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Innovative Passive Ventilation Water-Resistive Barriers—How Do They Work?

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M. Jablonka, A. Karagiozjs, and John Straube

Abstract:

The issue of solar driven moisture that is associated with water absorptive claddings has often been raised, and it is becoming increasingly relevant as the demand for improved energy efficiency buildings continues to rise. Improved energy efficiency building enclosures generally means an increase in R-value and reduced air leakage, which commonly reduces the drying potential of wall assemblies. Essentially, less energy is available from inside the structure to assist the transport of moisture away from the building enclosure. As energy efficiency requirements are pushing towards zero-energy structures, passive means the sun or wind become more critical approaches for achieving enhanced drying. This paper investigates the hygrothermal performance of wall assemblies with brick veneer cladding as well as manufactured adhered stone veneer with two different types of water resistive barriers. One type is a conventional spunbonded polyolefin-based WRB, and the other type is an innovative three-dimensional dual ventilated sheet. This paper not only shows field-monitored data for both assemblies, but it also explains the building physics involved in both systems. The field performance data is based on one year-long field studies with wood-framed test walls installed on the north and south side of test huts located in Charleston, SC and Waterloo, ON. This paper demonstrates the beneficial effects of passively driven airflow through both solar and wind forces allowing small amounts of air flow to provide a significant increase in drying potential to walls that include dual ventilation water resistive barriers. Results show that the three-dimensional dual ventilated WRB not only provides enhanced drying potential by deploying passive solar energy, but it also provides a control layer against warm-weather inward vapor drives from the absorptive claddings, which have been implicated as reasons for numerous moisture related problems.

Innovative Passive Ventilation Water-Resistive Barriers—How Do They Work?

M. Jablonka

A. Karagiozis, PhD

J. Straube, PhD, PE
Associate Member ASHRAE

ABSTRACT

The issue of solar driven moisture that is associated with water absorptive claddings has often been raised, and it is becoming increasingly relevant as the demand for improved energy efficiency buildings continues to rise. Improved energy efficiency building enclosures generally means an increase in R-value and reduced air leakage, which commonly reduces the drying potential of wall assemblies. Essentially, less energy is available from inside the structure to assist the transport of moisture away from the building enclosure. As energy efficiency requirements are pushing towards zero-energy structures, passive means the sun or wind become more critical approaches for achieving enhanced drying. This paper investigates the hygrothermal performance of wall assemblies with brick veneer cladding as well as manufactured adhered stone veneer with two different types of water resistive barriers. One type is a conventional spunbonded polyolefin-based WRB, and the other type is an innovative three-dimensional dual ventilated sheet. This paper not only shows field-monitored data for both assemblies, but it also explains the building physics involved in both systems. The field performance data is based on one year-long field studies with wood-framed test walls installed on the north and south side of test huts located in Charleston, SC and Waterloo, ON. This paper demonstrates the beneficial effects of passively driven airflow through both solar and wind forces allowing small amounts of air flow to provide a significant increase in drying potential to walls that include dual ventilation water resistive barriers. Results show that the three-dimensional dual ventilated WRB not only provides enhanced drying potential by deploying passive solar energy, but it also provides a control layer against warm-weather inward vapor drives from the absorptive claddings, which have been implicated as reasons for numerous moisture related problems.

INTRODUCTION

The demand for highly energy efficient buildings continues to rise. Improved energy efficiency of building enclosures generally means an increase in R-value and air-tightness, which commonly reduces the drying potential of wall assemblies, thus making them more vulnerable to moisture accumulation problems (Rose 2005). Essentially, less energy is available to assist the transport of moisture out of and away from the building enclosure. Under this aspect the issue of solar driven moisture that is associated with water absorptive claddings is becoming increasingly relevant: Highly energy efficient buildings with reduced drying potential of the wall cavity may not be able to sufficiently compensate for such external moisture loads when conventional moisture management approaches are being deployed. Better control of solar moisture drive and enhanced drying potential are therefore critical to ensure proper moisture management of building enclosures. As energy efficiency requirements are pushing towards zero-energy structures, passive means utilizing solar energy or wind become more critical approaches for achieving enhanced drying.

