Analyzing Increased Solar-Driven Moisture Through Two Rain-Wetted Cladding Assemblies

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INTRODUCTION AND EXECUTIVE SUMMARY

This case study supplements a prior report ("Solar-Driven Waves of Water Vapor Within Exterior Wall Cavities") published in the July 2014 issue of *Interface*. That article described our team's large-scale use of humidity/temperature loggers[1] to measure ambient moisture load data within occupiable apartments and exterior wall cavities at multiple two-story buildings at a residential complex near San Francisco. Specifically, this report analyzes the daily spikes of water vapor intrusion into these walls and buildings that occurred when two rain-wetted claddings (traditional three-coat stucco and fiber-cement lap siding) were heated by the sun.

As previously reported, during our 162-day testing period,[2] these dataloggers recorded (every 10 minutes, 144 times per day)[3] ambient relative humidity (RH) and temperature conditions at 24 ground-floor apartments. Concurrent measurements from several exterior loggers supplemented these interior data. In total, more than 4.8 million temperature and RH data points were collected from these various sensors.

This updated report addresses specific datasets recorded (via Loggers 1, 2, and 3) at each of these apartments from the three adjacent spaces (at and adjacent to bedroom closets) identified at *Photos 1* and *2*.

- Logger 1 was located in a bedroom closet that borders an exterior wall.
- Logger 2 collected its data within the plenum space directly above this closet—i.e., the large cavity between the drop ceiling at the lower apartment and the oriented strand board

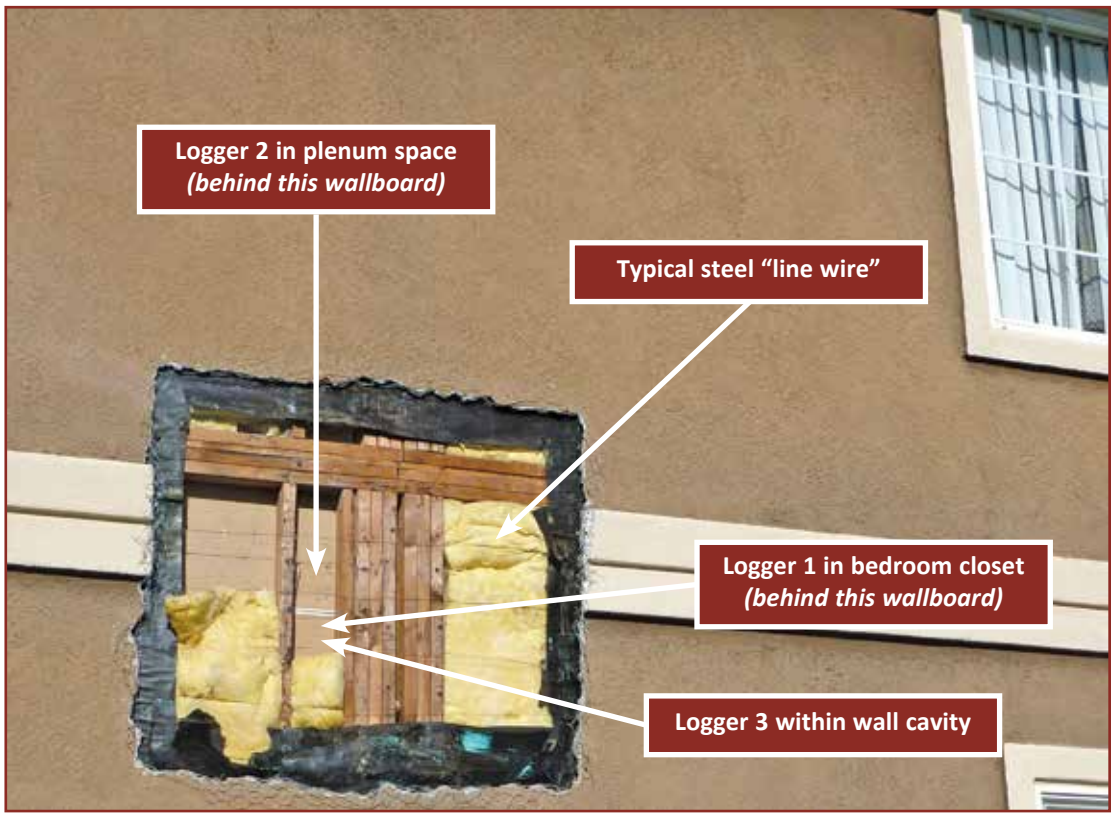


Photo 1 – Parallel wall: Expanded polystyrene foam "bellyband" at rim/plenum transition provides aesthetic relief between lower and upper floors. (Note: Building paper is backed only by steel line wires.)

(OSB) subfloor above.

- Logger 3 simultaneously recorded ambient RH and temperature conditions within a stud bay at the exterior wall that bordered both the bedroom closet and the plenum space.
- Additionally, for comparative purposes, we collected the same data from interior Logger 4, installed within each apartment's common area.

In summary, this article:

- Confirms that the ambient water vapor ratios within exterior wall assemblies cyclically rise and fall each day due to the effects of solar heating and nighttime cooling of moisture contained within the framing and sheathing.
- Graphs these cyclic daily variations in actual moisture content values (percentages) to evaluate building envelope performance.
- Demonstrates that this naturally-occurring process, in and of itself, typically is contained within these framed walls and commonly is not problematic.
- Shows, however, that in certain conditions, such rainwater leakage into the cladding systems may be driven by solar heating entirely through these exterior walls.
- Proves, in particular, that seemingly simple caulking, sealing, and closure deficiencies at the building envelope can lead to greatly increased levels of interior moisture within habitable interior spaces, potentially promoting condensation damage and fungal growth throughout an entire residence.
- Shows how, during the construction defects litigation process, the data-loggers can be used to better allocate to the parties who caused or allowed such problematic rainwater infiltration their fair shares of financial responsibility for remediation of the interior damage and fungal growth.

