

COMPARATIVE HYGTROTHERMAL PERFORMANCE TESTING OF WALL ASSEMBLIES WITH BRICK VENEER EMPLOYING A 3-DIMENSIONAL DUAL VENTILATED WRB, AND A SPUNBONDED POLYOLEFIN-BASED WRB

M. Jablonka, Cosella-Dörken, Director, Beamsville, Canada, mjablonka@cosella-dorken.com
A. Karagiozis, Oak Ridge National Lab, Distinguished R&D Engineer, Oak Ridge, USA,
karagiozisan@ornl.gov

ABSTRACT

As the demand for improved energy efficiency of buildings continues to rise, more and more activities are commencing to assist the development of building envelope systems that are even more energy efficient. One major objective within the Department of Energy is to create a series of advanced wall systems that can help achieve the goal of zero net energy residential buildings. As the energy efficiency of a building envelope is increased - the key method to improve energy efficiency of wall systems is to add insulation - durability challenges can occur that are related to moisture management. Essentially, less energy is available to assist the transport of moisture away from the building envelope. A number of innovative building envelope materials and systems are being introduced to the North American construction market to enhance the moisture drying potential. Some of these materials/systems are passive, i.e. do not require additional energy.

This study investigates the hygrothermal performance of a brick veneer wall assembly with two different weather resistive barrier (WRB) strategies. One of the WRB's deployed in this investigation is a spunbonded polyolefin-based material. The second WRB is an innovative 3-dimensional dual ventilated sheet. The performance analysis of these two different WRB's is based on long-term field-monitored results under challenging hygrothermal conditions. This paper conclusively demonstrates that the 3-dimensional WRB with ventilation on both sides of the membrane provides excellent hygrothermal performance when compared to the conventional spun-bonded polyolefin based material. The 3-D dual ventilated WRB provides enhanced drying potential by deploying passive solar energy, making this innovative material an excellent contender for present and future wall systems (Zero-Net Energy Buildings).

RÉSUMÉ

Pour répondre à la demande croissante de bâtiments plus efficaces énergétiquement, de plus en plus d'activités visent le développement de systèmes d'enveloppe du bâtiment plus efficaces énergétiquement. Un objectif majeur du Département of Energy (USA) est de concevoir une série de systèmes de murs avancés qui permettraient d'atteindre la cible de bâtiments résidentiels d'énergie zéro. L'augmentation de l'efficacité énergétique de l'enveloppe – dont la clé est l'augmentation du niveau d'isolation – peut mener à des problèmes de durabilité, découlant de la gestion de l'humidité. Essentiellement, moins d'énergie est disponible pour aider au transport de l'humidité hors de l'enveloppe. Plusieurs matériaux et systèmes innovateurs pour l'enveloppe du bâtiment sont apparus sur le marché nord-américain dans le but d'améliorer le potentiel de séchage. Certains de ces matériaux/systèmes sont passifs, i.e. ne requièrent pas d'énergie additionnelle.

Cette étude documente le rendement hygrothermique d'un assemblage à parement de brique avec deux membranes pare-intempéries différentes. Une membrane utilisée dans cette étude est un matériau à base de polyoléfine filée-liée. La deuxième membrane est nouvelle, un matériau tridimensionnel à double ventilation. L'analyse du rendement de ces deux pare-intempérie est basée des résultats de monitoring sur un longue période d'assemblages exposés à un environnement hygrothermiquement exigeant. Cet article démontre clairement que le pare-intempérie tridimensionnel avec ventilation sur chacune de ses faces procure un rendement hygrothermique excellent lorsque comparé au matériau conventionnel à base de polyoléfine

filée-liée. Le pare-intempérie 3-D à double ventilation permet un potentiel de séchage accru, en faisant usage de l'énergie solaire passive, rendant ce matériau une composante prometteuse pour les assemblages de murs, y compris les murs de maisons d'énergie zéro.

1. INTRODUCTION

The demand for improved energy efficiency of buildings is increasing world-wide. Building envelopes are being re-designed to achieve further reduction of thermal losses. Moisture control becomes more critical, and for the first time building physics principles (moisture control) are being implemented in the design process. Both, drying and wetting potentials are being considered in design applications. Building envelope systems with low energy losses often tend to have less drying potential, and thus are frequently more vulnerable to moisture accumulation problems (Rose, 2005). Moisture induced problems are widespread - even in existing buildings with moderate energy consumption rates. This has been well documented by Karagiozis [2001] for the Northwest, but it is also common in dry climates (i.e. Arizona, Las Vegas, etc.). These problems seem to indiscriminately be caused by, or related to installation details, certain types of cladding materials, certain weather resistive barriers, and indoor and outdoor climatic conditions. Many problems have been reported with absorptive and semi-absorptive cladding types.