In typical applications, brick veneer is installed with a 1 in. vented or ventilated air gap between the back side of the brick and a drainage plane. Manufactured masonry veneer units are usually being deployed over a bed of lath-reinforced mortar directly over a drainage plane without a drainage or

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***M. Jablonka** is a director at Cosella-Dörken Products, Inc., Beamsville, ON, Canada. **A. Karagiozis** is a senior research engineer at ORNL, Oak Ridge, TN. J. Straube is a principal at building science consulting, Waterloo, ON, Canada.*

Figure 1 *Impermeable three-dimensional polyethylene membrane with ventilated air-gap.*

ventilation gap. The drainage plane is typically provided by a single layer of a water-resistive barrier, which acts as the second line of defense against liquid exterior moisture behind the cladding (WRB) (Bomberg et al. 2003). Numerous moisture problems and building failures have been reported when such systems are used over wood- or steel-framed walls (Rymell 2007). Next to poor detailing or building envelope designs deploying materials with low moisture tolerance (Lstiburek 2008), the lack of well-defined drainage spaces and air cavity ventilation have been implicated as reasons for these moisture problems (Karagiozis 2005).

A second layer of water-resistive barrier can provide some drainage behind the cladding, provided that the wall assembly has proper flashing and weep openings at the bottom to allow water to safely exit the space. Conversely, controlling inward solar vapor drives is more difficult. Water-resistive barriers by design are vapor permeable in order to prevent moisture from accumulating in the wall cavity. Brick veneer and manufactured masonry veneer units as well as the mortar used for installation are highly absorptive and can store significant amounts of rainwater. When solar radiation heats the cladding following rain, elevated vapor pressures occur, and the water vapor stored in the brick or masonry veneer units is being driven through the vapor permeable WRB into the sheathing and further into the stud bay, causing higher moisture contents of the exterior sheathing and wood studs. This results in condensation on interior air-conditioned surfaces. The problem is intensified in air-conditioned buildings with low-permeance vapor retarders.

A proposed solution to minimize the risk of these moisture problems is the use of a vapor-impermeable ventilated air-gap membrane behind absorptive claddings. A three-dimensional polyethylene membrane will preclude inward solar moisture drive, and at the same time it allows water vapor within the wall cavity to diffuse into the ventilated air-space behind or inside the three-dimensional membrane and escape to the exterior. Hence the three-dimensional membrane allows a method of mass transfer to occur that is more effective than vapor diffusion: Air transport dries out both, the cladding and the sheathing board at the same time. An example of a three-dimensional vapor impermeable membrane with ventilated air-gap is shown in Figure 1.

Previous research describes the effectiveness of the drying effect in such a ventilated air space (Karagiozis et al. 2005; Straube et al. 2004).

The building enclosure performance is dependent on the wall composition, as well as interior and exterior hygrothermal loads. Past work performed in a laboratory environment at the University of Waterloo by Straube and Smegal (2005) characterized the airflow, drainage behavior, water retention, and drying behavior of a three-dimensionally patterned HDPE membrane, and indicated its superior performance when compared to a #15 building paper. In the laboratory, the exterior conditions were only imposed in terms of wind pressure and solar incidence, but not in terms of actual exterior temperatures and other relevant effects, such as night-sky radiation. The study provided quantitative empirical results that allowed the comparison to standard wall types employing conventional building paper as WRB, and generated data for use in advanced hygrothermal computer models by Karagiozis (2005a).

The field tests described in this paper were initiated to show how a three-dimensional water-resistive barrier with ventilated air-cavity provides enhanced drying potential by deploying passive solar energy, and how it also provides a control layer against warm-weather inward vapor drives from highly absorptive claddings—even under severe climate conditions.

EXPERIMENTAL SETUP

An experimental field test setup was chosen to determine and compare the hygrothermal performance of a number of different wall assemblies under various climatic conditions. Test walls with brick veneer installed outboard of a spun-bonded polyolefin-based, vapor permeable water-resistive barrier were tested side-by-side in a natural exposure test facility in Charleston, SC with walls employing an impermeable three-dimensional membrane with ventilated air-cavity.

