

# Field Monitoring of the Hygrothermal Performance of a New Class of EIFS Walls

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## ABSTRACT:

The development of new construction materials can be an expensive and risky proposition. This is particularly true if the material is to be used as a barrier to air movement and bulk water entry into the building envelope. How does a manufacturer ensure that a material will work in all climates without risking deterioration of the wall? Building test facilities in each climate zone and monitoring them over a multi-year period is not practical and would, in any case, only confirm performance during those years. A more economical and thorough approach is required to evaluate performance in a wide range of climates for an extended time period.

Research on walls with various cladding materials is being conducted at the Natural Exposure Test (NET) Facility located in Hollywood, SC. ORNL is monitoring the performance of fifteen panels of EIFS, stucco, brick and other materials. The results of continuous hourly monitoring are being compiled for subsequent comparison with the results of computer simulations.

A vast amount of hygrothermal performance data has been generated. This paper is the first in a series and will concentrate on the description of the research program that was undertaken, and to show some limited field data gathered during the first year. Experimental results for two panels, one having a brick veneer cladding and one having an EIFS, were selected for illustration as they represent a typical range of performance data that has been obtained for further hygrothermal analysis.

## INTRODUCTION

Prior to 1996, Exterior Insulation and Finish Systems (EIFS) had become popular as an exterior building envelope cladding system in the residential and commercial construction market in North America [1]. Since 1996, the commercial construction sector has continued to experience rapid growth; however, residential construction dropped as the EIFS cladding system, as being built at the time, became associated with certain water intrusion problems. Nissen [10] presented a summary of serious moisture problems in barrier EIFS-clad walls in New Hanover County, including the city of Wilmington, NC. Moisture problems ranging from high moisture content in the exterior sheathing to wood rot in some houses were observed. Many of the 3200 EIFS-

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clad homes in that area needed some remedial repair. Most of the water intrusion issues were traced to flashing details and the penetration of water into the wall systems at window joints [6, 8]. The installation of code mandated sub-sill window flashing was not practiced by builders nor was diverter flashing used at roof/wall intersections. Investigations showed that approximately 45% of the damage occurred below the corners of windows and 35% below missing roof flashing. Problems of water intrusion were not unique to EIFS but the adverse publicity was focused on the system. The issue of water penetration was limited to interface locations, not within the field of the wall. Typically, small amounts of penetrating water could dry through the wall assembly but problems developed if there chronic wetting and moisture did not dry out quickly enough [8]. Questions were also raised about the effect of interior vapor control strategy. At the time, an interior vapour barrier was mandated by code. Another major finding was that the windows installed in these homes were not appropriate for the climate zone. These two reasons, in combination with the flashing issues, were the prime reasons for the failed performance observed in Wilmington, NC. Although the problems with water intrusion appeared to be universal with all cladding materials, only EIFS was studied quantitatively. Information on other claddings in NC is mostly anecdotal.<sup>3</sup>

During this time period (1996 to 2001), a large number of papers appeared that sometimes added more confusion to the general literature. Many of the articles published were primarily generated by opinions and not basic building science. Early versions of MOIST (M1), MATCH (M2) and WUFI (W) were valuable in studies of moisture transport but were lacking material property data, surface transport coefficients, conservation of mass and energy, and ability to account for wind-driven rain (M1 & M2) and water penetration.

A number of scientific breakthroughs in the understanding of the transport of heat, air and moisture through a building enclosure became available from the International Energy Agency Annex 24 on Heat, Air and Moisture Transfer through New and Retrofitted Envelope Parts. Simpler versions of these models, such as WUFI, have now (since 2001) become available to the general public. The hygrothermal tools and data that would have assisted the analysis of moisture-induced failures were not available prior to 2001. Of course, it is not possible to predict system behaviour of improperly constructed wall systems even at this time simply because of the lack of detailed knowledge about specific faults.

In 2003, the Department of Energy (DOE) requested that Oak Ridge National Laboratory address the performance issues associated with exterior foam insulation. The perception of problems related to the use of exterior foam insulation (EIFS) led to a substantial reduction in construction built using EIFS. This reduced the potential energy savings in new and renovation residential construction. To meet the Zero Energy

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<sup>3</sup> *New moisture problems menace coastal homes*, Scott Brooks, Greater Wilmington Business, Volume 1.5, June 2000

Building (ZEB) objectives laid out by the DOE Building America program, one cost effective option was to use EIFS wall systems. A strategic research plan was developed and proposed to EIFS Industry Members Association (EIMA) to partner with ORNL to investigate the performance of EIF wall systems. At the same time, ORNL would integrate some newer concepts arising from their previous research on moisture-engineered EIFS walls. These innovations included, water drained systems using a fluid-applied water resistive barrier, and EIF systems designed with vented or ventilated drainage cavities.

The research project was conducted in two phases. Below is a brief description of each phase of the research project.

### RESEARCH STEPS

A number of steps are involved in the research for Phase I and II. Figure 1 provides an overview of the main tasks that are required to achieve productive end results.

