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A Primer on Deterioration in Building Envelopes

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Today's building envelope is a blend of complex technologies that can be used with resourcefulness and subtlety to achieve important benefits for the owner and the user. The medieval mason did a fine job with sand-lime mortar and local stone, but today's built environments offer a much greater potential for comfort and efficiency. The risks, however, are also greater: poor design, careless installation, and neglected maintenance will quickly undermine the value, purpose, and benefits of the modern building envelope.

Owners and facility managers can best protect their building investment by understanding the potential of the building envelope and its risks of deterioration. To do so requires an understanding of each building envelope component and its inherent strengths and weaknesses.

The building envelope as a whole is best defined as a filter between the interior and exterior environments, allowing some elements to freely pass through, while preventing others from entering or exiting, as the case may be. For example, cooled air is kept inside, while smoke is allowed to escape through vents. The envelope acts as a barrier to:

- Rain, snow, hail, wind, and humidity
- Dirt, soot, pollen, dust, and debris
- Insects, spiders, and animals
- Noise
- Fire
- Ultraviolet light
- Unauthorized people.

John J. Hoffmann, FAIA is principal of Hoffmann Architects, and is responsible for all the firm's activities in the restoration and renovation of building envelopes. He is a nationally recognized expert on the causes of and solutions for building deterioration problems.

Investigation of leaks in a bronze-and-glass curtain wall on a New York City building.

The Sources of Building Decay

Nothing, of course, lasts forever, and buildings are as subject to decay and deterioration as all else. The enemy is water, along with the effects of thermal expansion and contraction. While these forces of nature are constant and cannot be eliminated, their effects can be mitigated and protected against. The weapon of choice? A well designed, well constructed, and well maintained building envelope.

Unfortunately, the primary contributing factors to premature building deterioration — those events which open the floodgates, as it were — are those caused by the *human* element: design deficiencies, poor material selection, improper construction, deferred maintenance, applied forces, weight, vibrations, pollution, and vandalism.

In general, building envelope problems are usually caused by the failure of glazing compounds or sealants, corrosion of steel supports, clogged weep holes, loss of sealant adhesion, dislodged glazing gaskets, deterioration of mortar joints, or improper installation of flashing membranes.

What all these can lead to is damage from water infiltration and thermal action. Water works its way into a building through any one of six natural sources: gravity, kinetic energy, surface tension, capillary action, and air currents and pressure drops. Any of these, singly or in combination, can take their toll over time. A poorly designed or maintained building is simply one that's all the more ready for problems and one that will begin to decay all that much sooner.

Thermal movement does not cause damage in and of itself. The problems arise from the varying rates at which different building materials expand and contract. The pressures caused by these incompatible actions are what lead to cracks and openings in the building envelope, paving the way for future difficulties.

For example, an aluminum window frame set in a masonry wall can expand at twice the rate of masonry. This can lead to failure of improperly designed or installed sealant joints, ultimately creating openings for water entry.

While most thermal action is caused by seasonal temperature changes, even localized variations in expansion and contraction can occur from something as simple as shading from direct sun. A well designed building is able to accommodate these dimensional changes through the use of carefully calculated joint tolerances and flexible sealing methods. Joint tolerances are the open spaces between various structural components, while flexible sealing methods help keep water out of these spaces.

In the case of the aluminum window described above, the damaging effects of thermal action are resolved by using a flexible joint of sufficient width which consists of a pre-compressed joint filler, backer rod, and high-performance sealant. This construction allows the window to comfortably expand and contract within the masonry wall while preserving the weatherproof facade.

Example A below shows the varying rates of expansion for commonly used building materials, and underscores the importance of factoring in these expansion rates when designing a new facility.

Coefficient of Linear Expansion for 100° F

Aluminum	.00128
Stainless Steel	.00099
Steel	.00065
Concrete	.00055
Glass	.00050
Marble	.00045
Limestone	.00042
Brick Masonry	.00034

Example A: Building envelope failure can often be traced directly to a failure to plan for differing rates of movement among various building materials.