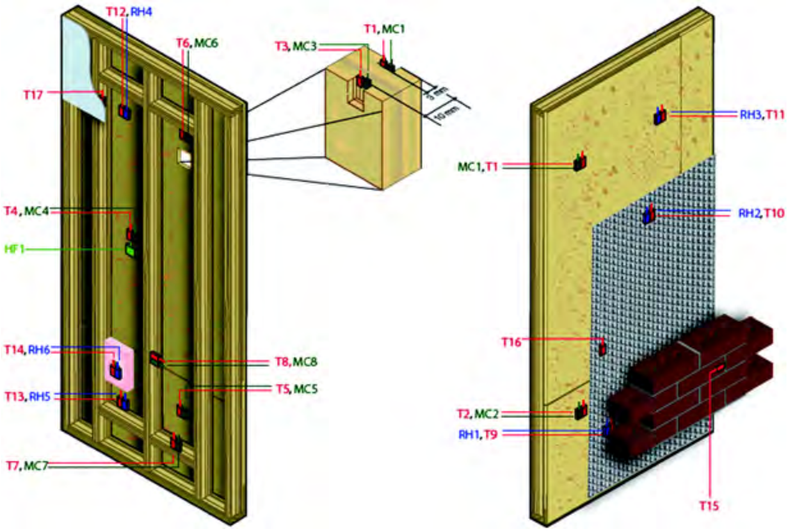

Figure 2 *Typical wall setup and sensor layout for full-scale wall testing in Charleston, SC.*

The test facility where these walls were tested is located in the city of Hollywood, SC, 21 miles from the center of the city of Charleston and 12 miles away from the Atlantic Ocean. Historical climatic data from 1961 to 1990 shows that Charleston receives an average annual precipitation of approximately 48 to 52 inches of rain (NOAA/USDA-NRCS). During the exposure time frame the exterior climate (temperature and rainfall) was within normal long term ranges, and the data monitored during the test period is representative of typical climatic conditions in that location.

In a separate setup in Waterloo, ON a series of wall assemblies was tested to compare their performance with manufactured adhered masonry veneer installed over the impermeable three-dimensional membrane in place of asphalt impregnated building paper. The average annual precipitation in Waterloo is 38 inches of rain and 58 inches of snow. During the exposure time frame the exterior climatic conditions were within normal long-term ranges in this test location also.

The field monitoring was conducted with a combination of temperature and relative humidity sensors in the drain space and the stud space, wood moisture content sensors in sheathing and framing, temperature sensors in the cladding and the drywall, and heat flux sensors located behind the interior drywall. The sensor locations in the brick walls tested in Charleston, SC is shown in Figure 2.

The sensor locations in the adhered manufactured masonry veneer walls tested in Waterloo, ON are shown in Figure 3.

The test walls were free of any penetrations to exclude the possibility for bulk water intrusion. All test panels were 8 ft in height and 4 ft in width, built with 2×6 wood frame construction with OSB sheathing, R19 fiberglass batt insulation and interior drywall finish and air barrier. The test walls at the natural exposure test facility in Waterloo, ON had an additional interior polyethylene vapor barrier, as required by the building code in this climate zone.

Monitoring of the brick walls in Charleston, SC began in June 2006 and ended in June 2007. The adhered veneer walls in Waterloo, ON were monitored from July 2007 to October 2008.

BOUNDARY CONDITIONS

The interior and exterior boundary conditions simulated normal conditioned spaces and were measured and recorded over the entire test period. The interior (R1 = room 1; R2 = room 2) and exterior temperatures and relative humidity for Charleston, SC are shown in Figure 4.

The interior and exterior temperatures and relative humidity for Waterloo, ON are shown in Figure 5.

The periodic increase of relative humidity in the Waterloo testing period did not affect the hygrothermal conditions in the test walls, since these walls had continuous polyethylene vapor barriers.

MEASUREMENT RESULTS AND ANALYSIS

The moisture content of the wood sheathing and framing, and the relative humidity of the stud space were analyzed to compare the hygrothermal performance of walls with and without a three-dimensional ventilated air-gap membrane.

