INTRODUCTION

Unless buildings are protected by giant umbrellas, they’re going to get wet. Before discussing how to measure a masonry wall’s resistance to getting wet and describing an actual case study at the end of this article, we shall briefly review how moisture enters a masonry wall in the first place and its effect on the structure once it gets there.

Review of Masonry Moisture Intrusion

All building envelopes leak to some extent. For one reason or another, some leak more than others. Moisture, in various states, passes through common exterior cladding systems such as masonry, wood, EIFS, and concrete. However, brick masonry has been selected for this discussion because it is a very common envelope material for both residential and non-residential construction. According to the Brick Institute of America (BIA), approximately 60 percent of construction in the Southeast consists of some or all brick. Of course, other geographic locations may experience different proportions. Brick is hard, solid, durable, and, for the most part, water resistant, so what is all the fuss about brick after a rainstorm?

Effects of Moisture on Masonry

Moisture is probably the primary ingredient for the deterioration of brick. Moisture, as the catalyst to deterioration of brick, can cause the following:

- Create or magnify odors.
- Carry harmful pollutant gases into the envelope.
- Magnify the effects of spalling from freeze-thaw cycles.
- Cause wood studs, blocking, and structural members to rot.
- Encourage growth of biological organisms (mold, mildew, etc.).
- Cause steel stud backup, ties, and masonry reinforcing to corrode.
- Dissolve latent salts and deposit them on the surface as efflorescence.
- Cause finishes on the inside of exterior walls to fail prematurely and to stain.

Typical Methods of Moisture Intrusion

Remember the nursery tale, The Three Little Pigs? The Big Bad Wolf blew the stick house and the straw house down, but was not able to budge the brick house. As shown in Figure 1, a brick wall can resist the wind from the Big Bad Wolf, but that same brick may not keep Mother Nature from sending moisture through the wall.

Those three little pigs were probably surprised to discover that the brick house may have leaked or at least passed moisture. How can this be? Masonry is often marketed as being hard, solid, and waterproof. A solid brick wall is a rain barrier, meaning that it sheds or deflects water. A typical brick wall is vertical, and when rainwater hits it, the brick stops the water, but gravity causes the water to run down the face of the brick. Well, most of the water runs down the wall.

Brick, by nature of its porous...
construction, can absorb some of the water before it all runs down the wall. Thus, the brick wall can become a vertical reservoir.

Although brick is porous and somewhat absorbent, very little water actually enters through the masonry units or the mortar. Water usually enters the shell at the bond (or lack of it) between the brick and mortar and through cracks in the mortar or masonry units. Thus, workmanship (proper mortar proportions and mixing, full head joints, correctly tooled joints, appropriate expansion joints, proper unit setting, etc.) is paramount in preventing moisture intrusion.

Cracks at the mortar-masonry bond or within the mortar can range from 0.004 inch to 0.040 inch wide. Stress cracks in the masonry units can be much wider. Wind-driven rain can enter openings as narrow as 0.004-inch. However, cracks 0.010 to 0.015 inch are often considered narrow as 0.004-inch. However, cracks the masonry units can be much wider. Although brick is outside, it is made of clay and absorbent, very little water actually enters through the masonry units. Thus, workmanship (correctly tooled joints, appropriate expansion joints, proper unit setting, etc.) is paramount in preventing moisture intrusion.

Moisture that enters masonry from the exterior surface either migrates all the way through to the interior or collects within the brick. Moisture that moves to the interior can damage wall and floor finishes. Moisture that collects within the brick can eventually move back to the exterior and cause efflorescence or staining on the exterior, corrosion of steel reinforcement, and decay of wood blocking. Thus, any moisture that enters the masonry can cause damage somewhere.

Brick, because it is outside, can experience wet-dry cycles and, depending on geographic location, can also experience freeze-thaw cycles. These alternating cycles can cause the brick to deteriorate. Once moisture has entered the porous structure of the brick units, the stage has been set for deterioration.

Going back to the Three Little Pigs tale, it is possible that the moisture from the warm breath of the Big Bad Wolf could have been absorbed by the brick and then migrated to the interior of the building, especially if the house was cooler inside.

INVESTIGATING MOISTURE

Now that it has been determined that brick leaks, how do we determine how much it leaks? Clues (surface discoloration, metal corrosion, decaying wood, slow drying, finish delamination, musty odor, etc.) suggesting the presence of moisture in the wall have been noticed. After the initial shock, the point of entry and the amount of moisture entering should be determined so that the appropriate remedial action can be taken. After initial visual inspection, one or a combination of the following common field-conducted and non-destructive tests can be performed.

