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Water Management and Moisture Transport in Direct-Applied and EIFS Wall Assemblies*

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ABSTRACT: An experimental program has been completed investigating water management and moisture transport in direct-applied finish system (DEFS) and exterior insulation and finish system (EIFS) wall assemblies. The first objective of the study was to understand and quantify drainage through water-managed DEFS and EIFS. A second objective was to understand moisture transport through the wall cladding under a variety of climatic conditions. A third objective was to better understand the role of the sheathing membrane on the moisture transport characteristics of the system. A drainage test has been developed, and a variety of water-managed DEFS and EIFS wall assemblies have been tested. Also, DEFS and EIFS wall assemblies have been tested in an environmental chamber using five different sets of climatic conditions to create a vapor drive through the wall. Results from the drainage and environmental chamber testing are presented, along with an evaluation of sheathing membranes with different performance characteristics.

KEYWORDS: direct-applied exterior finish system (DEFS), drainage, exterior insulation and finish system (EIFS), moisture content, rainscreen, sheathing membrane, wall cladding, water managed, vapor drive, vapor permeance

This paper presents results from an ongoing program of research investigating the performance of water-managed direct-applied finish system (DEFS) and exterior insulation and finish system (EIFS) wall claddings. These wall claddings incorporate water management into their design by combining the use of a sheathing membrane with flashing and weeps to direct any incidental intruding water out of the cladding. These systems are designed around a rainscreen principle. Rainscreen designs assume that some water will penetrate beyond the exterior face of the wall that must be removed by a second line of defense. The water-managed DEFS and EIFS systems provide the opportunity to combine a "stucco look" architectural style with traditional wall cladding water-management features.

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In direct-applied exterior finish systems (DEFS), the wall cladding includes a water-durable cement board substrate mechanically attached to the wall. A cementitious basecoat is applied over the cement board, and acrylic synthetic stucco finish is applied over the basecoat. Insulation for the wall is in the stud cavity. For EIFS, the wall cladding includes a layer of foam insulation with cementitious basecoat, reinforcing mesh, and finish applied over the foam. The foam can be attached using mechanical fasteners or adhesive.

Wall claddings designed with water management are fundamentally different than barrier EIFS systems. Barrier EIFS design assumes that all water penetration can be stopped at the exterior face of the wall. Water-managed systems provide a means for directing any water that intrudes the exterior face out of the system. This difference in design creates differences in the behavior of the two systems in areas such as water penetration, the location of the plane of airtightness, pressure equalization characteristics, and moisture transport through the system.

Numerous DEFS and EIFS systems that incorporate water-management features into their design are currently offered on the market today, and new systems are under development. However, there is a need for industry, regulators, and researchers to define the key performance characteristics of these cladding systems. Appropriate test methods and standards must be developed to measure performance and assess durability under a variety of in-service conditions. These performance characteristics must be developed with an understanding of the interaction the cladding has with other components in the wall assembly.

The experimental program described below has been designed to achieve three objectives. The first is to understand and quantify drainage of water through a particular water-managed DEFS or EIFS cladding system. A second objective is to understand moisture transport through the wall cladding under a variety of climatic conditions. This part of the investigation used an environmental chamber to create a range of vapor drives across several wall-cladding types. A third objective of the program is to better understand the role of the sheathing membrane on the moisture transport characteristics of water-managed systems and establish appropriate performance characteristics for them.

Evaluation of Drainage

Drainage Evaluation Experimental Procedure

Drainage tests were conducted by measuring the rate at which water drains through a cladding system. This has been done using a static water head test. A head of water is maintained across the top of a wall cladding assembly. The drawing in Fig. 1 illustrates the

FIG. 1—Schematic drawing of typical head box/specimen detail.

cross section at the top of a specimen. Specimens are prepared so that the top of the specimen is similar to the condition that occurs in service directly underneath a windowsill. Specimens were constructed using wood framing, OSB sheathing, No. 15 asphalt-saturated building felt, and an adhesive-backed, rubberized asphalt flashing material placed over the top of the framing. EIFS or DEFS cladding was applied with mechanical fasteners over the No. 15 felt. The typical specimen size was 305 by 1220 mm (12 by 48 in.).