Of particular importance in today's wall systems is the deployment of a weather-resistive barrier (WRB) – the second line of defense against moisture intrusion [Bomberg et al., 2003]. These materials are the element of the building envelope system designed to provide protection of the building materials from exterior water penetration (liquid transport resistance). WRB's, to a certain degree, also have the potential to control the diffusion of water vapor, ideally in both directions. Some WRB's may contribute to the reduction of air leakage across the wall as well, cutting utility costs and at the same time increasing the overall occupant comfort. A key duty of weather resistive barriers is to keep building materials dry, and to consequently improve the building durability and reduce the risk of moisture-related problems like mold, mildew, and decay.

The performance properties of existing weather resistive barriers vary widely, and frequently they do not provide sufficient moisture protection to building envelope assemblies. When solar radiation heats wet absorptive claddings, elevated vapor pressures occur, resulting in inward vapor drives. Consequently, moisture is being driven through the sheathing membrane and sheathing board into the insulated stud cavity. This results in higher moisture contents of the sheathing and wood studs, and may lead to condensation on the drywall or vapor retarder. Elevated relative humidities and moisture contents of the building enclosure may lead to premature building failure due to rotting or corroding of building enclosure components. There are many examples of these types of failures with absorptive claddings in British Columbia and the Pacific Northwest of the United States. The failures can also be a result of poor detailing, building envelope designs deploying materials with low moisture tolerance [Lstiburek, 2008], and the lack of air cavity ventilation as described by Karagiozis [2005]. Manufactured stone veneer, brick, and cement boards are highly absorptive claddings and thus can lead to such moisture accumulation problems in the building envelope, if applied directly over a conventional WRB. While a drainage and ventilation space between cladding and sheathing board can enhance the drying potential of the building enclosure, the installation of a WRB material between cladding and sheathing board which is impermeable to vapor diffusion may alleviate the moisture accumulation issues due to inward solar moisture drive. All three functions, halting the inward solar moisture drive, providing ventilation in form of two ventilated air cavities as well as drainage on both sides of the membrane can be provided by a vapor impermeable 3-dimensional weather resistive barrier.

In many weather resistive barrier applications, an intentional or unintentional air space is left between the cladding and the weather resistive barrier. Frequently, this air space is discontinuous due to periodic contact of the sheathing membrane with the backside of the cladding. The air space allows for hygrothermal interaction between the exterior surface of the weather resistive barrier and the adjacent air, and – if the space is either vented or ventilated – it also allows hygrothermal interaction with exterior air. However, in all

applications the membrane type weather resistive barriers are fastened securely to the sheathing board, and thus eliminate an air space between the exterior surface of the sheathing board and the inner surface of the weather resistive barrier. Building papers as well as perforated and non-perforated synthetic 'housewraps' belong to this category of weather resistive barriers, and are the most prevalent materials used as a secondary moisture protection layer in today's construction practice. Moisture may condense at the interface of the sheathing board and the membrane. In order to dry out this liquid moisture it needs to change its phase to vapor - requiring energy - and then slowly diffuse through the membrane or exterior sheathing. It is expected that significant improvements in moisture management of wall systems can be achieved through effectively ventilated air cavities - even under severe climatic conditions.

2. OBJECTIVE

The objective of this study was to measure and compare the hygrothermal performance of a traditional brick veneer wall employing two different weather resistive barrier strategies: a) a spunbonded polyolefin-based, and b) an innovative dual ventilated 3-dimensional membrane. Field monitoring of side-by-side test walls was conducted with a combination of temperature, relative humidity, wood moisture content, and heat flux sensors located in the cladding, drainage space, and test wall panels. The research approach integrates laboratory testing, advanced modeling, and field testing.

3. DESCRIPTION OF DUAL AIR CAVITY VENTILATED AND DRAINED 3-DIMENSIONAL WRB

In building envelope systems that incorporate a 3-dimensional WRB with a dual ventilated and drained air cavity, the cladding (stucco, manufactured stone veneer, siding, etc.) is entirely separated from the exterior sheathing. This creates a capillary break as well as a functional drainage layer for water that penetrates past the cladding material. In addition, the ventilated air cavity (open at top and bottom) promotes accelerated drying via moisture transport through air exchange. Hence, the air-gap effectively increases the durability of the wall assembly, particularly the sheathing and the cladding. The structure of the 3-dimensional, vapor impermeable membrane allows for drainage and ventilation in air spaces on either side of the barrier material, and thus effectively addresses the above mentioned shortcomings of conventional WRB's. This approach essentially combines a non-conventional weather resistive barrier and a rainscreen layer, which – according to Straube et al. [2005] – generally describes a number of different concepts to building a drained wall system. The 3-dimensional WRB 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. Furthermore, the ventilated rainscreen / weather resistive barrier isolates the microclimatic chamber between membrane and sheathing board from the microclimatic chamber between membrane and exterior cladding, and prevents inward moisture migration due to solar drive. An example of a 3-dimensional WRB as described above is shown in Figure 1. Even at rather small air cavity ventilation strengths, the amount of moisture that can be extracted from wall systems is very large - at magnitudes of 10 to 300 times higher than by vapor diffusion.