Building Envelope Components

Each building envelope component has its own inherent risks for deterioration, risks which must be guarded against both during initial design and in ongoing maintenance. The following looks at these components, their potential for decay, and some common causes of deterioration.

Curtain Walls

A curtain wall is an exterior building wall that carries no vertical loads, commonly known as a non-load bearing wall. While there are many variations in curtain wall construction, these wall types typically fall into five categories: metal curtain wall, masonry veneer, exterior insulation finish system (EIFS), stucco, and wall panels. Metal curtain walls and masonry veneer are the most common, and are explored in more detail below.

Metal curtain walls

These walls consist principally of metal, or a combination of metal, glass, and other surface materials that are supported by or within a metal framework. "Window wall" is a common term for a metal curtain wall installed between floors, or between the floor and roof. This wall type is usually composed of vertical and horizontal framing members (mullions) that contain fixed vision lights and opaque spandrel panels. The mullions hold the glass vision lights (glass windows) and spandrel panels in place, and give the metal curtain wall its characteristic appearance of a rectangular grid. The spandrel panels are the opaque panels that conceal the floors, ceilings, and mechanical spaces.

Masonry veneer

Masonry exterior facings, called veneers, can be installed using any one of four construction methods:

1. Attached directly to a masonry back-up wall with masonry ties or mortar.
2. Constructed with a cavity between the veneer and the back-up wall.
3. Pre-assembled into panels and

A rather poorly constructed masonry wall. Note the many openings in the mortar, which allow water entry.

attached to the structural frame.
4. Anchored to a back-up wall of steel studs and gypsum sheathing.

The most common type of masonry curtain wall is defined as a masonry cavity wall that consists of masonry veneer on the exterior, an inner air space, and a back-up wall. Relieving angles at each spandrel beam or floor slab are used to support the weight of the masonry, making the masonry wall a true non-load bearing curtain wall.

Curtain wall problems

Weak links in the waterproofing system are often found in curtain walls and masonry, particularly at intersections or joints where the roof meets the parapet. In addition, each type of curtain wall faces its own common construction or design defects, which are described in more detail below:

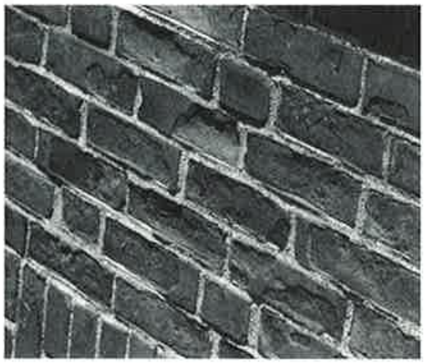
1. Masonry curtain walls: A major problem in masonry curtain walls is the *deterioration of mortar joints* (the horizontal and vertical bands of mortar between bricks in a brick facade), which leads to water entry. This deterioration is caused by:
• Excessive moisture penetration at joints.
• Successive freeze-thaw cycles.
• Exposure to weather and pollution.
• Uneven settlement of building foundation.
• Thermal movement of masonry.
• Unequal expansion and contraction between the face masonry and its back-up wall or structural support.

The following illustrates the damage potential of decaying mortar: Within one square foot of brick wall, there are 13 lineal feet of mortar-and-brick surface. If each brick-to-joint interface develops a hairline crack of only 1/64", the net effect on the building's waterproofing integrity would be equal to a 1/4" x 8" opening — ample room for plenty of water to get in.

Deteriorated mortar joints can be repaired by *repointing, tuck pointing, and pointing.* These are methods of removing and replacing old mortar with new mortar. This complex, labor-intensive, and costly process is, nevertheless, essential to preventing water entry and further building deterioration.