Following construction of the specimen, a steel head box was attached to the top of the specimen. The joint between the specimen and the head box was sealed with silicone sealant to prevent leakage. Figure 2 is a drawing illustrating a specimen in the apparatus. A 30-gal water supply tank was used to provide water for the drainage. The water supply tank was suspended from a load cell, enabling the change of mass of the supply tank to be monitored over time. A $\frac{1}{2}$ in. diameter supply pipe ran through a needle valve and solenoid into the head box. A level indicator controlled the solenoid, enabling a constant head of water to be maintained in the head box. A constant head of water $4 \pm \frac{1}{16}$ in. (102 ± 2 mm) was maintained on all specimens. Water flowed out of the head box through the drainage plane of the specimen and into the collection tank. The collection tank rested on a load cell, allowing the change in mass of the collection tank to be measured over time. The slope of the mass change in the collection tank over time is considered the drainage rate of the specimen. The units for this drainage rate are typically expressed as gallons/hour/linear foot of cladding assembly. Figure 3 shows a photo of an actual drainage specimen in the test apparatus. Note that 1 gal/h/ft is equivalent to 11.5 L/h/m.

Drainage Evaluation Results

The test results indicate that drainage in a wall cladding system is highly dependent on the drainage medium and cladding system details. Measured drainage rates vary from less than 1 gal/h/linear ft to over 200 gal/h/linear ft, depending on the drainage medium

FIG. 2—Drainage test apparatus.

and means of cladding attachment. Figure 4 shows results for a variety of different cladding systems in tabular form.

Figure 5 is a plot illustrating data from a drainage test on a water-managed EIFS system. These results are for a system with EPS foam mechanically attached over No. 15 felt into OSB sheathing. System details are shown in Fig. 6. In this system the foam is applied directly over the No. 15 felt; no furring lath is used. The upper line in the plot is the change in mass in the source tank. The lower line is the change in mass of the collection tank. The slope of the line of the collection tank is used to establish the drainage rate. The drainage rate for this system is 1.6 gal/h/linear ft.

Results from a drainage test for an EIFS system that uses a polymer mesh furring lath as the drainage medium are shown in Fig. 7. The plot displays the data in the same way as described for Fig. 6. The drainage rate in this system is 24.9 gal/h/linear ft. System details are included in Fig. 8.

Drainage tests have also been conducted on the DEFS system. This system uses a cement board cladding mechanically attached to wood framing. The cement board goes over the No. 15 felt that is attached to OSB sheathing. System details are shown in Fig. 9. Note that specimens for the DEFS systems were constructed using a stud spacing of 16 in. O.C., which is typical for most applications. Drainage data for a DEFS system is presented in Fig. 10. The drainage rate measured in this system is 42.8 gal/h/linear ft. It should be noted that with a drainage rate this high, a 4-in. head cannot be maintained throughout the test without an additional source of water supply. When a hose is added to the head box to increase the water supply rate and maintain a 4-in. head, the drainage rate was measured to be 55.2 gal/h/linear ft.

Water retained in the drainage specimens during the tests was also quantified. This was done by comparing the initial weight of the specimen before testing to the weight of the specimen immedi-

FIG. 3—Actual drainage specimen in test apparatus.

Wall Specimen	Cladding Specimen Type		Drainage Rate (gal/hr/linear ft)	Initial Drainage (seconds)	Steady State (min)	Total Test Time (min)
A	EIFS	Polyisocyanurate Foam, No Furring	0.7 ¹	120	10	975
B	EIFS	EPS Foam, No Furring	1.6	75	60	150
C	EIFS	EPS Foam, 1/32" Furring	24.9	5	5	45
D	DEFS	No Foam, No Furring	42.8	10	3	31 ²
E	EIFS	EPS Foam, Cement Board, 1/8" Furring	99.5	7	5	20
F	EIFS	Grooved EPS Foam	206.8	5	3	9

Specimen Descriptions:

- A: EIFS, 1" Polyisocyanurate Foam mechanically attached, 12" wide, no furring lath
 B: EIFS, 2" EPS Foam mechanically attached, 12" wide, no furring lath
 C: EIFS, 2" EPS Foam mechanically attached, 12" wide, polymer mesh 1/32" furring lath
 D: DEFS, 17/8" wide, no furring
 E: EIFS, 1" EPS Foam adhesively attached to cement board, 12" wide with 1/8" Polyethylene mesh furring
 F: EIFS, 2" Grooved EPS Foam mechanically attached, 12" wide

¹ Drainage of Specimen A varied over time as follows:
 3.5 gal/hr/linear ft @ 20 minutes
 1.9 gal/hr/linear ft @ 140 minutes
 0.7 gal/hr/linear ft @ 975 minutes

² 3 1/2" head

FIG. 4—Wall cladding drainage test results.

FIG. 5—Drainage test plot, Specimen B. EIFS: no furring, 2-in. EPS foam, mechanically attached.

ately after the test. Water retained in the specimens ranged from 3% of the original specimen mass in the DEFS and EIFS with 1/8-in. furring to 7% in the EIFS with EPS and no furring. How this water was distributed within the layers of the system (cladding substrate, foam, basecoat, finish, etc.) was not quantified.

Taken as a whole, the drainage results for EIFS and DEFS demonstrate that a variety of water-managed EIFS and DEFS claddings can be designed so that drainage rates through the systems have large safety factors when compared to incidental moisture the drainage planes under in-service conditions. Additionally, the mass of water retained in the water-managed DEFS and EIFS specimens is not excessive and would appear to be of the

same magnitude or lower than that of wood or brick-based claddings.

Based on previous work, the drainage rates recorded in these tests are far greater than actual drainage measured through water-managed EIFS and DEFS claddings under a variety of extreme test conditions [1]. In that work, water penetration in walls clad with water-managed EIFS and DEFS claddings were characterized. Water that drained through the drainage plain of water-managed EIFS and DEFS clad wall assemblies was collected and measured. The wall assemblies tested were wood frame walls with a window. The tests were run with the specimens in an as-built condition, as well as with defects introduced into the sealant joint.

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48 in.

window trim, or air barrier, simulating conditions likely to occur in service.

Drainage measured through the drainage plane, under both static and dynamic conditions, is shown in Fig. 11. A direct comparison of the drainage test results in this work, and the drainage measured

in the earlier water penetration study is not possible due to differences in test conditions and driving potentials. However, there is no evidence to suggest that a change in the rain penetration driving potential on the wall would reduce the large-drainage-capacity safety factors when results from Fig. 4 are compared with those in Fig. 11. This is supported by the data in the earlier Brown paper that indicate little difference in the drainage water collected between the as-built specimens and those tested with the air barrier having been defected. The drainage test results indicate that the DEFS and EIFS systems evaluated have more than adequate drainage capacity to direct back to the outside any intruding water that penetrates behind the face of the system.

Evaluation of Moisture Transport through the Wall

Moisture transport through water-managed EIFS and DEFS claddings has been studied in an environmental chamber. The environmental chamber allows the impact of different vapor pressure drives on moisture transport through the wall to be studied. This study tested eight wall specimens (four DEFS and four EIFS) under five different environmental cycles, each of which created a different vapor pressure drive. A schematic of the chamber is shown in Fig. 12. The chamber is configured with spray racks on one side of the dividing wall, allowing cladding specimens to be saturated with water. Both sides of the chamber are equipped with heating and air conditioning units, with independent controls. Air temperature and relative humidity are recorded on a continuous basis.

The properties of the sheathing membrane also influence drying in the wall assembly. Because of this, sheathing membranes with a range of water vapor permeances have been evaluated for use in different wall assemblies. Results from this evaluation are shown in Fig. 13. The water vapor permeances of six different sheathing membranes are shown as a function of relative humidity. The water vapor permeance of the membranes ranges from as low as 1.88×10^{-10} kg/Pa s m² (3 perms) to over 43.75×10^{-9} kg/Pa s m² (70

FIG. 6—System details, drainage Specimen B. EIFS: no furring, 12 by 48 in.