Figure 1: Three-dimensional Polyethylene membrane performs as rainscreen and WRB at the same time, while providing dual cavity ventilation

The system provides the following functionalities:

- Drains bulk water efficiently on both sides of the membrane
- Provides full capillary break through impermeable membrane plus air cavities
- Dries wall effectively through ventilation (two air cavity systems are created)
- Prevents solar moisture drive towards interior of wall (water vapor permeance < 0.1 perm)
- Creates two micro-climatic zones in the wall (cladding zone and interior wall zone)

Figure 2 shows the possible flow of heat, air and moisture through a wall system that deploys this system.

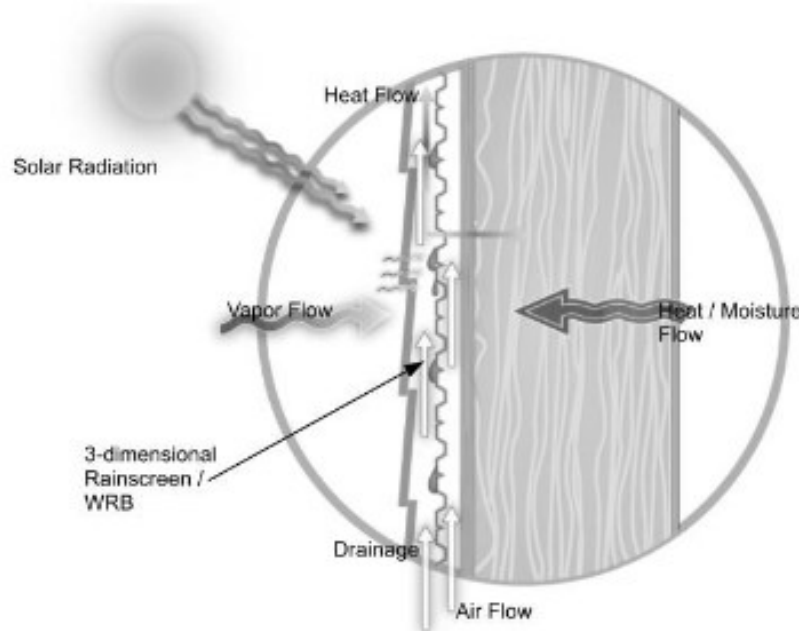


Figure 2: Three-dimensional Rainscreen / WRB membrane provides two drained and ventilated air gaps

Conceptually, the embossed Polyethylene membrane, especially when applied in conjunction with absorptive cladding systems, offers enhanced drying performance. Wall designs employing this system become more tolerant of water penetration or water condensation occurring on either side of the membrane.

4. PERFORMANCE EVALUATION UNDER LONG-TERM NATURAL EXPOSURE CONDITIONS

4.1 OVERVIEW AND METHODOLOGY OF PERFORMANCE EVALUATION

This research project required a holistic approach to moisture engineering analysis. The envelope 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 et al. [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 [2005], as depicted in Figure 3.

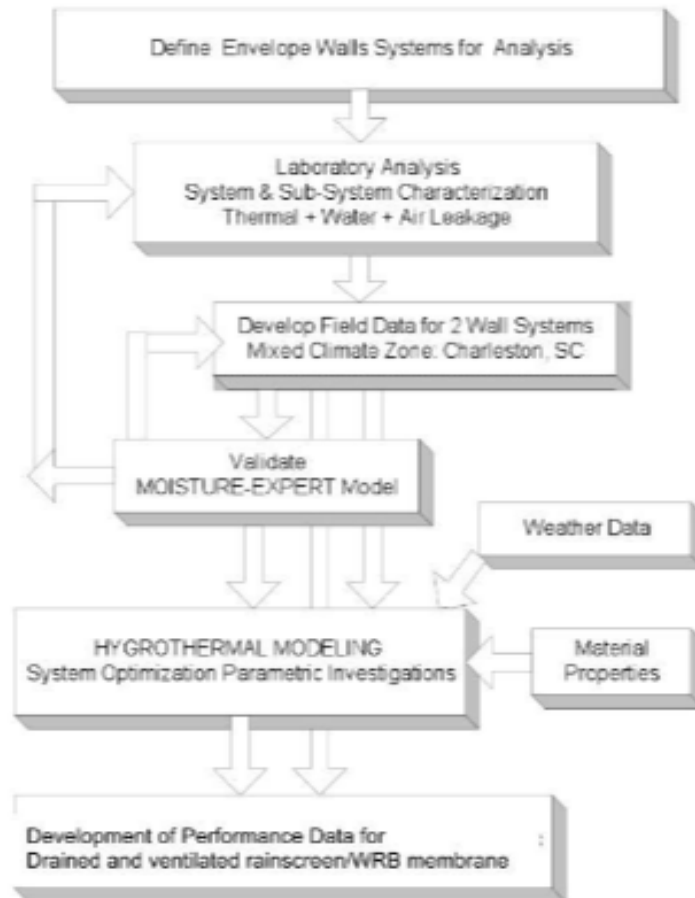


Figure 3: Research approach to evaluate the performance of a 3-dimensional Dual ventilated weather resistive barrier membrane

An absorptive wall system with brick veneer cladding was used in the computer modeling analysis. The wall assembly is shown in Figure 4.