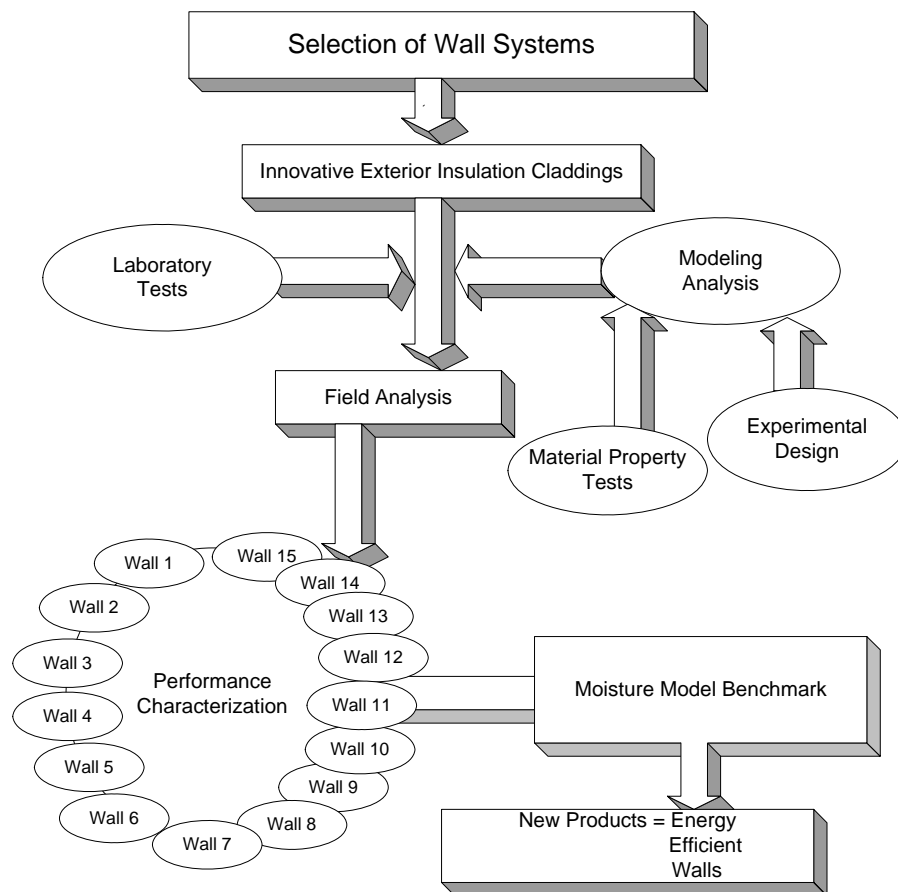


Figure 1: Research Approach for the EIMA/DOE/ORNL Project

## PHASE I OF THE RESEARCH PROGRAM

Phase I, a 15-month field research project initiated in January 2005, was conducted to characterize the moisture and thermal performance of various configurations of exterior cladding systems (EIFS, brick, stucco, concrete block, and cementitious fiber board siding).

The primary goals of the Phase I study were:

- To validate the moisture and thermal performance of a new class of EIF wall systems.
- To quantify the performance of new EIFS and other wall systems that employ other types of exterior cladding.
- To develop high quality data to calibrate a hygrothermal (moisture and temperature) computer model with the unique features of EIFS to permit applying the model to all climatic regions.

The hygrothermal research investigation included the impact of innovative EIFS features, specifically the application of fluid-applied moisture control membranes, smart vapor retarder systems (bi-directional membranes), and the impact of exterior cladding venting, as well as the overall thermal and moisture performance of EIFS.

**Phase 1 Study Approach:** In keeping with the DOE's directive of promoting a whole-building approach to building design, operation and maintenance, the research project considered the building envelope in its entirety, rather than studying isolated materials or component systems. The research approach is summarized below:

- Characterize the moisture and thermal performance properties of critical construction materials and sub-systems used in exterior wall systems.
- Conduct field testing on a variety of exterior wall systems to determine their thermal and moisture response to the local weather condition over the course of 15 months.
- Develop performance information useful to the design methodology that will permit architects and engineers to optimize energy efficiency.

To achieve these goals, a special building was designed and constructed at Hollywood, SC, a Zone 3, mixed climate location, on near the Atlantic coast, south of Charleston (Figure 2). A flexible design was implemented to allow the change of wall panels with ease, to compartmentalize the building into two zones, and to allow control of the interior conditions. In Phase I, a total number of 15 wall assemblies were integrated into one side of the building (south-eastern exposure). In this way, all of the assemblies would be exposed to similar weather conditions. Building orientation and placement of the exterior wall test panels were determined after careful consideration of historical weather patterns in that location, including the prevailing direction of wind driven rain..



Figure 2: Natural Exposure Test (NET) Facility in Hollywood, SC

The primary focus of this project was on the wall assemblies that employed various EIFS configurations, particularly EIFS with drainage systems. Table 1 lists the configurations for the 15 wall panels. Other cladding assemblies were also included to provide additional information for validating the computer model that represented widely different characteristics. These were selected based on the construction typical to the region. As noted previously, other cladding assemblies, existing and yet to be developed, will be able to be studied using computer modelling when verified by this kind of research.