Results from Charleston, SC

For the brick walls that were tested in Charleston, the moisture content in the wood sheathing and framing showed relatively low differences between the cases with and without air-gap membrane. However, the data shows that during several months of the year the relative humidity at the outer

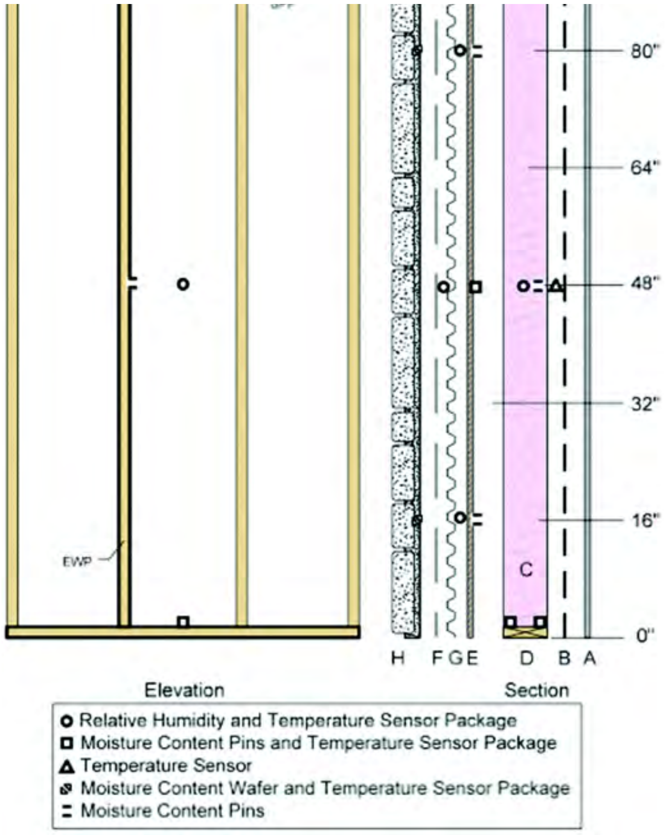

Figure 3 *Typical wall setup and sensor layout for full-scale wall testing in Waterloo, ON.*

surface of the wood sheathing was up to 20% higher for the walls without the ventilated air-gap membrane compared to the walls with the conventional spunbonded WRB. Figure 6 shows the relative humidity at the outer surface of the wood sheathing for the month of January 2007. It is evident from this data that the relative humidity in this location rises well above 80% for several days in January for the wall without the air-gap membrane. Moisture-related problems in wall assemblies may occur at relative humidity levels above 80% and wood moisture contents above 20%. Yet, the elevated RH levels of this wall did not cause the moisture content in the wood framing to rise to critical levels.

Figure 7 shows the relative humidity on the outer surface of the wood sheathing of the brick walls for the month of June 2006.

The analysis of the relative humidity inside the wall cavity (RH 4) during the same time periods shows consistently lower RH levels for the walls with the air-gap membrane by around 10% compared to the standard walls. Figure 8 shows the relative humidity inside the wall cavity of the brick walls for the month of June 2006.

Figure 9 shows the relative humidity in the wall cavity of the brick walls for the month of January 2007. Throughout the entire month the RH in the wall with the air-gap membrane is around 8% lower than in the standard wall.

The data in Figure 10 shows the average relative humidity on the outside of the OSB sheathing for the complete year of testing. It is evident that the brick walls with air-gap membrane show lower relative humidity during the summer and winter months. Both walls were averaging well under 80% relative humidity.

The red line in Figure 10 shows the measured data for three-coat stucco that was directly applied over a spunbonded Polyethylene based water-resistive barrier. It is evident that the average relative humidity on the outside of the wood sheathing was in excess of 80% from November 2006 to mid-March 2007, and even in excess of 90% for several weeks during this time period. The relative humidity for the stucco wall in this location is significantly higher than for both brick walls during the entire test period. The difference of the RH between the directly applied stucco wall and the brick wall with air-gap membrane is at times as high as 40%. This shows the significance of the ventilated air-gap between exterior sheathing and backside of absorptive cladding. The highest impact from exterior moisture load is to be expected on walls without such an air-gap.