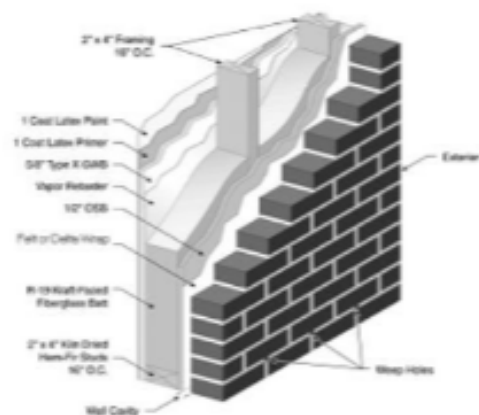


Figure 4: Wall Assembly used in hygrothermal computer modeling

Transient heat, air and moisture transfer computer simulations were performed for five location conditions (Toronto, Atlanta, Seattle, Norfolk, Baton Rouge). The hourly exterior temperature, relative humidity, cloud index, solar irradiation, wind speed and orientation, and rain precipitation were included in the model.

In addition, the air changes that occur due to wind pressure differences or buoyancies were also included in the simulations, and 1% water penetration (of what strikes the exterior wall) was included in the simulations, which deposited water at the exterior surface of the OSB sheathing board.

The results of the laboratory study as well as of the subsequent hygrothermal computer modeling showed that the test walls with the 3-dimensional membrane drained and dried out significantly faster than the wall assemblies with #15 building paper. The results have been discussed in detail by Jablonka et al. [2007]. Subsequently to the laboratory tests and advanced hygrothermal modeling, field monitoring was chosen for further performance verification of the system. The results of long-term tests under natural exposure conditions will be discussed in the following chapters.

4.2 GEOGRAPHIC AND CLIMATIC CHARACTERISTICS OF TEST LOCATION

The Natural Exposure Test (NET) facility 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, as shown in Figure 5. Historical climatic data from 1961 to 1990 shows that Charleston, SC 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 at the NET facility is representative of typical climatic conditions in Charleston, SC.

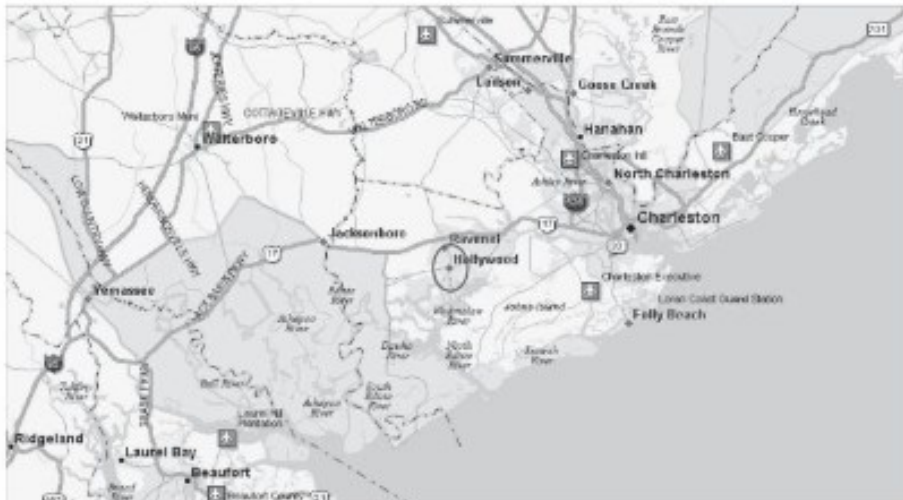


Figure 5: Proximity of the NET facility to Charleston, SC

4.3 SENSOR CONFIGURATION IN TEST WALL ASSEMBLIES

Two test walls were equipped with 17 thermistors, 6 relative humidity sensors, and 8 moisture content sensors. Figure 6 shows the sensor configuration in the wall assemblies. The same sensor arrangement is found in both types of wall assemblies (spunbonded polyolefin-based WRB, 3-dimensional WRB/rainscreen).

The experiment was set up to collect field data for a one year period for temperatures, moisture content of wood and relative humidity in the wall cavity at different locations in the wall assembly, as well as the heat flux through the wall assembly at mid-height.

4.4 RESULTS OF PERFORMANCE MONITORING – MEASURED DATA

In Figure 7, the monthly averaged interior and exterior temperatures and relative humidities (%) are displayed. The interior temperatures varied between 19°C and 21°C (66.2°F and 69.8°F), while the average exterior temperature ranged from 8°C to 26°C (46.4°F to 78.8°F).

The average interior relative humidity ranged from 34% to 55%, while the average exterior relative humidity varied between 62% and 81%. Note that these numbers are monthly averages; peak values may vary significantly from the averages.