**Table I.** Configuration of the Exterior Wall Assemblies Investigated During Phase I

Panel / System	EPS	Attachment	Drainage / Air Space	Weather Barrier	Sheathing	Framing	Insulation	Vapor Barrier
Panel 1 EIFS	1 ½" Flat	Ribbon & Dab	None	None		CMU		Note 1
Panel 2 EIFS	1 ½" Flat	Notched Trowel	Vertical Ribbons	Liquid	Plywood	2 x 4@16"	R-11 Unfaced	None
Panel 3 EIFS	1 ½" Flat	Notched Trowel	Vertical Ribbons	Liquid	Plywood	2 x 4@16"	R-11 Unfaced	Membrane
Panel 4 EIFS	1 ½" Flat	Notched Trowel	Vertical Ribbons	Liquid	Plywood	2 x 4@16"	R-11 Unfaced	Yes
Panel 5 EIFS	4" Flat	Notched Trowel	Vertical Ribbons	Liquid	Plywood	2 x 4@16"	Cavity empty	None
Panel 6 EIFS	1 ½" Flat	Notched Trowel	Vertical Ribbons	Liquid	Plywood	18 ga @16"	R-11 Unfaced	None
Panel 7 EIFS	1 ½" Flat	Mech. Fastened	Grooved EPS	House wrap	Plywood	2 x 4@16"	R-11 Unfaced	None
Panel 8 EIFS	1 ½" Flat	Mech. Fastened	Grooved EPS	House wrap	Plywood	2 x 4@16"	R-11 Unfaced	6 mil Poly
Panel 9 EIFS	1 ½" Flat	Mech. Fastened	Mat	House wrap	OSB	2 x 4@16"	R-11 Unfaced	None
Panel 10 EIFS Ventilated	1 ½" Flat	Adhesive	Lath	Liquid	Plywood	2 x 4@16"	R-11 Unfaced	None
Panel 11 EIFS Commercial	1 ½" Flat	Notched Trowel	Vertical Ribbons	Liquid	ASTM C1177 Gyp. Board	18 ga @16"	R-11 Unfaced	None
Panel 12 3 Coat PCP (Stucco)	None	Mech. Fastened Note 2	3.4 Metal Lath	2-Layers Grade D 60 Minute	OSB	2 x 4@16"	R-11 Unfaced	None
Panel 13 1 Coat PCP (Stucco)	1" flat	Paint – later date Note 2	Woven Wire Plaster Base 1 x 20 ga.	1-Layers Grade D 60 Minute (behind foam)	OSB	2 x 4@16"	R-11 Unfaced	None
Panel 14 Brick	None	Brick ties	Air Cavity 1"	1-Layers Grade D 60 Minute	OSB	2 x 4@16"	R-11 Unfaced	None
Panel 15 Cementitious Fiberboard Siding	1" flat	Mech. Fastened	None	1-Layers Grade D 60 Minute	OSB	2 x 4@16"	R-11 Unfaced	None
Typical Interior Finishing – ½" drywall, primed and painted (1 coat acrylic paint). Note 1 – Finished with furred (1x2 treated lumber) ½" drywall, primed and painted (1 coat acrylic paint). Note 2 - Painted white initially, plywood = ½", OSB = ½", lath = G 60.								

Each of the wall panels contained a variety of sensors that recorded temperature, relative humidity, and moisture content. Some panels included heat flux sensors. All sensors collected data on an hourly basis and transmitted it to the ORNL Building Thermal Envelope Systems & Materials Energy Division Research facility in Oak Ridge, TN for analysis. A total of 15 months of data were collected from January 1, 2005 through March 30, 2006. The panel test area arrangement is shown in Figure 3.

The research investigated the hygric performances of each wall assembly. The field data and the hygrothermal model derived from it are particularly useful not only in developing guidelines for the use of EIFS but also in demonstrating the moisture and temperature control performance of EIFS as compared with other types of exterior claddings. Ultimately, the validation of computer modelling would extend the value of the data to all cladding assemblies.