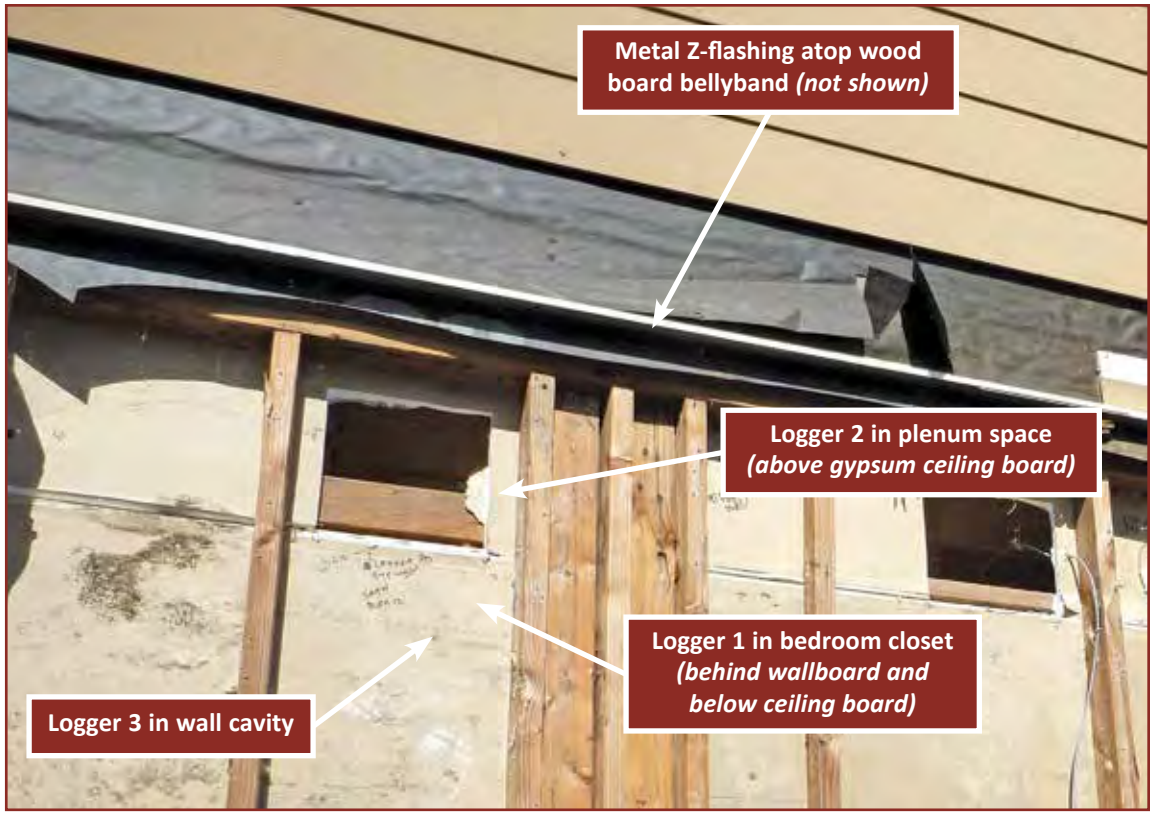


Photo 2 – Parallel wall: At buildings with fiber-cement lap siding, wood board bellybands (not seen in photo) below metal Z-flashings were installed at the rim/plenum transitions.

INTRODUCTION: PARALLEL VS. PERPENDICULAR WALLS – KEY DESIGN/CONSTRUCTION DIFFERENCES

It is important to note in *Photos 1* and *2* that at all exterior walls running parallel to the typical floor/ceiling joists seen in *Photo 3*, the wood stud framing for the

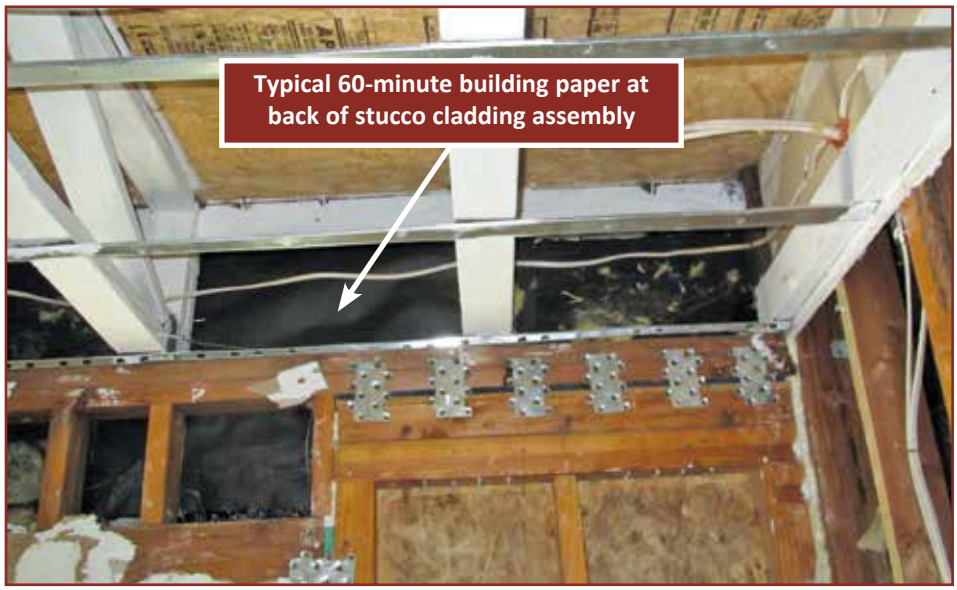


Photo 3 – Perpendicular wall (stucco): Plenum space above drop ceiling terminates at the building paper. (Note: gypsum wallboard interior envelope was not extended up from the bedroom wall.)

Photo 4 – Perpendicular wall (siding): Plenum space above drop ceiling terminates at inside face of the exterior gypsum sheathing behind the wood board bellyband and the fiber-cement siding.

lower apartment terminates at tripled plates at the top of the plenum cavity (as opposed to conventional platform framing where the lower studs would terminate at doubled plates at the bottom of the plenum space).

As reviewed below, this atypical design allowed us to directly compare migration rates of solar-heated moisture from the same stud bay (Logger 3) into two distinct spaces: the conditioned bedroom closet (Logger 1) and the indirectly conditioned plenum space above the drop ceiling (Logger 2).

In contrast, the wood-blocked construction of the opposing perpendicular walls (per *Photo 3*) is typical for Western platform framing; however, we can see in *Photos 3* and *4* that the gypsum wallboard interior envelope provided at the lower unit was not extended up into the plenum space. For example, the 60-minute building paper behind the three-coat stucco is visible in *Photo 3*.

Typical for mass-produced housing projects here in California, certain portions of the stucco cladding were installed over OSB shear panels (*Photos 5* and *6*); but for most of the stud bays, the building paper serving the stucco was backed only by steel "line wires," per *Photo 1*.