FIG. 7—Drainage test plot. Specimen C. EIFS: 1/32-in. furring, 1-in. EPS foam, mechanically attached.

perms), depending on the membrane type and relative humidity. Additional description and physical characteristics of the membranes are listed in Fig. 13. Note that membrane Type B, representative of No. 15 felt, has a permeance that varies greatly as a function of relative humidity. In the low-humidity range, No. 15 felt has a perm value less than 3; at 98% relative humidity, the perm rating is over 70 perms. The vapor permeance of the other sheathing membranes remained fairly constant over the 50 to 100% humidity range.

The gross water holdout of the sheathing membranes has also been evaluated. Gross water holdout was tested by placing a static head of water on the membranes and measuring water penetration

through the membrane under controlled conditions. Static water heads of 1-in. and 4-in. height were placed on the membranes and the water penetration measured over time. Membrane Types A, B, and C were found to exhibit good gross water holdout, with no significant penetration after 72 h of exposure.

Specimen Construction

Eight water-managed DEFS and EIFS wall assemblies have been tested. The four DEFS specimens all used the same construction. The four EIFS specimens were constructed differently. Two

FIG. 8—System details, Specimen C, EIFS: 1/32-in. furring, 12 by 48-in. specimen.

FIG. 9—System details, Specimen D, DEFS: no furring, 17.5 by 48 in.

FIG. 10—Drainage test plot, Specimen D, DEFS: no furring, no lath, 16-in. specimen width, standard water supply, 4-in. head not maintained.

Specimen Type	Drainage Through Drainage Plane (gal/hr/linear ft)									
	As-Built		Center Crack Defect		Corner Crack Defect		Air Barrier Defect		Total Sill Crack Defect	
	Static	Dynamic	Static	Dynamic	Static	Dynamic	Static	Dynamic	Static	Dynamic
DEFS—No Furring	0.02	0.07	0.15	0.06	0.03	0.03	0.03	0.08	0.22	0.13
EIFS—1/8" Furring Lath	0.34	0.21	0.18	0.39	0.52	0.53	0.39	0.41	0.03	1.08

Static Pressure: Water was sprayed on the exterior of specimen (8' x 8' wall specimen with combination wood window), at a rate of 6.2 gal/hr/ft² with a static pressure difference of 2.86 lbf/ft² (137 Pa), applied for 15 minutes, then increased to 6.27 lbf/ft² (300 Pa) for 60 minutes.

Dynamic Pressure: Specimen and spray rate same as above, while a Dynamic air pressure difference, consisting of a sinusoidal component of 4.18 lbf/ft² (200 Pa) at 0.5 Hz superimposed on a mean value of 6.27 lbf/ft² (300 Pa) was applied for 60 minutes.

FIG. 11—Measured drainage through the drainage plane: water-managed EIFS and DEFS.

FIG. 12—Schematic of environmental chamber: section through chamber.

EIFS specimens were constructed with OSB sheathing, and two were constructed without sheathing, simulating an "open frame" condition. Also, two EIFS specimens were constructed using membrane Type B and two were constructed using membrane Type C. This creates five different wall assembly types, which are summarized in Fig. 14. Figure 15 includes details for each assembly type.

Moisture Transport Test Procedure

EIFS and DEFS cladding specimens are mounted in the dividing wall of the chamber, as shown in Fig. 12. Specimens are instrumented with moisture pins into the cement board cladding and OSB sheathing. Thermocouples are mounted on the exterior and interior faces of the specimens, as well as in the cavity. The spray rack on the exterior side of the specimens is used to saturate the different claddings. Following saturation, the exterior side of the specimens was exposed to the following test conditions:

- **Series 1** After exterior wall specimen saturation, the exterior side of the specimen was exposed to a temperature of 20°C and 50% R.H. for a period of 72 h. The interior side of the speci-

men was maintained at 20°C and 50% R.H. throughout the test.