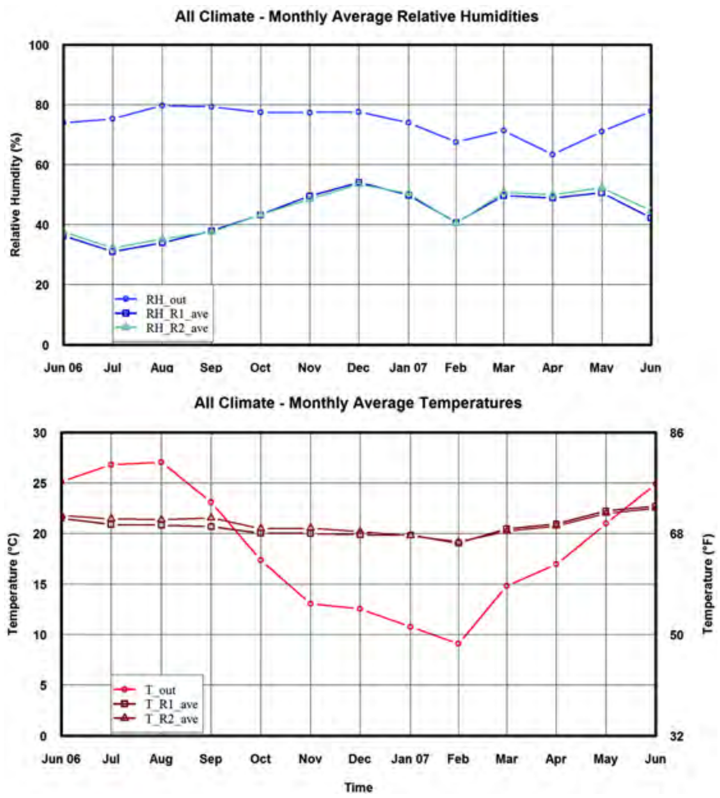

Figure 4 *Interior and exterior relative humidity and temperatures during testing in Charleston, SC.*

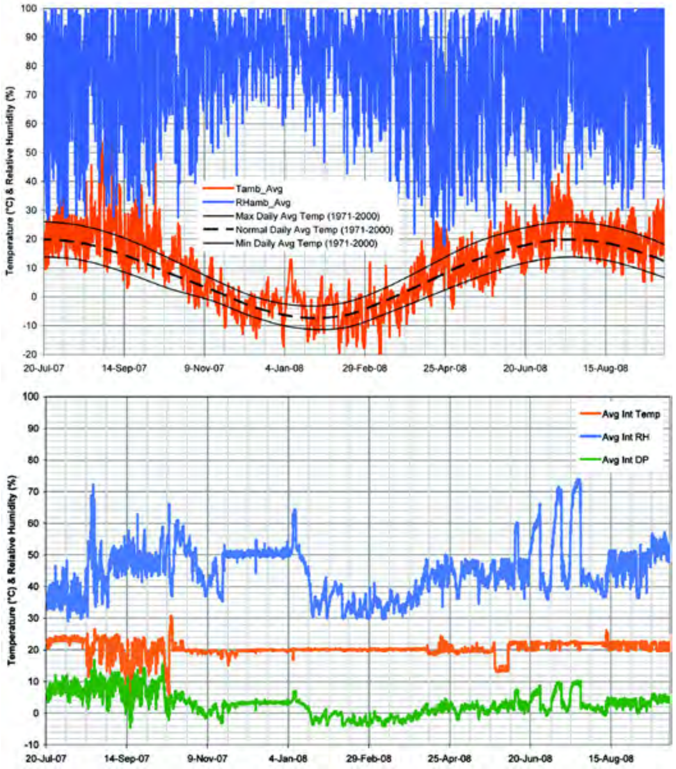

Figure 5 *Interior and exterior relative humidity and temperatures during testing in Waterloo, ON.*

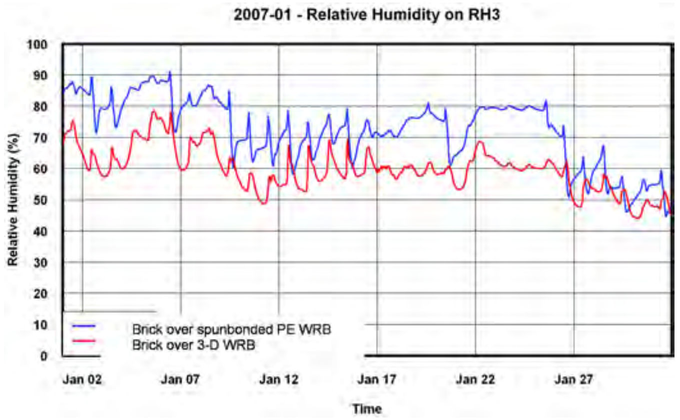

Figure 6 *Relative humidity comparison near sheathing of brick walls in Charleston, SC shown for the month of January 2007.*