A key goal of our testing program was to evaluate potential sources of the excess water vapor and related condensation damage (e.g., *Photos 6* and *7*) observed at the rim/plenum transitions.[4]

INTRODUCTION – THE HUMIDITY RATIO

Concurrent measurements of temperature and RH can be converted into the "humidity ratio"—the ratio or percentage of the weight of ambient water vapor molecules per pound of dry air.[5] The software for our loggers was programmed to calculate a grains-per-pound (GPP) ratio.[6]

In a manner comparable to a construction professional's forensic use of pin-style moisture meters to take multiple "wet" vs. "less wet" vs. "dry" readings (i.e., percentages) at wood studs and sheathing throughout a project, our loggers produced 2.4 million humidity ratio ("ambient moisture content") readings over the 162-day testing period.

Photo 5 – Perpendicular wall: Typical EPS foam bellyband at rim/plenum transition provides aesthetic relief between lower and upper floors. (At building corners, stucco is installed to OSB shear panels).

Photo 6 – Perpendicular wall (stucco): No interior envelope was provided at the rim/plenum transition.

Photo 7 – Typical closet ceiling and interior envelope at parallel wall. At all apartments, the drop ceilings are constructed from gypsum board panels hung from steel resilient channels.

We then used Microsoft Excel spreadsheets to process and graph selected portions of these data to evaluate questions of interest. For example, consider *Graph 1*, which displays ambient moisture content readings measured concurrently (144 times per day, starting at 12:00 a.m.) over a 17-day period at Logger 3 (within an exterior wall at one of the bedrooms) and Logger 4 (positioned between the kitchen and bathroom). As previously reported, we see at *Graph 1* that:

1. The tenants had moved out of the apartment by Day 8, as documented (per the blue line) by the dramatic decline of ambient moisture measured by Logger 4.
2. More importantly, as indicated by the red line, daily cycles of increased/decreased levels of ambient moisture occurred within the exterior wall (Logger 3) in direct correspondence to solar heating and nighttime cooling.

These conditions certainly are not unique to our testing; at all buildings, some degree of inward solar-driven migration of water vapor (due to increased vapor pressures) always will occur when an exterior wall with the ability to absorb moisture becomes heated by the sun.[7]

- "Sun-driven moisture is a phenomenon that occurs when walls are wetted and then heated by solar radiation. Upon solar heating, a large vapor pressure difference may occur between the exterior and interior, leading to the inward diffusion of moisture."[8]
- "It is clear that any wet material ... that is heated by the sun will generate large inward vapor drives."[9]

This phenomenon of solar-driven diffusion is further documented by *Graph 2*, which depicts a remarkably close correspondence between the daily high/low swings in exterior temperature (the dashed black line) measured hundreds of feet away from this particular building and the daily high/low spikes of ambient water vapor (the red line) recorded within an exterior wall cavity at Unit E. Clearly, a direct relationship exists between daily swings in exterior temperature and the cyclic peaks and valleys of the solar-heated moisture within the wall.[10]

The excellent long-term performance across North America of millions of exterior walls clad with stucco or fiber-cement lap siding is evidence that this ubiquitous process of solar-driven diffusion into wall assemblies should not, in and of itself, be considered alarming or problematic.

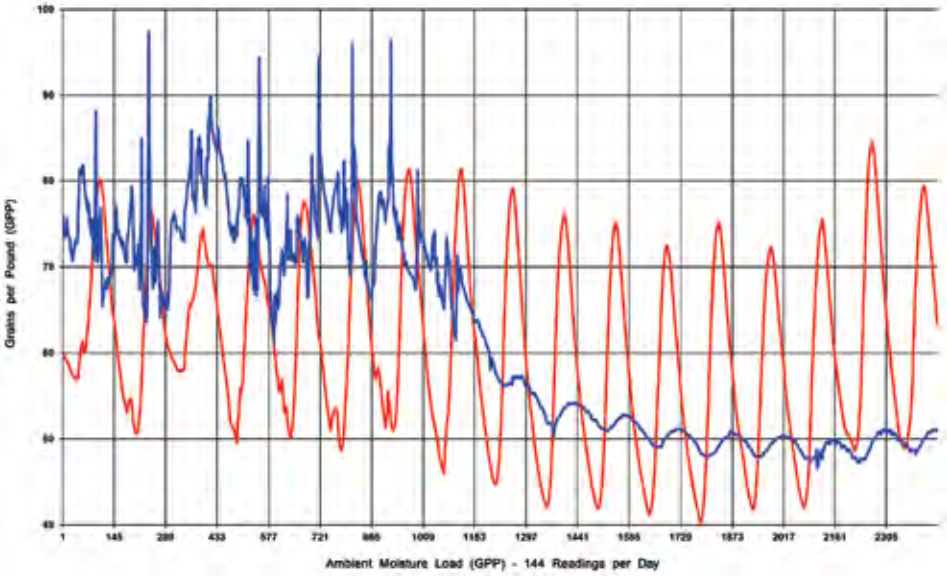
In general, building envelope professionals know from long experience that building envelopes can safely accommodate such inward and outward drives of water vapor. But what are the key(s) to controlling these spikes in moisture? Our testing and analysis explored this question by quantifying and comparing the sharply increased humidity ratios that occurred when our two rain-wetted cladding systems became heated by the sun.

INTRODUCTION – DROUGHT CONDITIONS IN CALIFORNIA

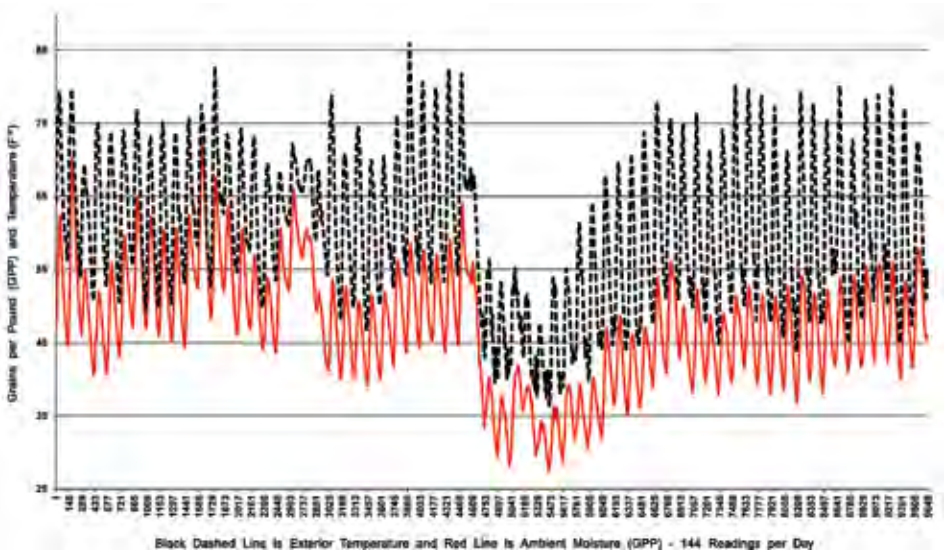
Due to California's extended drought, weather conditions generally were dry during much of our 162-day testing period; however, as shown at *Table 1*, a relatively cool 11-day stretch of intermittent rainfall in March/April 2014 that was followed by five days of hot sun facilitated a close comparison of varying responses of the wetted stucco and fiber-cement lap siding systems to solar heating.

