From: ICBEST '97 Proceedings, Bath, U.K., April, 1997, pp. 429 - 435.

Field testing of filled-cavity walls

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ABSTRACT

Poorly performing walls on all types of buildings constitute a serious problem, one that has professional, commercial, and social ramifications. The Building Engineering Group has, for some years, been conducting full-scale field testing of wall systems. Several projects have been completed. The primary objective in most of these projects has been to study the hygrothermal performance of wall systems common to colder climates. In particular, ways of minimizing rain penetration, methods of ensuring drainage, the mechanics of ventilation drying, and the drying of built-in moisture have been studied.

Wood- or steel-framed, masonry veneer wall systems with specific air spaces or cavities are commonly used in North America, especially as the enclosure to residential buildings. Although relatively common in Europe and Scandinavia, masonry veneer walls with the cavity space filled with a draining insulation are almost unknown in North America. Canadian interest in filled-cavity walls has been driven by the need to increase insulation levels, the need to provide a drainage layer behind the veneer that cannot be compromised by mortar droppings, dams or bridges and the desire to maintain or reduce wall thickness.

This paper describes some of the results of the field monitoring of wood-framed masonry veneer wall systems with both filled and unfilled cavities. Inward vapour drives, warm weather condensation, the location and use of vapour permeable ‘housewraps’, and the importance of ventilation drying are discussed.

INTRODUCTION

Multi-layer wall systems, especially on the exterior of North American residential buildings, often employ a masonry veneer. It is customary to provide an air space or cavity behind the brickwork. For example the so-called ‘pressure equalised rainscreen’ wall system uses the exterior brick masonry wythe as a screen with the cavity acting not only as a pressure chamber but also as a capillary break as well as a drainage path for any water that might penetrate the water permeable masonry screen.

Double wythe cavity walls have been used for many years in Europe, especially in areas of high driving-rain intensity. In the early 1970's (following the oil crisis of 1973), different types of insulating filler began to be used to fill the entire cavity. The filler material must, of course, be able to drain water and permit air flow as well as resist heat flow. This practice is now common in a number of European countries. Research on this new type of cavity-filled wall has been conducted by the national agencies in several countries. This research, combined with field experience, has demonstrated that these filled-cavity masonry walls perform well, provided the appropriate materials and procedures are employed. Framed (wood, light-gauge steel) wall systems with a filled-cavity masonry veneer have received little attention in Europe, while the practice of deliberately filling the cavity is rare in North America.

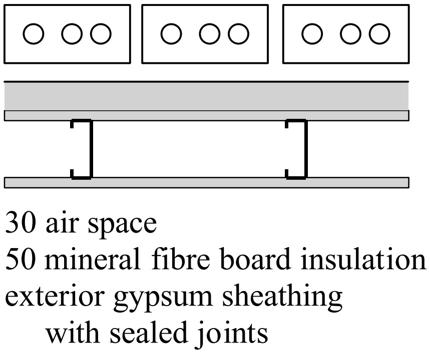
In North America wall systems with wood or light-gauge steel framing and an outer wythe of masonry veneer are very common. The stud space is insulated and additional thermal insulation, if needed, is usually applied as sheathing external to the framing. The amount of thermal insulation has increased with the demand for energy conservation. Field experience has shown that a 25 mm air space, commonly specified in Canada, is insuffient. Mortar dams and droppings commonly hinder the drainage and capillary break functions of the air space. Difficulty in providing a clear cavity (free of mortar droppings,etc) has led to designers specifying air spaces of 50 mm nominal width or wider. It follows that in walls with insulating sheathing the masonry ties and other structural connectors would have to span some 75 to 125 mm. In terms of wasted space and added structural cost these wider cavities are clearly expensive. The present interest in filled-cavity masonry veneer walls is therefore predicated on: 1) the need to increase the amount of thermal insulation with minimal increase in overall wall thickness, and 2) the need to ensure moisture control, especially of driving rain.

The Building Engineering Group has, for some years, been conducting full-scale field testing of wall systems. Several projects have been completed. The primary objective in most of these projects has been to study the hygrothermal performance of wall systems common to colder climates. In particular, ways of minimizing rain penetration, methods of ensuring drainage, the mechanics of ventilation drying, and the drying of built-in moisture have been studied.