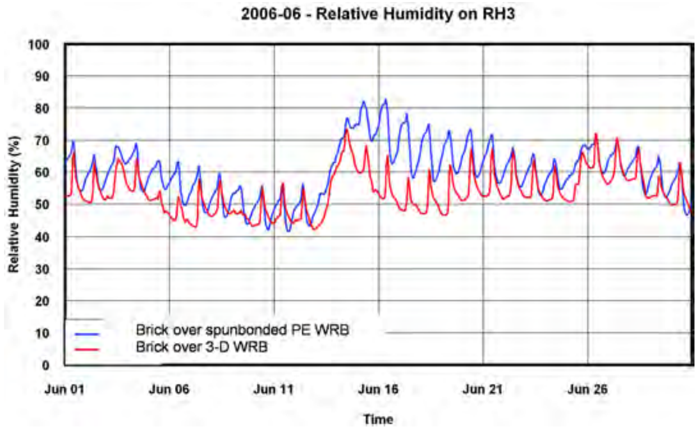

Figure 7 *Relative humidity comparison near sheathing of brick walls in Charleston, SC shown for the month of June 2006.*

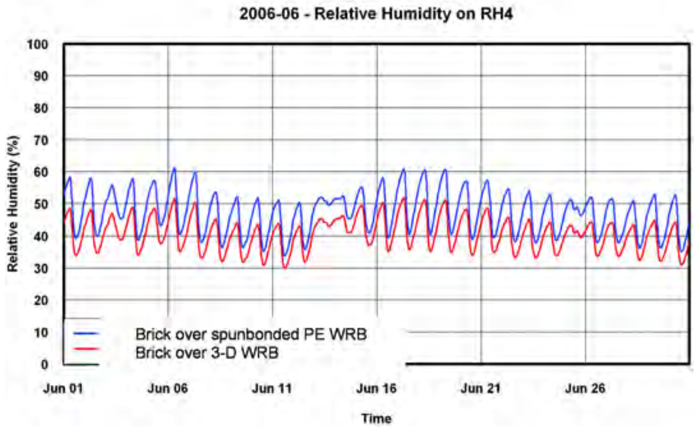

Figure 8 *Relative humidity comparison inside wall cavity of brick walls in Charleston, SC shown for the month of June 2006.*

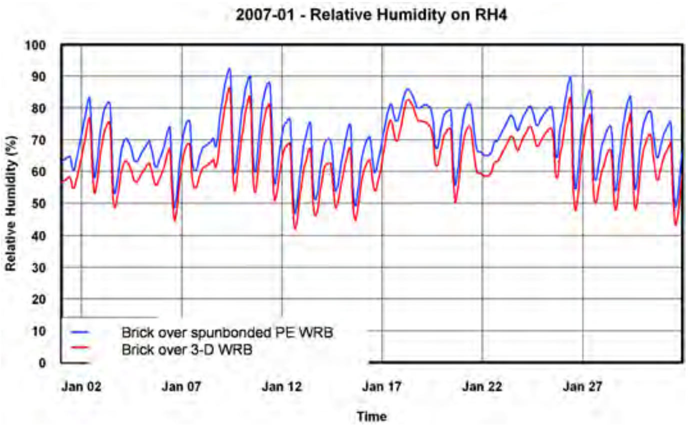

Figure 9 *Relative humidity comparison inside wall cavity of brick walls in Charleston, SC shown for the month of January 2007.*