Note that during the first 11 days of this analysis, a total of 2.23 inches of rain fell at the site, and the average high temperature was only 61°F. In contrast, there was no rainfall during the final five days of sunny weather, and the average high temperature was 80°F.

As documented with the following graphs, these hot, sunny days generated sharply increased humidity ratios within the tested exterior wall cavities. Then, due to the absence of an interior envelope at the perpendicular walls (see *Photos 3* and *4*), these spikes of moisture readily pushed



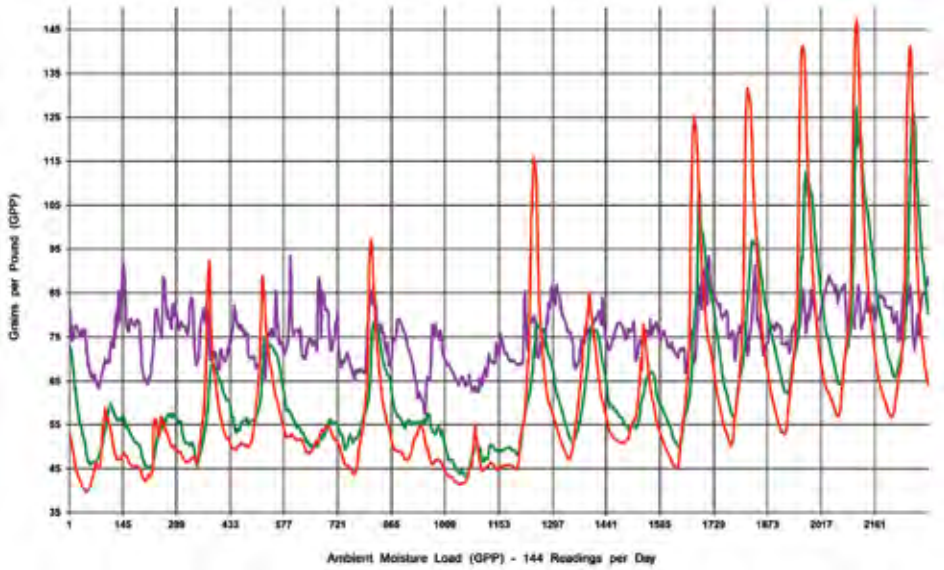
Graph 1 – Unit B: The blue line tracks ambient moisture ratio (GPP) at interior Logger 4, while red line records exterior wall cavity (Logger 3) – 144 readings per day for 17 days (starting at 12:00 a.m.).



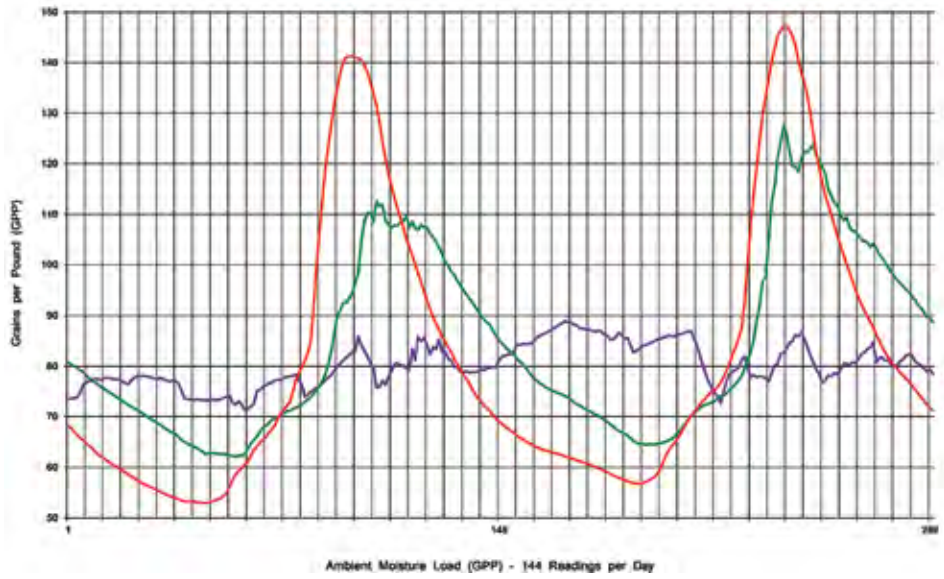
Graph 2 – The dashed black line is exterior temperature (°F) at the site, while the red line tracks ambient moisture load (GPP) within exterior wall cavity at Unit E-144 readings per day for 67 days.

Table 1 – National Weather Service data from March/April 2014: 11-day period of intermittent rainfall was followed by five days of hot sun.

Day	Date	Weather	Rain	Temperature	
			Inches	Low (F°)	High (F°)
1	March 25	Cloudy - Rain	*trace*	45	63
2	March 26	Cloudy - Rain	0.35	49	62
3	March 27	Cloudy - Rain	0.01	50	62
4	March 28	Sun & Clouds	*trace*	52	68
5	March 29	Cloudy - Rain	0.59	54	57
6	March 30	Sun & Clouds	0.00	39	62
7	March 31	Cloudy - Rain	0.17	45	58
8	April 01	Cloudy - Rain	1.08	45	55
9	April 02	Sun & Clouds	0.00	43	61
10	April 03	Sun & Clouds	0.00	45	65
11	April 04	Cloudy - Rain	0.03	49	59
12	April 05	Sun	0.00	41	70
13	April 06	Sun	0.00	45	79
14	April 07	Sun	0.00	48	81
15	April 08	Sun	0.00	54	84
16	April 09	Sun	0.00	55	81



Graph 3 – Unit F (stucco, parallel wall): Purple line records GPP ratio in closet, green line records plenum, and red line records exterior wall – 144 readings per day for 16 days (starting at 12:00 a.m.).