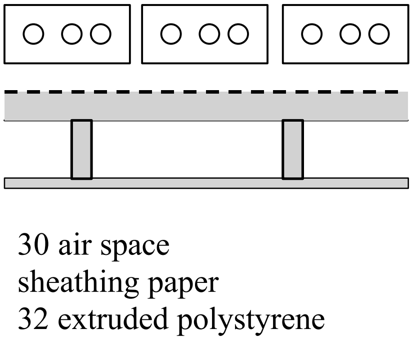
This paper describes some of the results from the field monitoring of various framed wall systems with a masonry veneer, with filled and unfilled cavities, and exposed to the climatic conditions of south-western Ontario. A great deal of information has been generated but the focus of this paper is moisture movement, specifically the phenomenon of warm weather wetting.

TEST PROGRAM

A total of 32 wall panels involving 15 different wall systems have been or are being monitored, of which 10 wall panels involving four different wall systems have filled-cavities . Four different wall systems will be examined in this paper. Figure 1 presents a simplified horizontal cross section of each.



Wall A



Wall B

Test panels for walls A and C were built with an airspace, as is the current accepted practice for masonry-clad, wood-frame housing. The brick veneer on these panels 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.

The filled-cavity test panels wall systems B and D were built using a filler consisting of either a 38 mm, medium-density (52 kg/m^3), fibreglass board (Wall B) or a 50 mm hydrophobically-treated, low-density (36 kg/m^3), rockwool board (Wall D). The only differences being the type and thickness of filler and thus the width of the filled cavity.

On the A and B walls a highly vapour permeable (Z = 3600 ng/Pa·s·m^2) housewrap or weather barrier was used. Wall D had a slightly less permeable housewrap (Z = 700 ng/Pa·s·m^2). Wall C had an asphalt-impregnated perforated sheathing paper as the weather barrier (Z = 300 to 700 ng/Pa·s·m^2 depending on RH) and extruded polystyrene insulating sheathing (Z = 32 ng/Pa·s·m^2). Apart from the housewrap and the insulating sheathing walls A and C are very similar. Except for the air space and the position of the housewrap, Walls A and B are the same.

Common to all panels was an 85 mm clay brick veneer, 2x4 wood framing (single top and bottom plates and studs at 400 mm on centre) filled with low-density batt insulation, a 0.15 mm polyethylene vapour retarder (Z = 0.33 ng/Pa·s·m^2) and painted gypsum board interior finish. The interior drywall/poly layer was confirmed to be airtight by testing.

Two panels of wall types A and B were built and installed with one facing east and the other west. Four panels of both wall types C and D were built and one panel of each was installed facing north, south, east and west. The 1.2 m wide and 2.4 m high full-scale panels were installed in the Building Engineering Group's (BEG) natural exposure and test facility (Beghut) located on the University of Waterloo campus in South-Western Ontario.

Each panel was instrumented with 12 to 15 temperature sensors, 3 to 6 pairs of Delmhorst pins (for measuring wood moisture content), and 4 to 6 relative humidity transducers. A special base detail allowed cavity drainage to be intercepted and measured. The panels were installed in July or August and exposed to the environment over at least two winters. The sensors were continously scanned and read every 5 minutes and average values were stored. The interior conditions were maintained at 50±5% relative humidity and 21±1ºC.

Selected Results

The moisture content (based on weight) of the wettest framing member (usually the bottom plate) in the east-facing panels for each of the four wall types is plotted in Figure 2 over a 16 month period. (Walls A and B, Fall 1991 to Spring 93, and Walls C and D, Fall 1995 to Spring 1997). The east orientation receives the largest amount of spring-time driving rain.

The moisture content of the wood framing in both of the filled cavity walls was well in excess of 20% over the summer and fall when wood temperatures were consistently above 15 ºC. These conditions, which are ideal for wood rot and mould growth, lasted for 5 months and for more than 7 months for walls B and D respectively. The walls did, however, dry to safe levels during the early winter.