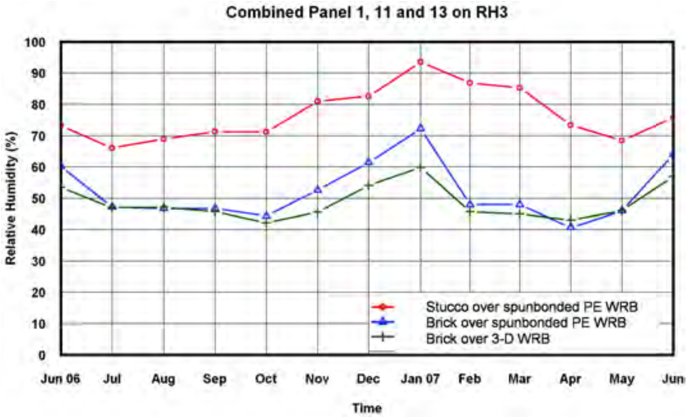

Figure 10 *Average relative humidity comparison near wood sheathing of brick and stucco walls in Charleston, SC shown for the entire test period.*

Results from measurements of three-coat stucco applied over a three-dimensional water-resistive barrier were not yet available at the time this paper was written.

Results from Waterloo, ON

Correspondingly to the measurements taken in Charleston, SC the moisture content of the wood sheathing and framing, and the relative humidity of the stud space were measured and analyzed to compare the hygrothermal performance of walls in Waterloo, ON with and without a three-dimensional ventilated air-gap membrane behind manufactured adhered stone veneer.

Figure 11 shows the moisture content of the framing lumber at mid height for the south and north orientation of the test walls with ventilated air-gap membrane in comparison with the walls with building paper without a ventilated air-gap. The moisture content in the wood studs on these walls was measured near the inside surface of the framing in order to capture potential condensation on the vapor barrier resulting from inward moisture drive. It is evident from the measured data that the moisture content exceeded 20% on the south-facing wall without air-gap from June till September. The moisture content in the wood framing of the north-facing wall without air-gap shows a moisture content of around 15% for the entire summer. The north- and south-facing walls with the air-gap membrane do not show any considerable increase in moisture content during the summer months. This clearly shows the significance of solar driven moisture and how it is influenced by a ventilated air-gap and the impermeability of the three-dimensional membrane behind the absorptive

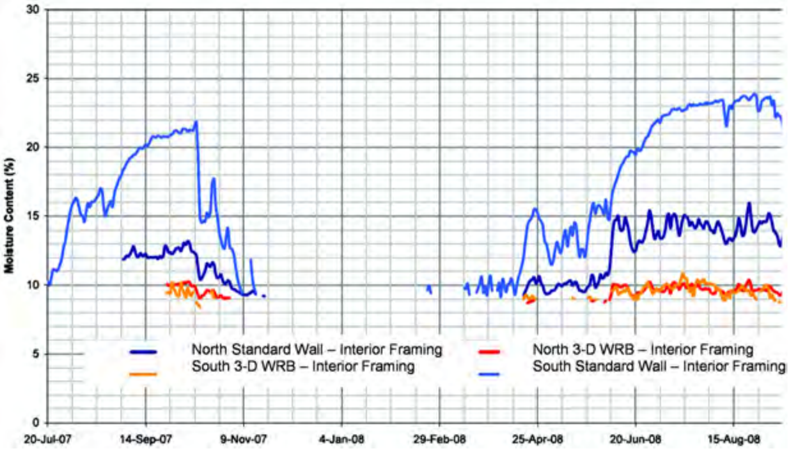

Figure 11 *Moisture content comparison of wood studs in walls with adhered manufactured veneer in Waterloo, ON shown for September 2007 to September 2008.*

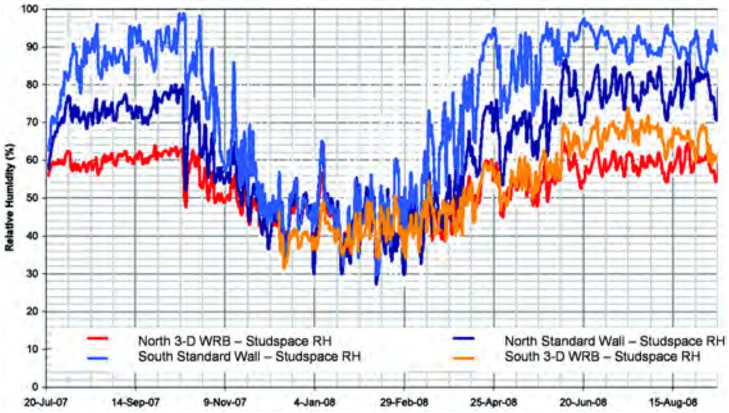

Figure 12 *Relative humidity comparison of stud cavities in walls with adhered manufactured veneer in Waterloo, ON shown for September 2007 to September 2008.*

adhered veneer. No data is plotted during the winter months due to the moisture contents in all walls dropping below the accuracy range of the measuring equipment (below 8%).