Wood Frame Panel Dimensions

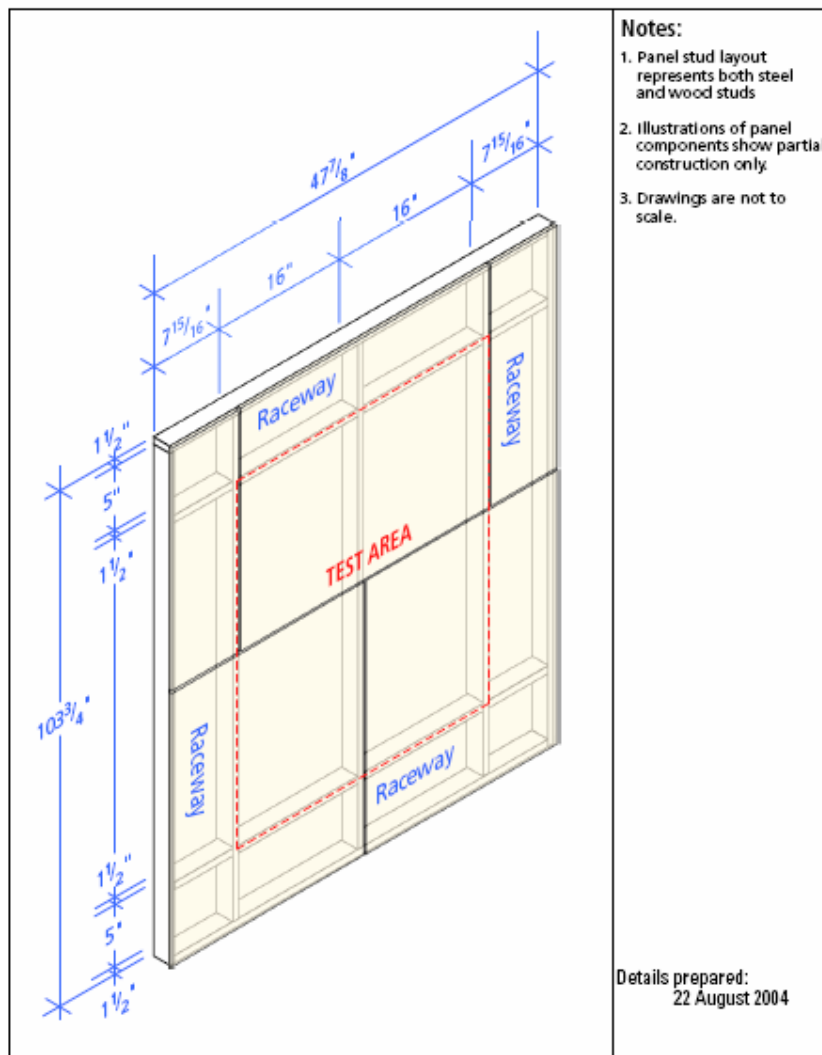


Figure 3: Field Testing Wall Dimensions for All Cladding Systems

## **Hygrothermal issues still not fully understood or quantified**

At this time, data is lacking on several aspects of the hygrothermal performance of many wall systems, including EIFS. This is true for several climatic effects, such as rainwater penetration, solar radiation, night sky radiation, and the influence of wind speed and site/wall orientation on both the convective and mass transfer coefficients. The response of various wall assemblies to exterior and interior hygric loading is complex and represents a large effort to undertake properly. The findings of Phase I (not reported here) go some way towards providing the necessary data. Earlier, some claims have been made that adding exterior insulation (EPS) reduces the drying performance of wall systems. For the Charleston region, the claim was not found to be supported. Other claims have yet to be tested. Phase II affords an opportunity to address some of these questions.

### **PHASE II OF THE RESEARCH PROGRAM**

Although the scope of the project was limited to fifteen panels, the second phase of the project took a more complete approach to gathering as much data as possible with specific attention to the following issues.

Newer exterior-cavity vented EIFS had been shown, in Phase I, to enhance the performance of conventional EIFS walls; still not investigated, however, is whether there is a degradation of their thermal performance as a result of air exchange in the drainage space. Scientific and code committees have posited that by introducing a vented air cavity between the insulation and water resistive barrier the effectiveness of the exterior insulation might be negated to some degree by cold air entering the drainage cavity. In Phase II, heat flux sensors for both the south-east and north-west orientations were added to measure the thermal consequences of cavity ventilation.

The question of hygrothermal performance in EIFS walls due to the effects of orientation (for example, a wall facing north vs. one facing south) has also been raised. This issue was found to be critical for the performance of stucco walls, where it directly affects both hygric loading and the accompanying drying potential. The orientation question becomes more complicated for both stucco and brick when coupled with the effects of absorptive cladding and solar driven moisture. It was not understood if the same factors would affect a low mass, relatively non-absorptive cladding like EIFS. Phase II afforded an opportunity to research and quantify this effect for EIFS.

Another unknown was the impact of incidental water penetrating the exterior EIFS lamina, the first line of defence. Currently, some literature suggests that even if very small amounts of water are allowed to pass through the exterior foam, catastrophic failure may occur. The proposed ASHRAE SPC 160P modelling standard recommends that 1 % of water that impacts the wall surface be injected onto the exterior surface of the water-resistive barrier to simulate a leak. A systematic moisture engineering research effort is being implemented in Phase II to provide data to address performance of wall systems associated with water penetration.



Finally, but not least, a limited hygrothermal property database exists for EIFS materials. This hampers designers, who cannot conduct an analysis of the performance of EIFS in different climates with sufficient accuracy. In Phase II, an extensive testing program is being carried out to obtain data on the moisture performance of various materials used in Phase I and II of this research study.

### **Phase II Study Approach**

Phase II used the same research approach and protocol as Phase I. The Phase II research approach is summarized below.