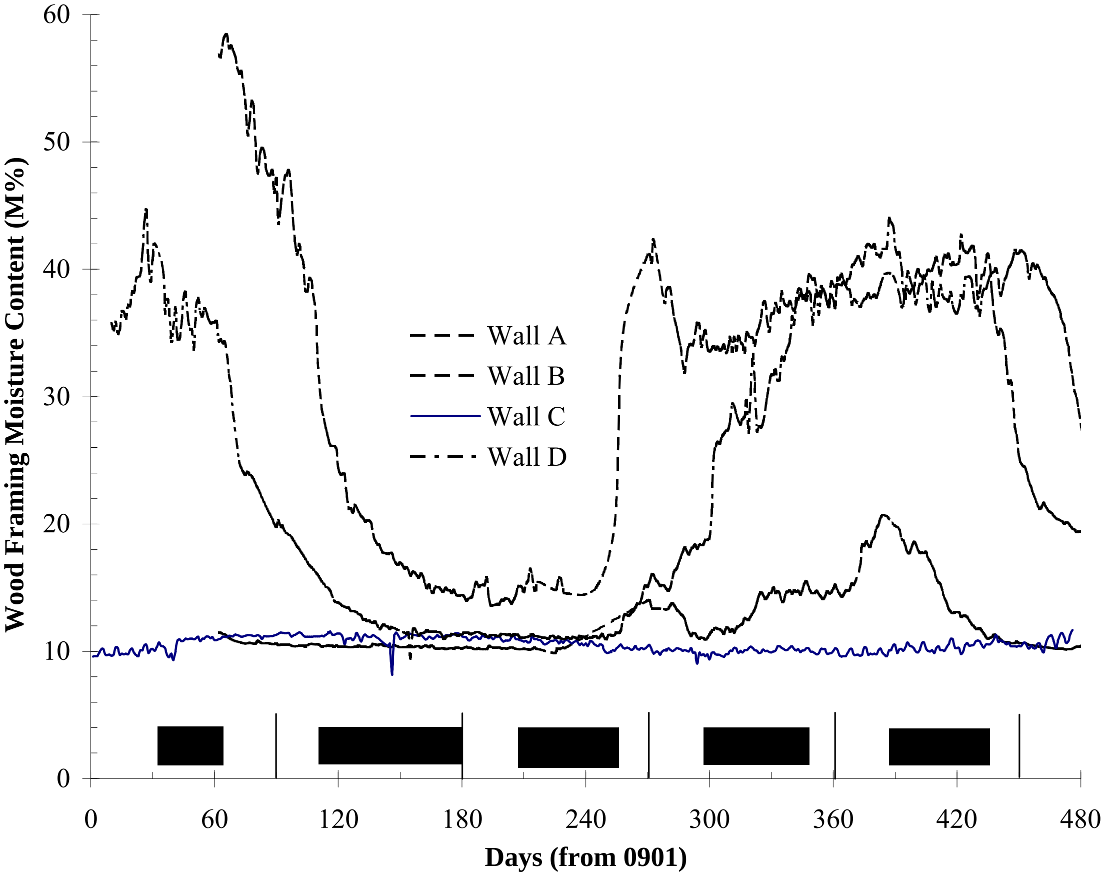


Figure 2: Moisture Content vs Time for Four Walls

Analysis of the daily measurements showed that most of the wetting of the framing occurred after driving rain events. Solar heating of the masonry veneer (to temperatures of 20 to 25 ºC above that of the interior air) caused water vapour to evaporate from either the back of the saturated veneer or within the insulting filler or both. The vapour then diffused inward through the vapour permeable wall assemblies where condensation could occur on the vapour impermeable poly vapour barrier (it was kept at a low temperature (23-25 ºC) by the air conditioned interior).

Figure 3 is a plot of the measured vapour pressure conditions in Wall D for a July day. The saturation vapour pressures calculated from the temperature sensors on the back of the brickwork and the poly have also been plotted. It can be seen that vapour pressure differences of 5000 Pa consistently occurred for a significant number of the hours during which condensation could occur. These vapour pressure differences are significantly greater than those that occur in the winter.

Inward vapour drives resulting in summer condensation have been reported by several researchers, starting with Canadian test huts in the 60's [i], and then by others [ii,iii,iv]. Field monitoring [v] and lab tests [vi] have both shown that moisture from inward vapour drives generally does not cause problems in walls with an inner masonry wythe because the masonry has sufficient capacity to store moisture. Wood- and, much less so, steel-framed stud spaces, however, do not necessarily have sufficient moisture storage. Calculations, modelling, laboratory tests and field experience all show that one or more layers with a relatively low vapour permeance (i.e. waferboard, special tar paper, etc.) must be used on the outside of the framing, behind the cavity fill, to prevent sufficient quantities of vapour from diffusing into the batt space, where the vapour can condense and damage the framing and other materials. Based on our measurements and simple calculations, the maximum permeance of the layers behind the brickwork and outside the framing should be of the order of $Z = 50$ ng/Pa·s·m^2.