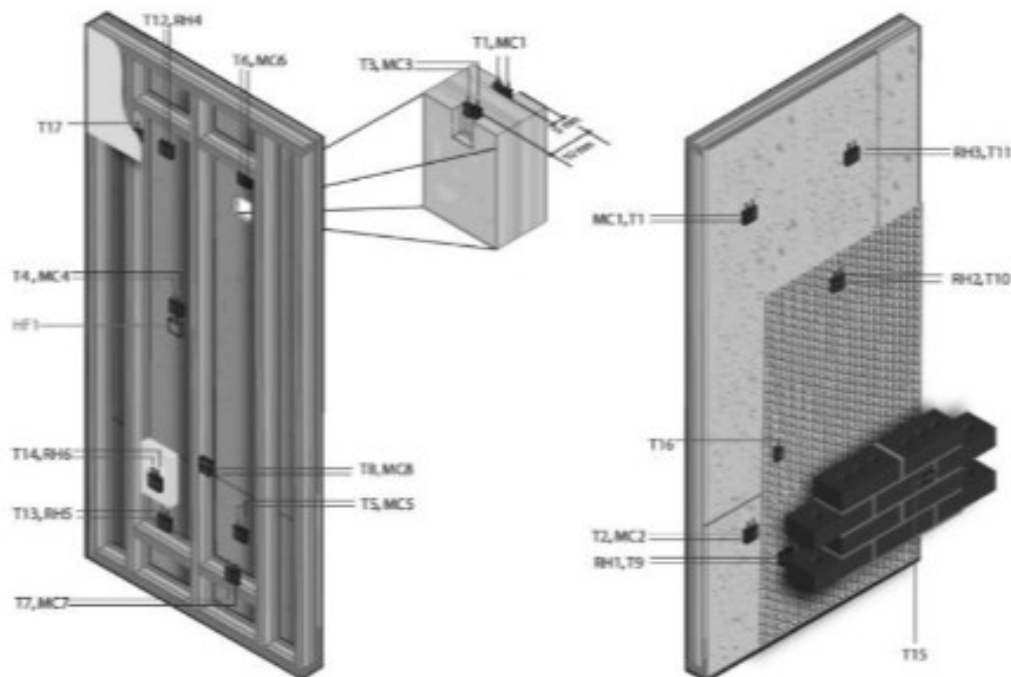


Figure 6: Sensor configuration for test wall assemblies

As depicted in the instrumentation section, heat flux sensors were located in the test walls to measure the impact of a ventilated air-gap outboard of the sheathing board on the energy consumption. The heat fluxes were measured on an hourly basis. Positive heat fluxes were designated as heat fluxes that provided a net positive heat flow during the specific hour into the NET building through the wall segment. Negative heat fluxes were designated as heat fluxes that left the building. In Figure 8 the hourly heat fluxes are shown as a function of time of day at different times of the year. During the summer period the brick wall system with the ventilated 3-dimensional rainscreen/WRB membrane shows reductions of the total inward heat flux, as well as a substantial peak reduction, when compared to the conventional wall system with a flat WRB membrane.

During colder periods, the heat flows are very close between the two evaluated wall systems. In fact, they are within the experimental uncertainty of the measurements. In Table 1 the hourly heat flux data has been processed to yield total positive and negative heat fluxes for the time period from June 2006 to July 2007.

The below data shows the negligible impact that ventilation flow in the dual air cavity of the 3-dimensional rainscreen membrane had on the heat fluxes measured at the interior of the walls. This means that the air leakage through the wall as well as ventilation flow in the dual air cavity did not appreciably degrade the energy balance.