Graph 4 – Unit F (stucco, parallel wall): Purple line records GPP ratio in closet; green line records plenum; and red line records exterior wall (144 readings each for days 14 and 15, starting at 12:00 a.m.). Every vertical line on this graph corresponds to one hour.

into the plenum spaces above the drop ceilings. Further, the data from some—but not all—of the apartments revealed that these solar-driven moisture waves also migrated into the occupiable rooms below the drop ceilings.

GRAPHS 3 AND 4 – STUCCO (SOUTH ELEVATION, PARALLEL WALL) AT OCCUPIED UNIT F

As seen at *Graph 3* for Unit F, the hot, sunny days generated strong daily increases in ambient moisture at both Logger 2 (plenum space = green line) and Logger 3 (exterior wall cavity = red line). For each logger, we then compared the average (mean) humidity ratio for the first 11 days of testing with the overall average humidity ratio for the final five days.

- We found that Logger 2 had recorded an average 40.0% increase within the plenum space, and Logger 3 had measured a 43.3% average increase within the exterior wall cavity.
- In contrast, data from both Logger 1 (closet = purple line = 7.3%) and kitchen Logger 4 (3.3%, not graphed) suggested that solar heating of the wetted stucco-clad walls below the rim/plenum transition had not greatly impacted humidity levels within the occupied rooms.

To better understand the substantial differences in vapor-retarding performance between the rim/plenum transition (behind the bellyband) and the lower wall below, which share the same solar-heated stud bay (see *Photo 1*), we considered *Graph 4*, which focuses only on the data from hot, sunny Days 14 and 15 of this testing. Upon review, we determined:

1. The closely similar, cyclic shapes of the red line (exterior wall, Logger 3) and green line (plenum space, Logger 2) again prove that the daily cycles of increased/decreased moisture within the ceiling cavity correspond to solar heating and nighttime cooling of the rain-wetted stucco walls.[12]
2. However, because the greatly dissimilar shape of the purple line (bedroom closet, Logger 1) is not consistent with direct solar heating, the interior envelope—typical painted gypsum wallboard—at this apartment has, to a great degree, resisted and tempered the daily pushes of solar-driven moisture.
3. Further, because the daily rise of the heating phases at the green line occurs approximately one to two hours later than at the red line (even though these two data loggers are only inches apart), the unpainted gypsum wallboard (see *Photo 7*) above the drop ceiling also served to satisfactorily retard the daily drives of solar-driven moisture.
4. Therefore, the most likely source (and route) of these daily increases in ambient moisture above the ceiling was the opposite perpendicular wall (*Photo 3*), where the absence of an interior envelope had created the path of least resistance.

To evaluate this seemingly obvious finding, we then considered comparable data from another parallel wall at an apartment clad with fiber-cement siding.

GRAPHS 5 AND 6 – SIDING (NORTH ELEVATION AT PARALLEL WALL) AT OCCUPIED UNIT G

At *Graph 5* for Unit G, clad with fiber-cement lap siding, we see that the hot, sunny weather beginning on Day 12 (again

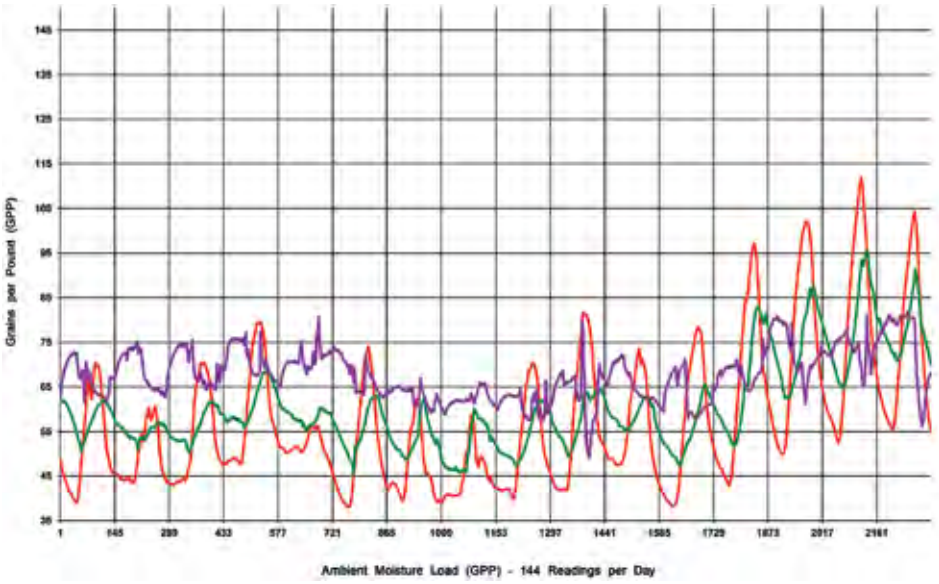
reference the weather matrix at *Figure 1*) similarly produced strong increases in average moisture content at Logger 2 (plenum = green line = 24.2%) and logger 3 (exterior wall cavity = red line = 31.8%).

And again, the data from Logger 1 (closet = purple line = 6.1% increase) and kitchen Logger 4 (6.7%, not graphed) indicated that solar heating (from the same stud bay) of the wetted siding below the rim had not greatly impacted humidity levels within the occupied rooms. Then, to better confirm this analysis, we reviewed data (per *Graph 6*) from the hottest days (Days 14 and 15) of this testing period.

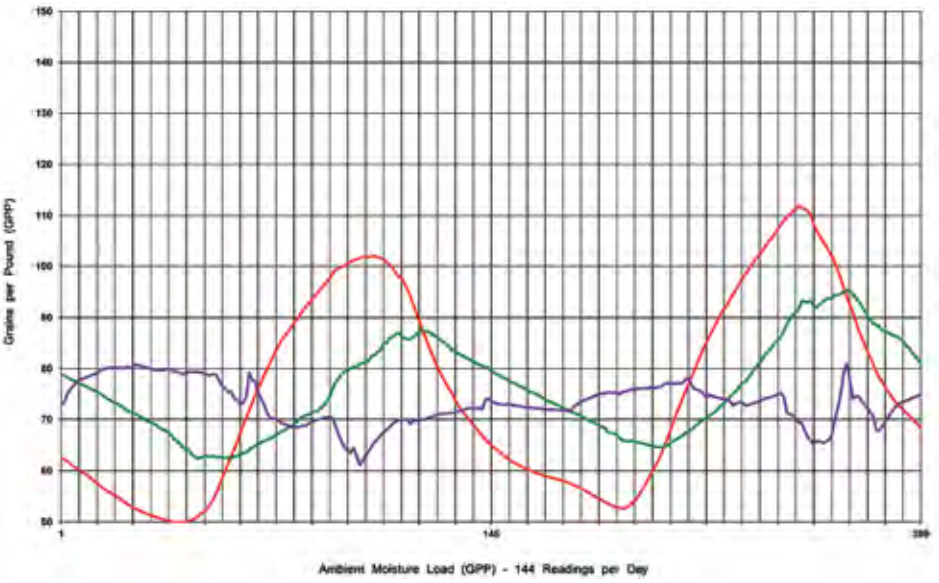
Upon review of both graphs, we concluded:

1. The generally similar shapes of the red line (Logger 3) and green line (Logger 2) again demonstrate that the daily cycles of increased/decreased moisture within the ceiling cavity corresponded to solar heating and nighttime cooling of the wetted siding assembly.
2. Again, because the generally dissimilar shape of the purple line (Logger 1) is inconsistent with direct solar heating of the occupied spaces, the interior envelope (painted wallboard) had resisted and tempered the spikes of solar-driven moisture.
3. Similarly, because the heating phases at the green line occurred three to five hours later than the red line, the unpainted gypsum wallboard (*Photo 7*) between Loggers 2 and 3 again had retarded these waves of water vapor.
4. This demonstrated again that the source (and route) of the increased moisture above the ceiling was solar-driven migration through the perpendicular wall (*Photo 4*) where the absence of an interior envelope had created the path of least resistance.

Note also that comparing *Graphs 3* and *4* (stucco: south-facing parallel wall at Unit F) with *Graphs 5* and *6* (lap siding: north-facing parallel wall at Unit G) reveals highly different shapes for the moisture cycles being recorded at the two red lines. At *Graphs 3* and *4*, we see high, steep, and narrow spikes of increased vapor on hot, sunny days, while the corresponding red line cycles at *Graphs 5* and *6* tend to be flatter and wider.



Graph 5 – Unit G (siding, parallel wall): Purple line records GPP ratio in closet, green line records plenum, and red line records exterior wall – 144 readings per day for 16 days (starting at 12:00 a.m.).



Graph 6 – Unit G (siding, parallel wall): Purple line records GPP ratio in closet; green line records plenum; and red line records exterior wall (144 readings each for days 14 and 15, starting at 12:00 a.m.) Every vertical line on this graph corresponds to one hour.

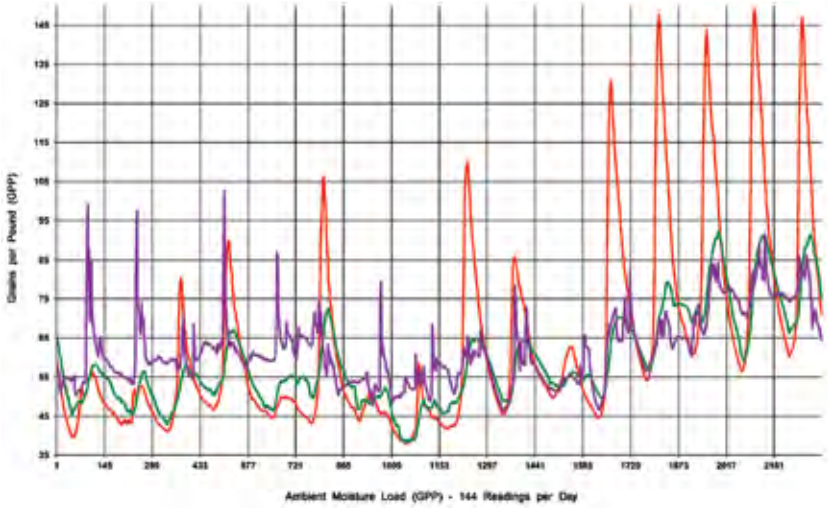
Upon review, it was discovered that the primary factor in determining the cyclic shapes of these red lines appears to be solar exposure; wetted walls that receive greatest exposure to direct sunlight during the hottest portion of the day simply will, in general, encounter higher, steeper spikes of solar-driven moisture.

We then evaluated data collected from loggers installed at typical perpendicular walls clad with stucco (*Graph 7*) and fiber-cement lap siding (*Graphs 8* and *9*).

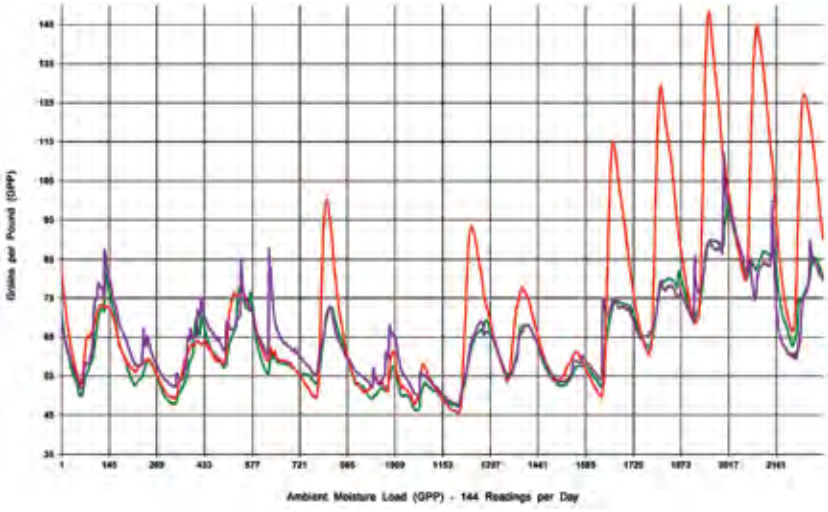
GRAPH 7 – STUCCO (SOUTH ELEVATION – PERPENDICULAR WALL) AT OCCUPIED UNIT J

Graph 7, at stucco-clad Unit J, demonstrates that at all four loggers recorded large increases in average moisture content during the final five days of hot weather: Logger 1 (bedroom closet = purple line = 19.5%), Logger 2 (plenum space = green line = 35.2%), Logger 3 (exterior wall cavity = red line = 58.6%), and also at kitchen/bathroom Logger 4 (12.8%, not graphed).