- Continue the development of accurate hygrothermal property characterizations of the critical construction materials.
- Conduct field testing to expose a series of innovative wall systems (trowel applied water-resistive barriers) to real environmental conditions.
- Conduct field testing to expose a series of innovative wall systems with additional water penetration loading by directing water into the wall.
- Develop performance information to be used in the formulation of design guidelines, which will provide options for energy efficiency, while addressing heat, air and moisture transport (Phase I and II).

Phase II includes both newly constructed wall panels and some original 20 month old Phase I panels. The total number of panels remained at fifteen. The description of each panel monitored in Phase II is provided in Table 2

The emphasis of DOE and ORNL participation throughout Phase II has been on the development of quality temporal (time-dependent) data for the calibration of the ORNL hygrothermal models.

**Table 2.** Configuration of the Exterior Wall Assemblies Investigated During Phase II

Panel / Orientation / Heat Flux Sensor (HFS) / System	EPS	Attachment	Drainage / Air Space	Weather Barrier	Sheathing	Framing	Insulation	Vapor Barrier
Panel 1	Not used for the EIMA – ORNL Research							
Panel 2, SE, EIFS	1½" Flat	Notched Trowel	Vertical Ribbons	Liquid	Plywood	2 x 4@16"	R-11 Unfaced	None
Panel 3, SE With Flaw, HFS EIFS	1 ½" Flat	Notched Trowel	Vertical Ribbons	Liquid	Plywood	2 x 4@16"	R-11 Unfaced	None
Panel 4, SE EIFS	1 ½" Flat	Notched Trowel	Vertical Ribbons	Liquid	Plywood	2 x 4@16"	R-11 Unfaced	6-mil Poly
Panel 5, SE, HFS EIFS	4" Flat	Notched Trowel	Vertical Ribbons	Liquid	Plywood	2 x 4@16"	None in stud cavity	None
Panel 6, SE, HFS EIFS	1 ½" Flat	Notched Trowel	Vertical Ribbons	Liquid	Plywood	18ga@16"	R-11 Unfaced	None
Panel 7, SE With Flaw, HFS EIFS	1 ½" Flat	Notched Trowel	Vertical Ribbons	Liquid	Plywood	2 x 4@16"	R-11 Unfaced	6-mil Poly
Panel 9, SE, HFS EIFS	1 ½" Flat	Mech. Fastened	Mech. Fastened	Mat	OSB	2 x 4@16"	R-11 Unfaced	None
Panel 10, SE Ventilated, HFS	1 ½" Flat	Adhesive	Metal Lath	Liquid	Plywood	2 x 4@16"	R-11 Unfaced	None
Panel 11	Not used for the EIMA – ORNL Research							
Panel 12, 3 Coat Portland Cement Plaster (Stucco) SE, HFS	None	Mech. Fastened Note 2	3.4 Metal Lath	2 Layers Grade D 60 Minute	OSB	2 x 4@16"	R-11 Unfaced	None
Panel 13	Not used for the EIMA – ORNL Research							
Panel 14, SE, HFS Brick With Flaw	None	Brick ties	Air Cavity 1"	1 Layer Grade D 60 Minute	OSB	2 x 4@16"	R-11 Unfaced	None
Panel 15, SE, HFS Brick	None	Brick ties	Air Cavity 1"	1 Layer Grade D 60 Minute	OSB	2 x 4@16"	R-11 Unfaced	None
Panel 16, NW EIFS	1 ½" Flat	Notched Trowel	Vertical Ribbons	Liquid	Plywood	2 x 4@16"	R-11 Unfaced	6-mil Poly
Panel 17, NW, HFS EIFS	1 ½" Flat	Notched Trowel	Vertical Ribbons	Liquid	Plywood	2 x 4@16"	R-11 Unfaced	None
Panel 18, NW, With Flaw, HFS EIFS	1 ½" Flat	Notched Trowel	Vertical Ribbons	Liquid	Plywood	2 x 4@16"	R-11 Unfaced	None
Panels 19 to 25	Not used for the EIMA – ORNL Research							
Panel 26, NW, Ventilated, HFS EIFS	1 ½" Flat	Adhesive	Metal Lath	Liquid	Plywood	2 x 4@16"	R-11 Unfaced	None
Typical Interior Finishing – ½" drywall, primed and painted (1 coat acrylic paint) Note 1 – Finished with furred ½" drywall, primed and painted (1 coat acrylic paint) Note 2 – Painted white initially, Plywood = ½", OSB = ½". Lath = G 60								

## Instrumentation Layout

The same number of sensors was used for each wall system in both Phase I and Phase II, with the exception of the heat flux sensors (used only in Phase II) that were added to a number of panels.

In each of the Phase II panels, the wall system included 17 thermistors, 6 relative humidity sensors, and 8 moisture content sensors. In Figure 4 the sensors locations are noted for two different wall assemblies. The same sensor arrangement is found in all three types of wall assemblies, the only difference being in the positioning of the RH sensors in the brick and EIFS cladding (see Figure 4). The sensors in the stucco panels were positioned in the same way as in the brick panel.