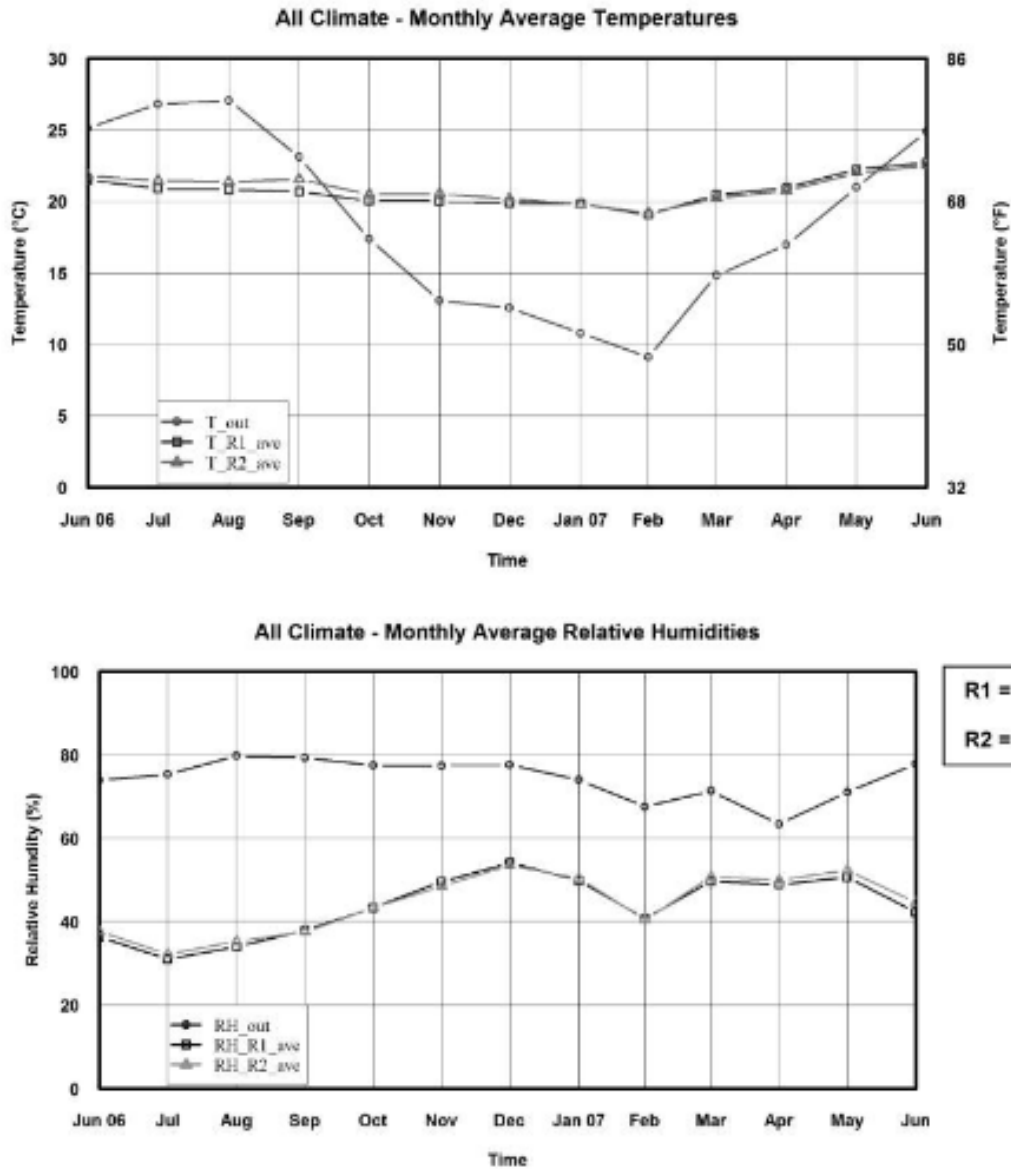


Figure 7: Monthly averaged Temperatures and Relative Humidities (%) as a function of time

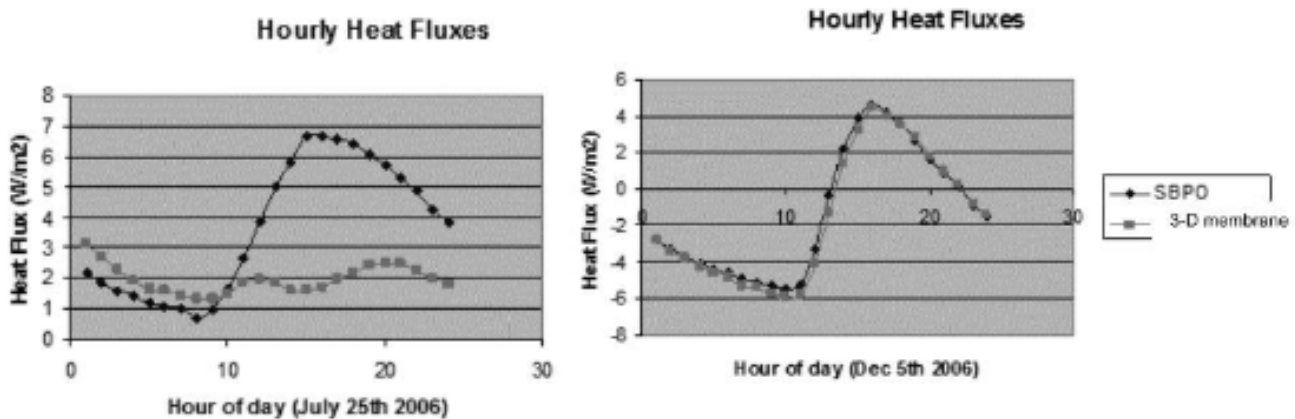


Figure 8: Hourly Heat Fluxes measured in July and December (3.5 W/m^2 is approximately $1.11 \text{ BTU/ft}^2 \text{ hr}$)

Wall Description	Weather Barrier	Framing	Average Positive Heat Flux (W/m^2)	Average Negative Heat Flux (W/m^2)
Brick Wall (SE orientation), Air Cavity 1", OSB Sheathing, No VB	SBPO membrane	2 x 4@16"	3.199493	-2.04331
Brick Wall (SE orientation), Dual Air Cavity, OSB Sheathing, No VB	3-dimensional rainscreen membrane	2 x 4@16"	3.24717	-2.15978

Table 1: Total Positive and Negative Heat Fluxes for the testing period

The measured monthly mean relative humidities and moisture contents are plotted out in Figure 9 for both brick wall systems. The results indicate that both brick wall systems performed satisfactory, with slightly higher relative humidities shown in Panel 11 (SBPO type WRB).