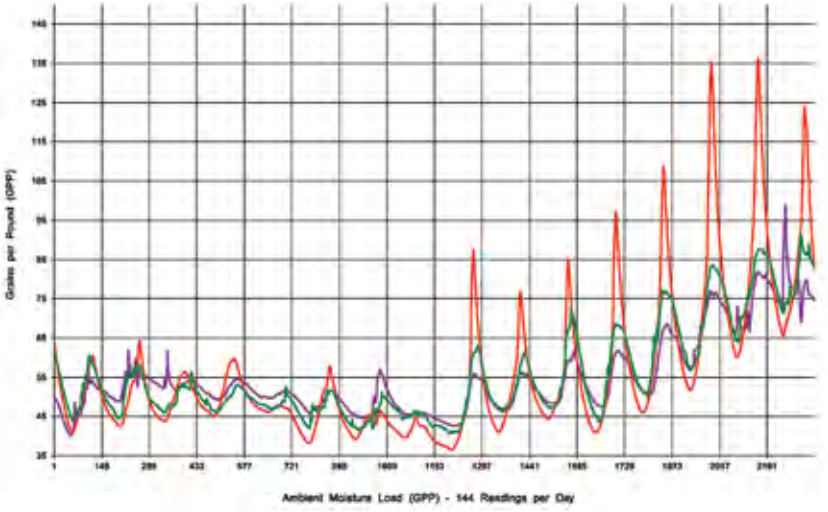
Further, close correspondence between the shapes and timing of the



Graph 7 – Unit J (stucco, perpendicular wall): Purple line records GPP ratio in closet, green line is plenum space, and red line is exterior wall – 144 readings per day for 16 days (starting at 12:00 a.m.).



Graph 8 – Unit K (siding, perpendicular wall): Purple line records GPP ratio in closet, green line is plenum space, and red line is exterior wall – 144 readings per day for 16 days (starting at 12:00 a.m.).



Graph 9 – Unit H (siding, perpendicular wall): Purple line records GPP ratio in closet, green line is plenum space, and red line is exterior wall – 144 readings per day for 16 days (starting at 12:00 a.m.).

purple and green lines indicated that solar heating of the rain-wetted stucco had concurrently driven water vapor directly into both the occupied bedroom and the plenum space above.

GRAPH 8 – SIDING (EAST ELEVATION – PERPENDICULAR WALL) AT OCCUPIED UNIT K

Similarly, *Graph 8* for Unit K (clad with fiber-cement), reveals strong increases in average moisture content at all four loggers: Logger 1 (bedroom closet = purple line = 23.7%), Logger 2 (plenum = green line = 30.4%), Logger 3 (exterior wall cavity = red line = 55.1%), and also kitchen/bathroom Logger 4 (16.4%, not graphed).

Again, the remarkably close correspondence between the shapes and timing of the purple and green lines during the final five days demonstrated that solar heating of the rain-wetted wall had pushed moisture directly into both the occupied bedroom and the plenum space.

GRAPH 9 – SIDING (SOUTH ELEVATION – PERPENDICULAR WALL) AT OCCUPIED UNIT H

Finally, *Graph 9* for the south-facing perpendicular wall at Unit H (also clad with fiber-cement) again showed large increases in average moisture content at all four loggers: Logger 1 (bedroom closet = purple line = 31.2%), Logger 2 (plenum = green line = 39.4%), Logger 3 (exterior wall cavity = red line = 49.6%), and also kitchen/bathroom Logger 4 (25.4% – not graphed).

And yet again, close correspondence between the shapes and timing of the purple and green lines during the final five days demonstrated that solar heating of the rain-wetted perpendicular walls (all of which lacked an interior envelope at rim/plenum transitions, per *Photos 3* and *4*) had driven moisture directly into the occupied bedroom and the plenum cavity above.

Interestingly, *Graph 9* also demonstrates that these solar-induced waves of water vapor had commenced on Day 9 (even though the high temperature was only 61°F, per the *Table 1* weather matrix) and continued through Day 11 (cloudy all day, with minor precipitation and a high temperature of only 59°F).

After review, we concluded that these seemingly "early" spikes of moisture at this south-facing perpendicular wall at Unit H represented the expected effects of direct heating of atypically high amounts of trapped moisture within the wall assembly—very likely due to rainwater leakage behind the wood bellyband boards.[13]

Per *Photos 8* and *9*, destructive investigation confirmed areas of rainwater infiltration adjacent to typical locations being tested with Loggers 1, 2, and 3 at these perpendicular walls, below wood bellyband boards below poorly installed Z-flashings.[14] (Note the "burned" building paper.)[15]

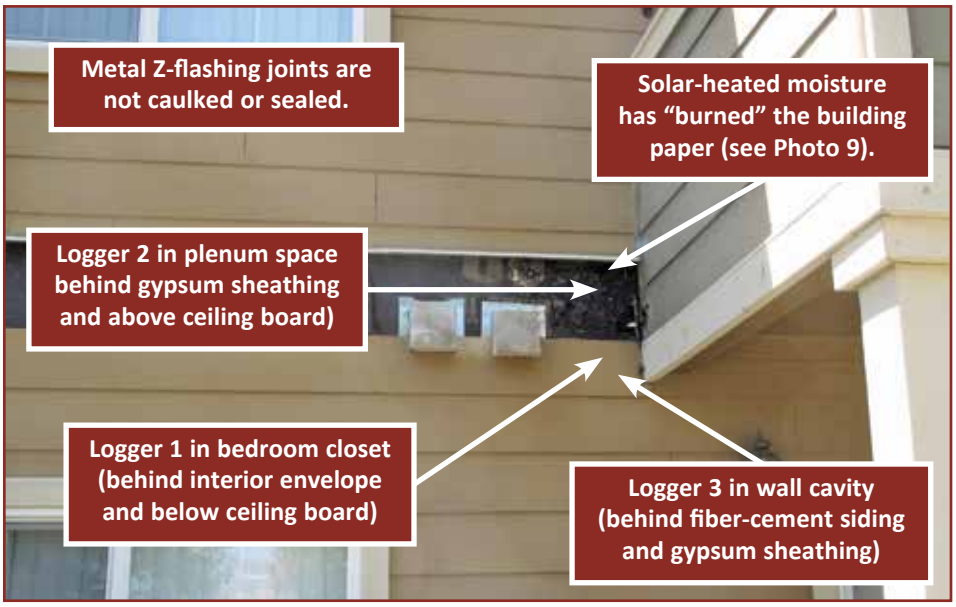


*Photo 8 – At wood bellyband boards, rainwater infiltration at nonsealed joints and transitions at metal Z flashings has led to increased levels of solar-driven moisture through some exterior walls (*Graph 9*).*

SUMMARY DISCUSSION

Virtually all exterior walls experience some degree of inward vapor drive when heated by the sun; however, after a period of rainy weather, even greater quantities of water can be driven into the wall cavities from wetted claddings. While this ubiquitous process is not problematic in and of itself, providing a continuous interior envelope (or solid wood blocking) at these walls will keep these daily cycles of solar-heated moisture safely contained within the wall cavities. Our testing suggests that in the moderate climate zones near San Francisco, an interior envelope constructed only of unpainted gypsum wallboard will satisfactorily retard these inward pushes of moisture—even on the sunny days that immediately follow a rainy period.[16]

Conversely, our data clearly demonstrate that the general failure to provide any form of interior envelope at certain rim/plenum transitions at this residential complex created pathways for large amounts of water vapor to be pushed directly into first-floor building interiors, including occupiable spaces below drop ceilings. The size and extent of such solar-driven moisture (vapor) waves of course were exacerbated wherever rainwater (liquid) already had leaked into the wall systems due to construction defects at the exterior envelopes.