The elevated moisture content levels in the wood framing of the walls without air-gap indicate that the relative humidity in these walls would also be elevated.

This is verified in Figure 12, which compares the relative humidity of the stud cavities for all four test walls. The south-facing wall without air-gap membrane shows the highest relative of all walls, ranging around 90% for more than 6 months of the test year. While the north-facing wall without air-gap membrane shows elevated relative humidity levels of around 80% during the summer months, the north- and south-facing walls with air-gap membrane remain at 60% to 70% for the entire summer. The combination of ventilated air-gap with the vapor impermeable three-dimensional membrane does not allow the solar driven moisture to get pushed into the wall cavity.

CONCLUSIONS

The measured data from monitoring a series of different wall setups with and without air-gap membrane behind various types of absorptive claddings in Charleston, SC and Waterloo, ON allows drawing the following conclusions:

- The brick veneer walls with air-gap membrane in Charleston experienced lower relative humidity near the sheathing during summer as well as winter months than the comparison test walls without air-gap membrane, which employed a standard spunbonded polyolefin-based water-resistive barrier. It must be noted that all brick veneer test walls had a ventilated 1 in. air-cavity between sheathing board and back side of the brick. This shows that a vapor impermeable three-dimensional membrane not only provides the ventilation that a regular air-cavity would provide, but furthermore blocks inward moisture drive originating from the absorptive brick veneer, which results in the mentioned lower relative humidity.

- The relative humidity measured inside the wall cavities of all test walls in Charleston showed to be 8% to 10% lower in the walls with air-gap membrane than in the standard walls during both summer and winter months. In this challenging climate with year-round high ambient relative humidity this is a significant safety margin for wall assemblies, even if they already include a ventilated air cavity behind the cladding.
- When comparing the relative humidity near the sheathing of these walls to a wall with directly applied three-coat stucco it becomes evident that solar driven moisture plays a significant role. The relative humidity was measured to be up to 42% higher in the stucco wall without air-gap membrane compared to the brick veneer wall with air-gap membrane.
- The north- and south-facing walls with adhered stone veneer over without ventilated air-gap that were tested in Waterloo, ON all showed elevated moisture levels which crossed the generally accepted threshold where moisture related problems may occur. The sheathing of the walls that employed a ventilated air-gap membrane all stayed below 12% sheathing moisture content year round.
- Inward vapor drive caused by solar exposure of the absorptive veneer cladding caused the moisture content in the wood framing of the standard walls to rise, while the walls with the vapor impermeable air-gap membrane did not show such elevated moisture content levels due to the decoupling effect of the membrane between wood sheathing and moisture absorptive cladding.
- During the summer months solar driven moisture caused the relative humidity in the stud cavities of the standard walls to get elevated above 80% for several consecutive months, hence creating the risk of moisture related failure over time. The walls with the ventilated air-gap membrane did not experience humidity levels that would cause any moisture related damage to the walls.

The forgoing analysis convincingly demonstrates that the combination of a small gap produced by the air-gap membrane together with its vapor impermeability not only provides enhanced drying potential by deploying passive solar energy, but that it also provides a control layer against inward solar drives from absorptive claddings.

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About this Paper

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About the Authors

John Straube teaches in the Department of Civil Engineering and the School of Architecture at the University of Waterloo. More information about John Straube can be found at www.buildingscienceconsulting.com.

M. Jablonka is a director at Cosella-Dörken Products, Inc., Beamsville, ON, Canada.

A. Karagiozis is a senior research engineer at ORNL, Oak Ridge, TN

Direct all correspondence to: Building Science Corporation, 30 Forest Street, Somerville, MA 02143.

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