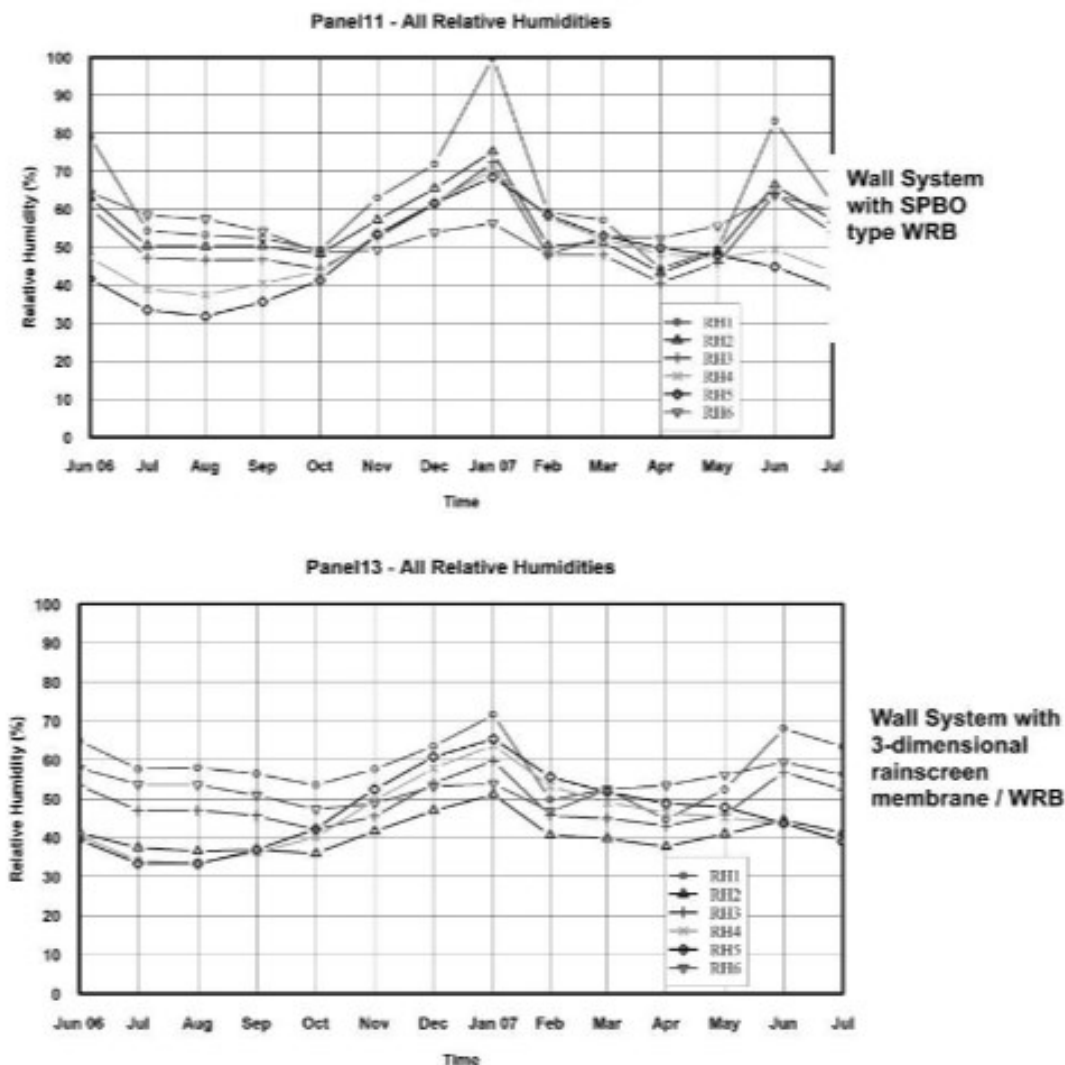
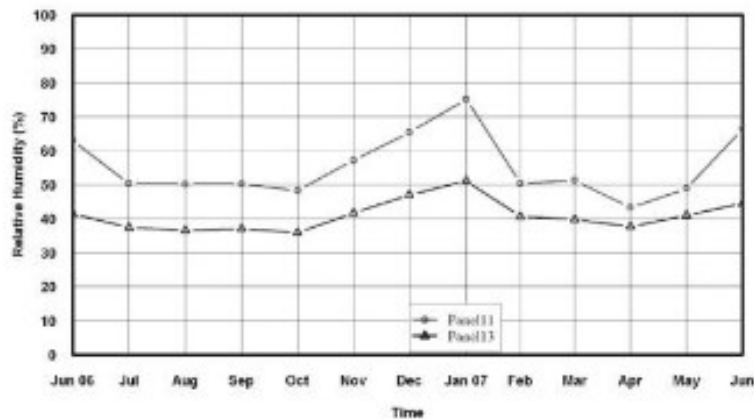