This suggests that whenever forensic investigators find condensation damage and fungal growth at interior walls in residential spaces, they should closely consider the possibility that primary origin(s) of this problematic moisture might be solar heating of trapped rainwater at potentially distant defects in the exterior walls.

Further, this investigation and similar recent datalogger testing by our firm indicate, as evidenced by *Graph 1*, that diffusion (due to vapor concentration differentials) into exterior walls of occupant-produced "lifestyle" moisture generally is far less likely to cause damage than is convection (via air pressure differentials) of humid interior air into exterior walls due to unsealed gaps and voids. As noted within ASTM International's *Manual 18, Moisture Control in Buildings: The Key Factor in Mold Prevention*, "Requiring careful moisture management by the occupant is no substitute or excuse for inadequate moisture-resistant design."[17]

In cases where a wide gamut of opinions and theories is being offered by the investigating consultants, the data collected from well-positioned loggers can be used to better allocate to the parties whose deficient work caused or allowed this excess vapor moisture intrusion their fair shares of financial responsibility for interior remediation. In particular, our firm's data analyses center

Photo 9 – Rainwater infiltration at nonsealed joints and transitions at metal Z-flashings has led to increased levels of solar-driven moisture migration through the exterior walls (see Graph 9*).*

on short- and long-term changes in ambient moisture content ("humidity ratio") readings because most parties involved in the typical construction defects litigation process intuitively understand the probative values of "wet" vs. "less wet" vs. "dry" moisture content readings.

We recommend that most data-centric evaluations of interior humidity levels and/or building envelope performance similarly should be focused on tracking changes in actual moisture content over time, as opposed to changes in relative humidity (which, of course, is a "relative" value that can change greatly even when the actual moisture content ratio remains the same).

FOOTNOTES

1. For this testing, we used the HOBO U23-002 Pro v2 data loggers manufactured by Onset Corporation (http://www.onsetcomp.com).
2. November 1, 2013, to April 10, 2014.
3. For this type of testing and analysis, we recommend programming the loggers to record RH and temperature data at least every 10 minutes; otherwise, potentially informative changes in these dynamic processes can be missed.
4. To that end, we followed the highly perceptive guidance of William A. Rose (*Water in Buildings – An Architect's Guide to Moisture and Mold*, John Wiley & Sons, Inc., 2005): "Most moisture problems can be diagnosed by looking at the condition and asking how much water it took to create that problem. Solving the problem amounts to asking where that amount of water could have come from and where it should go."
5. Donald P. Gatley, *Understanding Psychrometrics*, Second Edition, ASHRAE, Inc., Atlanta, GA 2005: "Humidity ratios provide a simple, effective, and most convenient means of accounting for the mass of water vapor in a psychrometric process…by relating it to the nonvarying mass of dry air."
6. There are 7,000 grains in one pound.
7. Note: at the ordinary temperatures encountered by construction professionals in North America, corresponding measurements of "water vapor pressure" and the "humidity ratio" are essentially proportional; therefore, whenever an engineer references an increased (or decreased) vapor pressure, it is okay for us nonengineers to simply envision a proportional increase (or decrease) in ambient moisture content. Conversely, the relative magnitudes of the humidity ratios depicted in these graphs can be used to identify the orientation (inward or outward) of the dominant vapor drive through the interior envelope at any particular point in time. Whenever the red line (Logger 3) is higher than the purple line (Logger 1), water vapor is being pushed inward and vice versa.
8. Wahid Maref, et al., "Laboratory Demonstration of Solar Driven Inward Vapour Diffusion in a Wall Assembly," National Research Council Canada, 11th Canadian Conference on Building Science and Technology, Banff, Alberta, 2007.
9. John F. Straube, "The Influence of Low-Permeance Vapor Barriers on Roof and Wall Performance," *Proceedings of Thermal Performance of Building Envelopes VII*, Clearwater, Beach, Florida, 2001.
10. Lonnie Haughton, "Buildings That 'Leak' Only On Sunny Days – Case Study and Investigative Guidelines" (http://www.rci-online.org/interface/2010CTS-Proceedings-haughton.pdf): "If the general timing, shape, and/or amplitude of vapor cycles from one logger correspond to vapor cycles from another logger in a separate space, there probably is a direct relationship between the measured conditions."
11. Our data analyses revealed no evidence that the overall performance of the stucco cladding would be more (or less) satisfactory than the fiber-cement lap siding—assuming both systems are installed in conformance with industry standards and best practices.
12. Lonnie Haughton, op. cit.
13. None of the Z-flashing's joints and transitions atop the wood bellyband boards at this residential complex were caulked or otherwise sealed.
14. Very likely, this condition also is evidenced by the data depicted at *Graph 8* for an east-facing perpendicular wall at Unit K.
15. Building envelope investigators in climate zones that experience alternating periods of rainy and sunny weather will encounter the conditions seen in *Photo 9*, where wetted areas at asphaltic building papers exhibit a pattern of deterioration visually consistent with having been burned. Clearly, such damage results from solar heating of rainwater infiltration trapped behind the cladding or siding.
16. It is worth noting that the solar-heated moisture being pushed through these open rim/plenum transitions would be substantially diminished if an engineered wood sheathing had been installed behind the stucco (see *Photo 3*) and the fire-rated fiber-cement lap siding system (see *Photo 4*).
17. Heinz R. Trechsel and Niklas Vigener, "Investigating Moisture Damage Caused by Building Envelope Problems," *Moisture Control in Buildings: The Key Factor in Mold Prevention* (Manual 18 - 2nd edition), Heinz R. Terchsel and Mark T. Bomberg, editors) ASTM International, 2009.

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