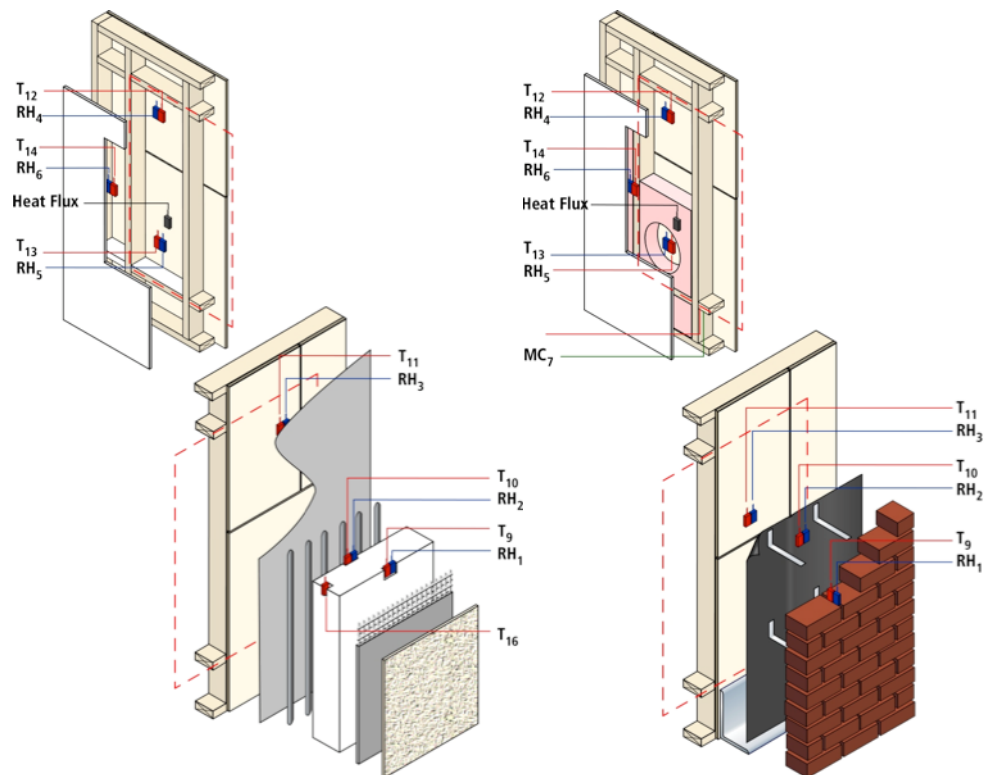


Figure 4: Relative Humidity Instrumentation Layout for EIFS Panel 5 and Brick Panel 14

## Hygrothermal Results

This paper provides some results for two panels - an EIFS and a brick assembly, evaluated during Phase I of the study. It is beyond the scope of this paper to present all the findings for even a single wall; a comprehensive report of the study will be published.

The relative humidity was measured in six locations in each of the two walls. The results are shown in Figures 6 and 7. The averaged monthly relative humidities are plotted for each wall. Results are plotted for all six sensors for a period of 1.4 years, starting in January 1 2005.

Sensors RH\_1 and RH\_2 are located in the exterior cladding, RH\_3 is located in the exterior side of the sheathing board, while sensors RH\_4 and RH\_5 are located on the interior side of the sheathing board, top and bottom, and the last sensor, RH\_6 is located at the outer face of the gypsum board. For the EIFS wall, RH\_1 is located in the exterior EIFS lamina, while RH\_2 is located at the interface between the inner face of the foam and the vapour-permeable, trowel applied weather resistive barrier. For the brick wall, sensor RH\_1 is imbedded in the mortar joint half thickness of the brick, while RH\_2 is located on the building paper.

In Figure 5, a clear yearly cycle is exhibited, showing the decoupling of the thermal and moisture performance due to the presence of the exterior foam insulation. The sensors bounding the exterior sheathing board show very low relative humidities that have not