Figure 9: Relative Humidities in both Brick Wall Systems

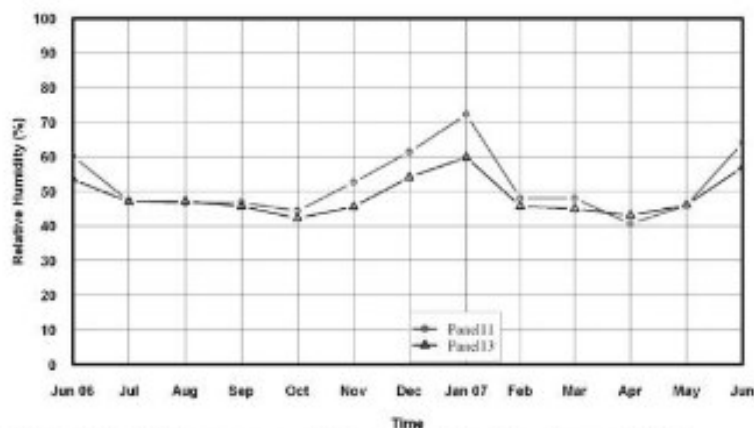
Figures 10, 11, and 12 display the monthly averaged relative humidities for sensor locations RH2, RH3, and RH4 for both brick wall systems. The results show that the dual ventilated cavities provided by the 3-dimensional membrane generate drier conditions at the exterior cladding as well as in the concealed wall region.



Panel 11:
Wall System with
SPBO type WRB

Panel 13:
Wall System with 3-
dimensional
rainscreen
membrane / WRB

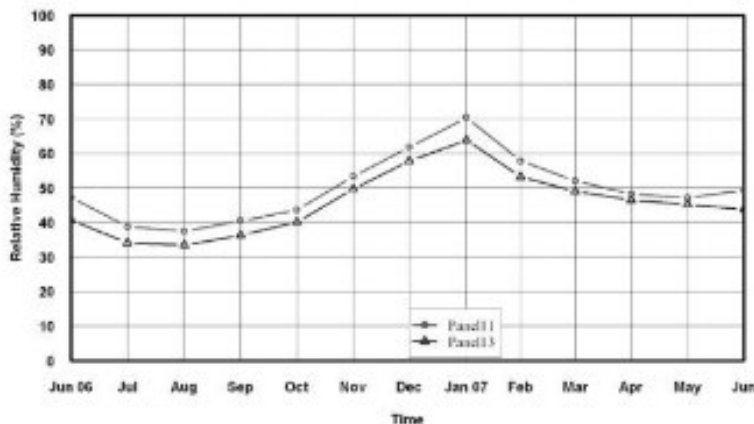
Figure 10: Relative Humidities measured in both brick wall systems at RH2



Panel 11:
Wall System with
SPBO type WRB

Panel 13:
Wall System with 3-
dimensional
rainscreen
membrane / WRB

Figure 11: Relative Humidities measured in both brick wall systems at RH3



Panel 11:
Wall System with
SPBO type WRB

Panel 13:
Wall System with 3-
dimensional
rainscreen
membrane / WRB

Figure 12: Relative Humidities measured in both brick wall systems at RH4

5. DISCUSSIONS OF RESULTS AND CONCLUSIONS

This report provides performance data on two wall systems that have been monitored for a period of 1 year and 1 month (June 1, 2006 through July 30, 2007).

The results of the hygrothermal performance evaluation of wall systems with a SBPO type WRB versus a 3-dimensional rainscreen membrane / WRB that are discussed in this paper are displayed as monthly averaged data and provide insight on the heat and moisture performance of these walls for a 13 months period. The

investigation focused on the impact of the choice of the weather resistive barrier (flat SBPO based versus 3-dimensional) and the influence of a dual ventilated air cavity. The wall systems that were investigated demonstrated cyclic performance in terms of wall wetting and drying as a function of time of year. The accuracy of the relative humidity sensors is significantly higher than those measuring the moisture content. Therefore the relative humidity data provided a significant amount of insight. The measured data shows that differences in relative humidity can be quite significant between the two wall systems. The following can be concluded from the data gained during this long-term evaluation:

- Wall systems with absorptive claddings that employ a 3-dimensional membrane as a rainscreen / WRB like the product that was used in this evaluation perform well in the hot and humid climate of Charleston, SC. The results from this study evidently confirm previous observations from the laboratory evaluation and advanced computer modeling that indicated the superior performance (lower MC and RH) of a 3-dimensional membrane in hot and humid climates for wall systems with absorptive claddings.
- Comparisons between the investigated wall systems demonstrated that neither wall system shows moisture accumulation problems during the exposure period.
- The wall system with the best hygrothermal performance and higher reserve capacity was found to be the wall that employed a 3-dimensional membrane. As the RH in the cavity of this wall stayed significantly lower (drier) during the winter months (when moisture condensation is most likely to appear on the inside surface of the exterior sheathing) it is evident that, due to the additional drying capacity through ventilation in the dual air cavity, the 3-dimensional product has a higher reserve capacity to deal with moisture than the wall assembly with a SBPO type WRB.

6. REFERENCES

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