be placed on mean values. Particularly with brickwork, solar-radiation plays a very significant role that cannot be ignored; this is particularly true during the spring and summer when on sunny days large inward vapour pressure differentials can be developed within the wall. When coupled with a material with low vapour resistance, such as Tyvek™, moisture transport into the wall can occur.

Finally, it is evident that the Zero-Cavity approach contributed significantly to providing a cavity space free of mortar droppings with a continuous and clear space for air and water flow. Even under test conditions enough mortar droppings accumulated at the base of the Datum panel cavity, not only to impede lateral flow but also to accumulate moisture by absorption and by damming drain water. It is evident that any material, method, or product that ensures drainage of water which penetrates the brick screen will greatly reduce the potential for moisture damage.
REFERENCES


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