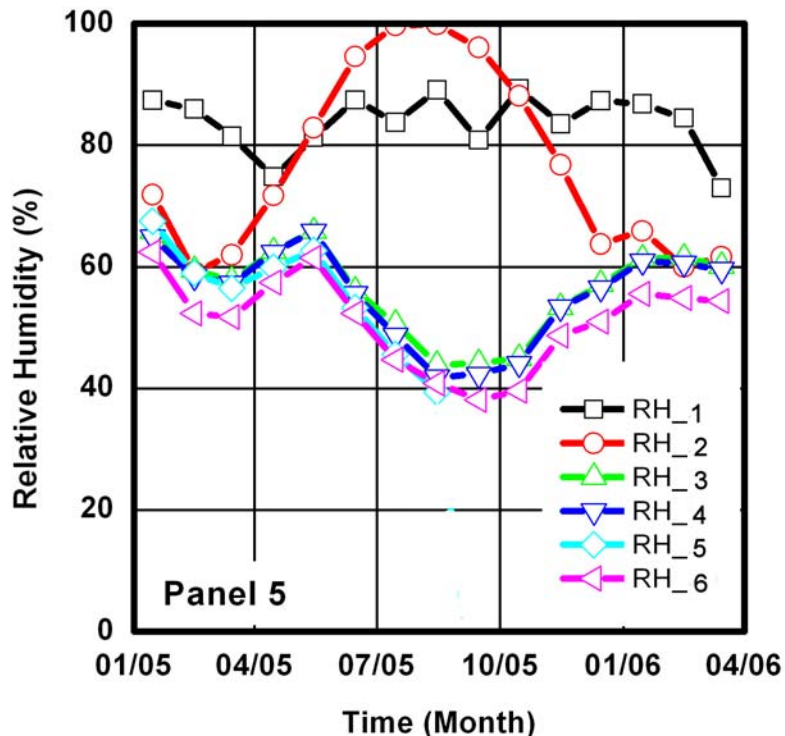


Figure 5: Monthly Average Relative Humidity Distribution in EIFS

exceeded 68 % at any period of the year RH\_1 and RH\_2 show close agreement with the exterior environment, with a condensation period present in RH\_2 during late August and the beginning of September. However, as this occurs in the vicinity of the air gap close to the interior side of the foam, no damage is expected to occur.

In Figure 6, the inner portions of the wall system (i.e. the wood framing and sheathing) are coupled to the brick exterior. As expected, very high relative humidities were found in sensor RH\_3 (imbedded in the exterior sheathing board). For at least 7 months of the year, the average monthly relative humidity at that sensor exceeded 80 %. According to the proposed ASHRAE 160P such hygric conditions can cause mold damage to a material. Indeed, even on the interior side of the sheathing board, the readings for one month (December) showed average monthly relative humidity exceeding 80 %. It is evident that this brick wall arrangement is not performing satisfactorily for the climatic conditions present in the Charleston region.

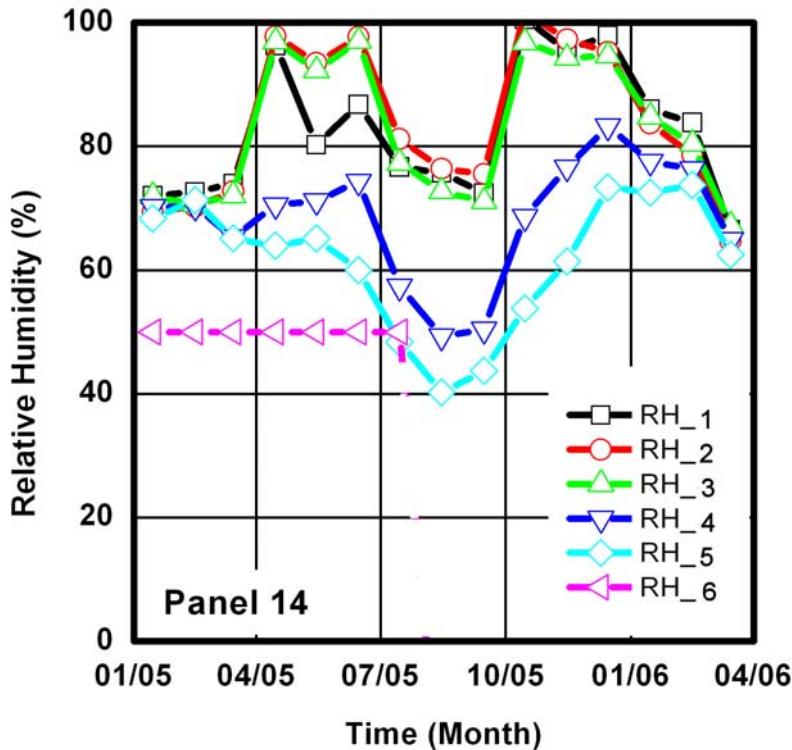


Figure 6: Monthly Average Relative Humidity Distribution in Brick Wall System

The cooling heat fluxes into the interior of the building are shown for Wall 5 (EIFS) and Wall 14 (brick) in Figure 8. The average cooling season values are plotted for each wall. A heat flux sensor was located at the exterior side of the gypsum board. The measured heat fluxes from the brick wall are approximately 2.6 times higher than those measured in Wall 5. This represents a substantial savings in energy required to cool the space insulated with exterior foam vs. fiberglass batts in the wall cavity. To a lesser yearly degree the opposite effect occurred during the winter months. The brick stored energy and conducted it inwards reducing the heating load. It should be pointed out that the EIFS wall has a higher nominal R-value and that better performance should be

expected. It is interesting however, that the ratio of the R-values is approximately 1.4 times.