Diagnostics

Removing or otherwise disturbing masonry courses is discouraged, unless there is specific evidence of water entering the envelope through defects in flashing or similar building elements. This can be a very expensive procedure and involves not only removing the masonry coursing, but also adding temporary supplemental reinforcement, inspection, and replacing the coursing to match adjacent construction. Before going to such extremes, one of the following listed non-destructive tests should be considered. Each test has its advantages, and frequently, it is beneficial to utilize more than one of these tests. The fourth test listed is the MAT or RILEM tube test and is a relatively unknown and infrequently used test. For that reason and because it can be a very effective diagnostic tool, the remainder of this article will focus on the RILEM tube test and its actual use in the included case study.

1. Hose Test: A hose test can apply a water spray over a large area or a concentrated water stream to a small area. Unless the nozzle is calibrated, it is difficult to regulate pressure and volume. The hose test requires a minimum of two people – one to direct the water and the other to check for intrusion during water application. This test will often identify points of water entry. Unless water pressure and stream are carefully controlled, excess pressure can actually damage the mortar matrix and cause even more problems.

2. Moisture Meter: A moisture meter tells us that there is moisture in the structure at the point of measurement. Unless a moisture meter is designed and calibrated for a specific substrate such as wood or concrete, it does not indicate actual moisture content. Instead, it indicates the relative amount of moisture compared to the same type substrate that is known to be dry. The meter does not necessarily tell us how the moisture got there or the point of entry.

3. Film Test: A polyethylene film test per ASTM D-4263 is not a quantitative test, but it is a reliable indicator that there is moisture directly behind the film. However, the film test does not indicate the amount of moisture. Moisture that collects on the inside of the plastic is either from moisture inside the wall or from surface condensation. This test would be difficult to conduct on rough and irregular brick surfaces, so it is best conducted on smooth interior walls.

4. RILEM Tube Test: The RILEM tube test is conducted according to the RILEM Commission 25, PEM, Test Method 1154 to evaluate a masonry structure’s resistance to wind-driven rain. It can identify a potential problem, the possible points of entry, the approximate rate of absorption, and the approximate wind speed required to produce entry. Unlike other previously mentioned tests that detect the presence of moisture, the RILEM tube test quantifies the rate of moisture penetration in a brick wall structure.

RILEM Tube

Of the four mentioned field tests, the RILEM tube test has been selected for discussion because it seems to be a misunderstood and relatively unknown test. Also, this test proved to be an effective diagnostic tool as described in the case study. It is a simple test, but can be a time consuming procedure. RILEM tube test is the most common name, but it is sometimes called the Masonry Absorption Test (MAT) or the Low-Pressure Tube Test. The RILEM tube was developed by the European organization RILEM, which is headquartered in Paris France. RILEM is the acronym for Réunion Internationale des Laboratoires et Experts des Matériaux, Systèmes de Construction et Ouvrages (International Union of Laboratories and Experts in Construction Materials, Systems, and Structures). Like our ASTM, RILEM has committees that develop standards for testing and evaluating construction materials.

The terms “penetration test” and “permeability test” are often used interchangeably. However, they are not the same.

a. Penetration Test: Penetration tests are usually conducted under labora-
Figure 2: The traditional RILEM tube is shaped like a pipe. Its bowl has a brim similar to that of a hat.

Figure 3: A lone RILEM tube is representative of only a small area.

Figure 4: Tubes that are used concurrently can speed up the testing and be more representative of the condition of the wall or structure.

tory conditions according to ASTM E-514. This test uses a sheet of water cascading down the face of a brick assembly.

• Permeability Test: This test can be field conducted with a very expensive apparatus that measures the time required to absorb a known volume of water at a constant pre-selected pressure. The quicker the absorption, the higher the permeance.

Since each test involves only a small area (approximately the size of a quarter), not all portions of a brick assembly (part of the brick, an intersection of mortar and brick, and a mortar joint) may be included.

The RILEM tube test is an absorption test and is a variation of the permeability test. It measures the quantity of water absorbed over a specific period of time. Since the pressure varies with the level of water in the RILEM tube, this is not a penetration or permeability test.