- **Series 2** After exterior wall specimen saturation, the exterior side of the specimen was exposed to a temperature of 40°C and 50% R.H. for a period of 72 h. Following this, the exterior side of the chamber was exposed to a temperature of 40°C and 19% R.H. for an additional 96 h. The interior side of the chamber was maintained at 20°C and 50% R.H. throughout the test.
- **Series 3** After exterior wall specimen saturation, the exterior surface of the specimens was held at 55°C for 72 h using radiant heat lamps. After 72 h of heat lamp exposure, the exterior side of the chamber was held at 20°C. The interior side of the chamber was maintained at 30°C and 50% R.H. for the first 72 h and 20°C and 50% R.H. for the remainder of the test.
- **Series 4** After exterior wall specimen saturation, the exterior side of the chamber was maintained at 20°C and 100% R.H. for a period of seven days. The interior side of the chamber was maintained at 20°C and 50% R.H. throughout the test.
- **Series 5** After exterior wall specimen saturation, the exterior side of the chamber was maintained at 20°C and 50% R.H. for a period of eight days. A positive air pressure of 137 Pa was

Membrane Type A: Low Vapor Permeance (60 minute paper)
 Membrane Type B: Low to High Vapor Permeance (#15 reli)
 Membrane Type C: High Vapor Permeance (spun polyolefin sheet)
 Membrane Type D: Low Vapor Permeance
 Membrane Type E: Lower Bound Vapor Permeance
 Membrane Type F: Mid Range Vapor Permeance

FIG. 13—Water vapor permeances of sheathing membrane materials.

Cladding Type	Structural Sheathing	Membrane Type	Maximum Moisture Gain in OSB (series 2) (%)	Drying Trend Observed
DEFS	OSB	B	2.3	After 4 Days
EIFS	OSB	B	5.5	After 6 Days
EIFS	OSB	C	2.0	After 6 Days
EIFS	None (open framing)	B	-	After 2 Days
EIFS	None (open framing)	C	-	After 2 Days

FIG. 14—Environmental chamber test summary.

FIG. 15—Environmental chamber specimen details.

also maintained for eight days in the exterior side of the chamber. The interior side of the chamber was maintained at 20°C and 50% R.H. throughout the test.

Moisture Transport Test Results

The environmental chamber results led to several important findings. The first is that the water-managed DEFS and EIFS systems did not experience excessive moisture gains in water-sensitive framing materials to the interior of the sheathing membrane. Figure 16a summarizes the moisture content, in percent by weight, of the OSB sheathing behind the No. 15 felt sheathing membrane for the DEFS system tests. The initial average moisture content in the OSB sheathing was between 4 and 5%. Data for each of the five test series, using different environmental conditions to create the vapor drive, are included in the plot. For the DEFS specimens, none of the vapor drive conditions resulted in average moisture contents in the OSB above 7%. This is a moisture content within the range considered normal for OSB.

In a similar fashion, Fig. 16b summarizes the moisture content, in percent by weight, of the OSB sheathing behind the No. 15 felt sheathing membrane for the EIFS system tests. It should be noted that for the radiant heat panel tests, the starting moisture content of the OSB was 14%. A net gain of 2% occurred during this test, meaning the maximum moisture content during the test was 16%. Maximum moisture contents for the other test series were all below 12%. Drying began to occur in the specimens in the third or fourth

day of testing, with moisture levels dropping to below 15%. As with the DEFS, these moisture levels will not result in deterioration of the wood-based structural elements.

The second finding, as expected, is that drying in the cladding and through the wall assembly is dependent on the type of cladding material used and the properties of the sheathing membrane. The chamber results indicate that the moisture content of the structural framing behind water-managed EIFS and DEFS claddings remained well below levels that cause deterioration to the wood. Any water retained in the claddings did not result in excessive moisture buildup in the wood framing. However, as discussed above, the drying rate of the DEFS systems was measured to be more rapid than the EIFS systems. One reason for this is the higher water vapor permeance of the DEFS claddings (7.0 perms) compared to the EIFS (2.1 perms). This encourages more rapid drying to the exterior of the cladding.