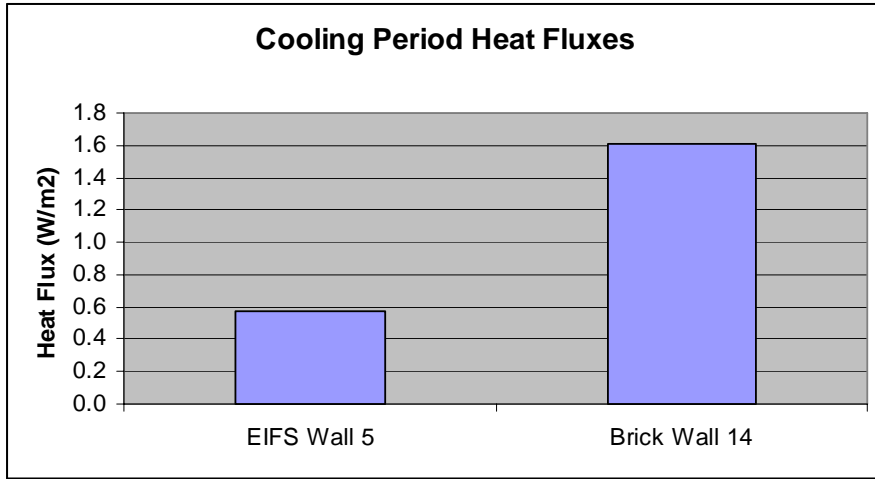


Figure 7: Cooling Period Positive Heat Fluxes into Interior Space

### Weather Station

A dedicated weather station was deployed at the NET Facility where the exterior temperature, relative humidity, wind speed and orientation, solar insolation normal to wall, horizontal rainfall, and wind-driven rain were continuously monitored. In Figure 8, some weather data is shown for Phase I of the study.

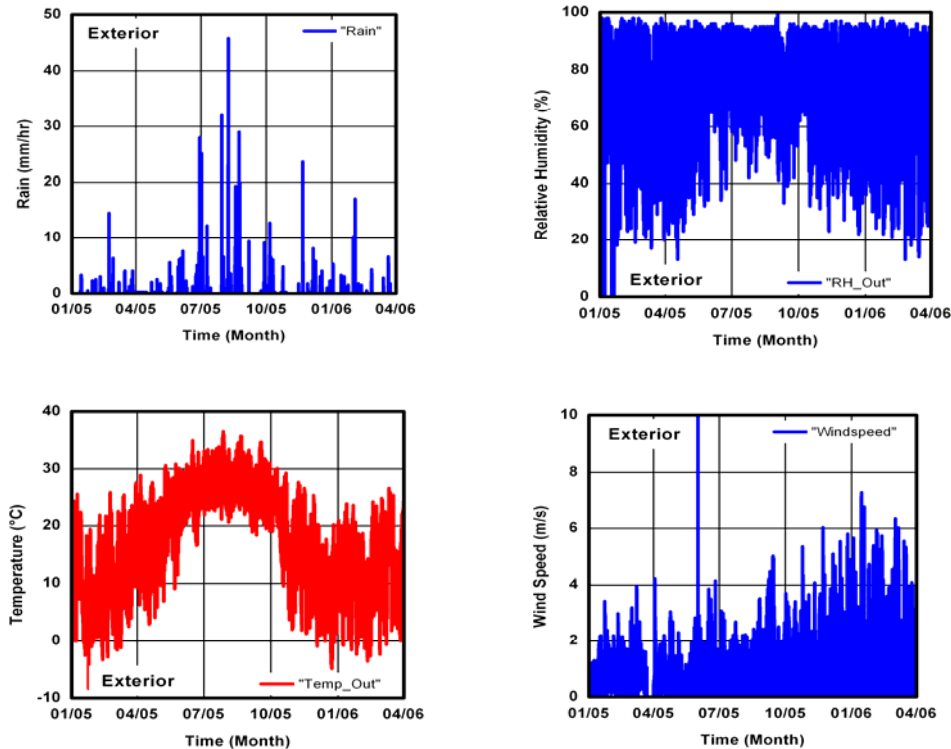


Figure 8: Dedicated Weather Station at the Net Facility

## CONCLUSION

This is the first study that has monitored the heat and moisture performance of a wide range of EIF wall systems. The test program described provides the scope of the effort expended thus far. The detailed findings will be published in due course and will illustrate how well the performance can be modelled. The inclusion of several other different cladding systems allows the side by side performance comparison for the specific climate of the test facility. This side by side wall heat and moisture performance provides a sound foundation for generating quantitative building science knowledge. An enormous amount of information has been generated that will become available for hygrothermal modelling validation analysis. It is planned that after the *MOISTURE-EXPERT* model has been validated, additional analysis will provide performance assessment of these wall systems for other locations in the USA.

Many different systems were monitored during the 2.5-year period of the DOE/ORNL/EIMA study. While not reported here, the drained EIFS walls were found to perform as well as or better than other cladding systems during all parts of the year.

The field analysis performed in the Charleston region has the potential to provide wall performance answers to a number of issues of interest in hot and humid climates. In Phase III, we expect to extend this investigation to a number of other regions of the USA, using advanced hygrothermal modeling.

## ACKNOWLEDGMENTS

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