As shown in Figure 2, the traditional RILEM tube is shaped like a pipe with the slender shaft attached to the bowl. The bowl has a brim similar to that of a hat. The distance from the 0 graduation to the centerline of the brim is 12 cm. The 12 cm of water is equal to approximately 1172.2 pascals (approximately 0.17 psi) or a dynamic wind speed of approximately 157.8 kilometers per hour (approximately 98.1 mph). There are design variations to the RILEM tube that have shortened stems, smaller capacities, and are calibrated in miles per hour. Regardless of the tube used, the principle is still the same. However, this discussion is applicable to the traditional 5-ml capacity RILEM tube.

The RILEM tube test is time consuming because it tests only a very small area (approximately 1 square inch) at a time and...
is representative of only that small area. This is especially true when only one RILEM tube is used, as shown in Figure 3. However, when the test is conducted in multiple areas, it becomes more representative of the absorption characteristics of the wall. The more RILEM tubes that are used concurrently (as shown in Figure 4), the faster the testing can be done and the more the results will be representative of the condition of the wall or structure.

What does the RILEM tube test tell us?

The test can do the following:

- Identify a point of entry.
- Measure a wall’s resistance to wind-driven rain.
- Measure masonry’s rate of moisture absorption.
- Measure the effectiveness of applied water repellants.

Some professionals believe that this type of test is not accurate, dependable, or reliable because the pressure on the surface being tested is not constant. However, the general consensus seems to be that the varying pressures caused by changing water levels in the tube are consistent with actual wind conditions because wind does not blow at a steady velocity. The changing levels of water in the tube are caused by the masonry absorbing the water, which lowers the water level and, consequently, the pressure in the tube. Replacing lost water in the tube increases the water level and pressure accordingly. There are also variations in the RILEM Tube design that allow it to be used to test water absorption of concrete unit masonry and concrete.

The RILEM Tube Test Procedure

1. Prior to testing, examine the brick and joints to determine conditions and possible sources of leaks.
2. Determine a baseline by checking absorption of an unweathered, dry area. Record the baseline area.
3. Ensure test surfaces are clean and dry.
4. Attach the tubes to the wall in suspected locations with reusable, non-staining putty, clay, or molding clay, or other easily removable media that will provide a complete waterproof seal between the tube, brick, and joints and will not damage or stain the brick or mortar. Do not attach the tube just to the brick units. The tubes should be attached so that the top, middle, and bottom of the head joints and the bed joint are tested and should be attached to only the brick. Attaching the tube to both the joint and the brick will not provide an accurate test of the brick because the mortar will usually absorb water much more quickly than the brick. Number the tubes and locations for future reference.
5. Slowly fill the tube with water to the first graduation; pause and check for leaks. Distilled water is preferred because of its purity and resemblance to rainwater. Continue to fill the tube while pausing at each 1/2 graduation for approximately two seconds to check for leaks. Fill the tube to the top graduation. If leaks are noted before reaching the top graduation, stop where leaks are first noted and do not fill beyond this point.
6. Using a watch with a second hand, observe the rate of absorption over 5-, 10-, 20-, 30-, and 60-minute intervals. Record the water level in the tube at each interval on a form similar to the accompanying Moisture Absorption Test Form.
7. Add water to a tube when the level reaches the 5 ml mark and record the amount and the time that water was added to a tube.
8. Note the location of the highest absorption and record on the graph.
9. Cover the top of the tube if the air is not calm to prevent additional evaporation from wind. Tests should not be conducted in the rain, because the rain can wet the brick being tested and alter absorption rates.
10. Retain the recorded test results for future reference and comparison to establish possible trends.
11. Follow-up testing should be done in the same spot and baseline area as
**MASONRY ABSORPTION TEST**

**BY RILEM TUBE**

**Project:** Brick Structure  
**Date:** June 17, 2004  
**Temperature:** 84 deg. F.  
**Wind Speed/Direction:** 4 mph  
**Time:** 1 - 3:30 p.m.  
**Relative Humidity:** 53%  
**Sky:** Clear, Hazy, Partly Cloudy, Cloudy, Rainy  
**Observer:** Cris Crissinger  
**Location:** South Wall

<table>
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<th>Location</th>
<th>5 Minutes</th>
<th>10 Minutes</th>
<th>20 Minutes</th>
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<td></td>
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<td>ML Added</td>
<td>Reading ML</td>
<td>ML Added</td>
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<tr>
<td>2.</td>
<td>MHJ</td>
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<tr>
<td>3.</td>
<td>BHJJ</td>
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<tr>
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**LEGEND:**  
B: Brick; THJ: Top of Head Joint; MHJ: Middle of Head Joint; BHJ: Bottom of Head Joint; BJ: Bed Joint

In the initial testing, In addition to retesting the initially tested areas, testing other areas is acceptable to establish additional data.