The impact of sheathing membranes with different water vapor permeances has also been studied. EIFS wall cladding assemblies using membrane Types B and C have been tested in the environmental chamber. Identical water-managed EIFS claddings were constructed on wall specimens and tested with the different conditions described in Series 1 through 5. Results are shown in Fig. 17. Figure 17a is the EIFS cladding with the sheathing membrane with a high-water-vapor permeance (Type C). In this case, the OSB moisture content never exceeds 12% in any test series. Maximum moisture content occurs during the third day of exposure. By Day 4 of the tests, all specimens have an OSB moisture content below

FIG. 16a—Environmental chamber test results. DEFS system: Membrane Type B, OSB sheathing, moisture content versus time.

FIG. 17b—Environmental chamber test results, EIFS system: Membrane Type B, OSB sheathing, moisture content versus time.

10%. Figure 17b is the assembly that uses the sheathing membrane with low-vapor permeance (Type B). In Series 3 (radiant heat), the moisture content reaches a peak of 16% in the second day and begins to dry. In Series 2 (high temperature), a drying trend starts in the sixth day. After the sixth day, the OSB moisture content in the radiant heat series is 15%; in the high-temperature series it is 12%.

The high-permeance sheathing membrane would appear to reduce moisture gain in the OSB sheathing and encourage drying in the EIFS assemblies. However, inspection of the specimens after testing indicates that the high permeance may be only one of several factors involved. It is likely that, for the specimen with membrane Type B, No. 15 felt is at high humidity throughout the test, meaning that the vapor permeance in this specimen is actually quite high, possibly higher than the specimen with membrane Type C, identified as high permeance. Additionally, upon removing the back of the specimens after the test, the No. 15 felt was noted to be damp. This may act to hold water next to the OSB sheathing and reduce drying. In contrast, in the specimen with membrane Type C, the membrane was not damp and did not appear saturated. A combination of good gross water holdout and consistent, relatively high vapor permeance likely increased drying in this specimen.

A third finding relates to the control of condensation inside the wall cavity. As described in Fig. 15, specimens were constructed with a 6-mil (0.15-mm) polyethylene vapor retarder between the stud framing and the gypsum drywall on the interior side of the

specimen. Following test Series 2 through 5, specimens were opened from the interior side, removing the drywall, vapor retarder, and insulation to inspect the cavity. For the EIFS specimens, condensation was present on the cavity side of the polyethylene vapor retarder in each test series, with the exception of the open frame specimens in Series 4 and 5. For the DEFS specimens, only Series 3 (radiant heat) had condensation on the vapor retarder. Given the vapor drives used in these experiments, the condensation observed is not surprising and would be predicted using analytical moisture transport models. The condensation emphasizes that even when water management principles are used in a cladding and moisture levels in the water-sensitive structural elements are not elevated, condensation can occur in the wall assembly. Control of condensation in the wall assembly requires that a moisture analysis be performed for all building envelopes, taking into account the climate to which the wall will be exposed and local codes and building practice.

Conclusions

The results from the drainage and environmental chamber testing lead to several important conclusions. First, the drainage test results indicate that the water-managed DEFS and EIFS systems evaluated have more than adequate drainage capacity to direct any intruding water that penetrates behind the face of the system back to the outside. Second, when water-managed DEFS and EIFS claddings are used in combination with appropriate sheathing

membranes, wood sheathing and structural framing members inside the wall are not exposed to excessive increases in moisture content. The sheathing membranes must combine good gross water holdout with an appropriate water vapor permeance. Conventional No. 15 asphalt-saturated felt, 60-min Grade D paper and a high-vapor-permeance flash, spun-bonded polyolefin sheet membrane have been demonstrated to work well in DEFS and EIFS applications. Finally, even when water management principles are used in a cladding, and moisture levels in the water-sensitive structural elements are not elevated, condensation can occur in the wall assem-

bly. To avoid problems with condensation, all building envelopes, including those with water-managed EIFS and DEFS, should have a moisture engineering evaluation completed during the design phase.

Reference

- [1] Brown, W. C., Tonyan, T., Ullett, J., and Adams, P., "Water Management in Exterior Wall Claddings," *Journal of Thermal Insulation and Building Envelopes*, Vol. 21, 1997, pp. 23-43.