Sandin [vii] monitored the framing moisture content of a number of different brick-veneer framed walls in a comprehensive series of test-hut studies. He also found that inward vapour drives caused the moisture content of the framing to increase during the late summer in almost all of the walls exposed to both rain and sun. The greatest amount of wetting was measured in walls almost identical to Wall D, although walls with narrow air spaces and intentional mortar dams exhibited almost as much wetting. Therefore, while the use of highly vapour-permeable materials such as housewraps and exterior gypsum sheathing, promotes rapid drying in the winter, these same materials also permits warm weather diffusion and condensation that could result in serious damage.

The monitored data does not indicate whether the vapour came from water stored in the cavity fill or from the brickwork. Upon completion of the first project (Walls A and B), it was concluded that the water stored in the cavity fill (glass fibre board) was probably the main source. Our laboratory tests showed that a significant quantity of water could be retained within the cavity fill at the base of the wall cavity by capillary attraction to the glass fibres. It was thought that the lack of a hydrophobic treatment may have been the reason for water storage within the insulating cavity fill. Results from the recent monitoring of walls using a hydrophobically-treated rockwool cavity fill (Wall D) and other wall systems with hydrophobically-treated glass fibre cavity fill, suggest that hydrophobic treatment alone will not be sufficient to control summer-time condensation. This finding supports the conclusions of both Sandin and Künzel.

It should be noted from Figure 3 that Wall A also exhibited some small degree of warm weather wetting. In this wall system moisture was not stored in the glass fibre but measurements show that wood wetting did occur because of inward vapour drives. The fact that Wall A, with an air space but the same very high internal vapour permeance as Wall B, exhibited only limited wetting suggests that either (i) removing the material used to fill the cavity decreases the internal moiture load (i.e., using a filler increases the amount of moisture stored) or (ii) that a clear air space vented to the exterior can remove sufficient water vapour to reduce the severity of inward vapour drives or that both occur.

It is often assumed that a vented air space does not provide a significant amount of ventilation drying. For example, Hens [6] reported laboratory experiments in which air (at 21 ºC of 50% RH) was forced into the cavity between two masonry wythes. While he showed that ventilation drying accounted for only about a third of the veneer drying, the effect of solar heating was not accounted for. The vapour pressure difference between the saturated outer wythe and the ventilation air was about 1100 Pa. In a second set of experiments, the same walls were ventilated with 1.8 m^3/hr of air at 6.5 ºC and 89% RH. This wall exhibited no ventilation drying. (Note the vapour pressure between the saturated brick and the ventilation air was only a few hundred Pascals).

During sunny periods, the sun will not only aid in drying from the exterior surface by evaporation, but it will also cause evaporative drying within the cavity and drive stack effect pressures and thus ventilation. Air density differences add to the ventilation pressures. The average difference in moisture content between saturated cavity air and ambient air over the day considered in Figure 3 is 20 g/m^3. Ventilation drying during those hours of a sunny day when solar heating raises the brickwork temperature above ambient, can therefore be very effective. For example, if ventilation at a rate of 1 m^3/m^2/hr were provided by the thermal and moisture buoyancy forces in the cavity, 480 g of moisture per m^2 of brickwork could theoretically be removed in this one day.

Considerations such as these strongly suggest that one of the reasons for the superior performance of Wall A is the presence of a vented air space. Field measurements suggest that the outer wythes of partiallyfilled cavity walls tend to have somewhat lower moisture contents than walls with fully filled cavities. Ventilation drying is likely responsible for some of the extra drying. For example, Sandin[7] tested two wood-framed, filled-cavity walls that differed only in that one had no open joints for ventilation and the other did. Both the brickwork and framing in the ventilated wall were always drier than in the unventilated wall, sometimes significantly so.

CONCLUSIONS

In framed, brick veneer, wall systems that have a fully filled cavity, warm weather diffusion into the stud space can result in potentially damaging wetting unless sufficient water vapour resistance is provided behind the cavity filler. The amount of wetting will depend on orientation, the amount of spring and summer driving rain, the number of hours of bright sunshine, and the moisture storage capacity of the brickwork.

If the dynamic effects of solar radiation are accounted for, it is suggested that ventilation may play a significant role in drying. A role that cannot be ignored if a true understanding of wall behaviour is sought.

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