**TEST INTERPRETATION**

Compare the results of the suspected area with the unweathered area. If average absorption values of weathered areas are approximately twice that of the unweathered areas, then weathering should be a concern, provided the brick and joint work are in the same condition.

Areas having an absorption rate of 5 ml of water or more in five minutes or less are most likely to leak during wind-blown rain. Those with absorption of 5 ml of water in 15 to 25 minutes usually do not leak.

Head joints are the usual leakers, specifically at the bottom of the head joint. Based on numerous tests and experiments conducted under both laboratory and field conditions, moisture absorption is usually found in the following locations (as shown in Figure 5), beginning with the most absorptive location and progressing to the least absorptive location:

- Bed joints  
- Top of head joints  
- Brick

If the back of the masonry wall is visible, water entry can often be seen beginning as a damp spot or a circle of water and then enlarging and moving downward. Observe wetting patterns and the rate of movement on the brick and joints. Shape, direction, and rate of movement can tell a big story. Of

*Figure 5: Moisture absorption is usually found at bed joints; at the top, bottom, and middle of head joints; and in brick.*
course, when possible, this means watching the backside of the wall.

When the brick itself leaks, a small, circular wetting pattern develops on the backside of the masonry and then gradually enlarges and may change shapes. When joints leak, the wetting pattern can begin as a circular pattern, but usually quickly spreads as a bead of water along the interface between the mortar and brick. A small trickle or beading of water is often associated with a leaking joint. The faster the pattern spreads, the more questionable the joint. However, just because a joint leaks does not necessarily mean the defects or points of intrusion will be visible.

It has been calculated that when the water level in the tube is level with the 0 graduation mark, the water pressure against the surface being tested is approximately 0.17 psi. This is equal to a dynamic wind speed of approximately 98.1 mph, which is a high Category 2 hurricane (74-95 mph). At the zero graduation, exerted pressure is approximately 0.04 psi, which is equal to approximately 49 mph. Refer to the accompanying table, Relationship Between Tube Water Level and Wind Speed. Isn’t it comforting to know that the masonry will resist the wind-driven rain, provided it survives the hurricane?

### RELATIONSHIP BETWEEN TUBE WATER LEVEL AND WIND SPEED

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<th>Theoretical Wind Speed (mph)</th>
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</tbody>
</table>

### CASE STUDY

Until now, we have discussed theory. But can the RILEM tube test really be an effective diagnostic tool? Initially, there were numerous suspects that could have caused the paint to peel. These suspects included the obvious, such as improper surface preparation, surface condensation, improper paint selection, incompatibility, and improper application. Visual examination, adhesion tests, thickness tests, and dewpoint measurements on the paint and plaster cleared this list of suspects. Now, another and more devious suspect – moisture – was considered.

If moisture is the main suspect, it had to have a willing and able accomplice. In other words, what let it in? Another list of likely...
partners in crime was prepared. This list included weathering, openings, flashing, joints, cracks, roof, and foundation. Weathering is often a prime suspect for moisture intrusion in restoration cases, but it is often easier to eliminate other usual contributors with a visual inspection and by asking the right questions. Getting the suspects to talk and then understanding what they are saying can be a challenge. After the likely culprits, (except for one) had been cleared of suspicion, attention was re-focused on the prime suspect – weathering.

Close examination of the masonry revealed areas where the mortar appeared to be somewhat granular and the brick had a more open texture. Unlike most mortars used today, the typical mortar used when this building was constructed usually had a high lime content. The high lime content makes a softer mortar that is able to absorb movement without cracking. This mortar is also more porous, which allows absorbed moisture to evaporate easily. This easy evaporation is important in solid brick construction that does not have a cavity to collect and weep out moisture.

Also, unlike the brick produced in today’s modern kilns, 1850s vintage brick were frequently handmade and fired in unregulated kilns at temperatures that were lower than those used to produce brick today. Being fired at a lower temperature, the brick did not have the surface glaze that is characteristic of bricks that are fired at today’s higher temperatures. This surface glaze can improve water repellency and reduce absorption. To ensure a conviction of weathering, with no chance of appeal, convincing evidence had to be gathered. This was achieved with appropriate tests.

Testing

First, known dry interior areas of plaster walls that were not experiencing paint adhesion problems were tested with a calibrated moisture meter to establish a baseline. When areas that were having paint adhesion problems were tested with the same device, moisture was detected, but the meter reading did not appear to be significant when compared to the baseline readings.

Next, film tests were performed on areas where a meter detected moisture. The film tests were monitored before and after a rain. Water droplets and vapor formed on the back of the plastic sheet, suggesting moisture within the wall. When the film was left in place for several days during a dry spell, moisture that formed on the back of the film had evaporated, and the droplets did not necessarily return during or after a rain. However, wind-driven rains that struck the walls in question assured the return of the moisture droplets. This hinted at moisture movement between the inside and outside surfaces of the wall. To confirm suspicions, RILEM tube tests were conducted on both the masonry joints and the brick units.

First, RILEM tubes were attached to protected and unweathered areas to establish a baseline. The average baseline reading was 3.7 ml of water absorption in 60 minutes. Readings were then taken at points on the brick masonry that were opposite the points where the film tests were being conducted. Absorption ranged from approximately 0.25 ml to 0.75 ml in five minutes for brick and 2.75 to 4.5 ml in five minutes for mortar. This confirmed suspicions that wind-driven rain might be the source of moisture. Interestingly, the RILEM tube test introduced enough additional moisture into the brick to cause moisture droplets to reappear on the film. With sufficient evidence to convict weathering, what next?

Remediation

The first solution was applying a negative-side water repellent coating directly to the prepared plaster substrate. Tests, however, indicated that the vapor drive was sufficient to create blisters in the coating as it did to the paint. It was also believed that other possible materials, such as special undercoats, might not be compatible with the selected finish coats.

Eventually, a spray-applied, clear, penetrating liquid water repellent applied to the exterior face of the brick was considered as a possible remedy. To check for discoloration of the brick, the water repellent was applied to a small, inconspicuous area of the structure. The water repellent was then applied to a small test area that had the highest absorption rate and then retested with RILEM tubes.

Retesting done under similar conditions (time of day, weather conditions, etc.) as the initial tests showed that the water repellent had been effective. Water repellent was then applied to all masonry surfaces to ensure uniform appearance over the entire structure. Surfaces were retested with RILEM tubes to confirm repellency. Prior to retesting interior locations, the brick masonry was allowed to dry for several days during a dry period.

When both film and moisture meter tests were repeated at the same interior locations as initially tested, the results indicated reduced moisture levels. Furthermore, as the masonry continued to dry, measured moisture levels fell to a trace. The problem interior walls were then pronounced suitable for painting.

The water repellent was used with the understanding that it was not necessarily a permanent cure, that reaplication might be necessary in approximately seven to ten years, and that absorption tests should be conducted periodically and compared with previous tests. Comparing the periodic tests will help establish any trends, evaluate performance, and determine the approximate expected life of the water repellent. Additionally, a water repellent would not have been applicable had the masonry conditions been more severe, such as cracked mortar or broken bonds. Such conditions usually require more drastic repair procedures, such as cleaning and repointing joints.

Probable Cause

In the case study, it appears that years of weathering had washed away the surface matrix of the mortar. This is significant because in mortar, the fine aggregate (sand) is encapsulated in the Portland cement and lime paste. When laid up and tooled, the mortar forms a surface matrix over the sand that becomes a water-resistant barrier. If the integrity of this matrix is broken, the mortar can lose some of its water resistance. This is a good reason to discourage removing residue from existing masonry or hardened mortar stains during new construction with pressure washing or strong detergents or – the unthinkable – sandblasting.

CONCLUSION

Visual inspection, including feeling, listening, and smelling is the initial step in evaluating moisture problems in brick masonry. However, frequently, the visual inspection must be supplemented with applicable diagnostic tests to confirm initial suspicions, to eliminate possibilities, to verify successful repairs, to establish a baseline for diagnostic evaluation, and to monitor trends. In this arena, the RILEM tube is a powerful instrument to be added to the tool box.
REFERENCES
ASTM E-514
BIA Technical Notes
Test Method 11.4 by RILEM Commission 25-PEM

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