Another problem facing masonry walls is *water infiltration* at the relieving angle that supports the weight of the masonry. This is usually caused by a failure to leave adequate room for expansion under the relieving angle. Thermal movement between the brick and the steel relieving angle will ultimately force the brick to bulge out and pull away from the structural support. The solution — either during original design or as a major repair effort — is to re-set the bricks and install a proper soft joint. A soft joint consists of sealant and a backer rod set in front of the angle and empty space or compressible filler under the angle. Flashing membranes and weep tubes must also be incorporated.

2. Metal curtain walls typically suffer from *glazing failure*, often caused by the following design and construction errors:
• Failure to properly seal miter and butt joints.
• A dirty or contaminated sash rabbet.
• Lateral shifting or "walking" of glass.
• Failure to properly bed, cushion, or center the glass.
• Improper glazing system that is incompatible with the sash design or building conditions.
• Incorrect use of or failure to use setting blocks.



The brick has lost its face from water entering the wall through the back of the parapet.

• Out-of-plane, out-of-square, or improperly anchored window frames or surrounds.
• Lack of or improper positioning of spacers or edge blocks.
• Damage to sash, rabbets, or stops.
• Damage to glass edges, eventually leading to large cracks.
• Incompatible sealants.

Joints and Sealants

The joint is where two parts of the building structure meet and must be held together. As with all else in the

This completely deteriorated copper counterflashing was not replaced when the wall was re-pointed, a poor effort in itself.

building envelope, joint integrity is vital to building longevity and must be well constructed and regularly maintained. Joints must be both flexible and watertight. Use of proper sealants and correct joint size is a critical factor in every sealing situation where building movement will occur. The size of the joint is defined as the distance from one substrate to another, with joint movement expressed as a percentage of this distance.

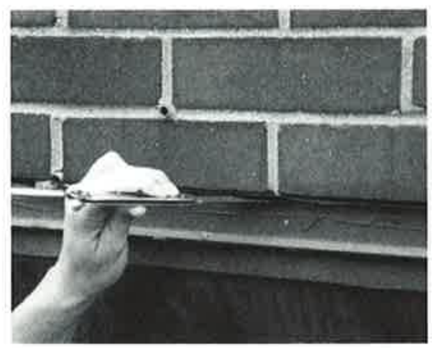
Temperature changes have the most impact on joints and their sealants. Cold tends to stiffen most sealants, reducing both their resiliency and their ability to absorb the stress caused by building and thermal movement. Exposure to the sun's ultraviolet rays can prematurely age some sealant compounds, while moisture within a sealing system causes damage through erosion or the pressure of successive freeze-thaw cycles.

Choosing the right sealant

The basic sealant materials available today are one-part and two-part polysulfides, one-part and two-part polyurethanes, silicones, acrylics, acrylic latexes, butyls, and oil-based caulks. For major expansion joints, a heavy-duty compressible material called a compression seal can be used to accommodate building movement. Each chemical ingredient used in sealants has unique properties that must be thoroughly investigated with the sealant manufacturer to ensure proper selection for specific building conditions.

One-part moisture-cured silicone and polyurethane are the most commonly used sealants for building envelope joints. Relatively new to the sealant industry, silicone works well for glazing and joint sealing because of its good adhesive qualities and performance in elongation and compression. Because silicone tends to attract and hold dirt, however, it may be an aesthetically questionable choice, especially in the case of light-colored sealant.

The movement capability of the sealant must be able to accommodate the expected range of movement for a given joint width. In some structures, the movement may be cumulative and impossible to predict. In those cases, the sealant choice should be one with high movement capability to ensure maximum safety. Polysulfide and polyurethane sealants are recommended for movement rates between ± 12.5% and ± 25%. Silicone sealants are highly resistant to weathering and provide excellent flexibility and resilience for movement rates as high as ± 50%. The latter would be the only choice for a butt joint with a joint width of 1/8" and an expected movement of ± 1/16".



Adhesive failure of the sealant at the joint connecting the brick masonry, wall flashing, and aluminum window.

Sealant joint problems

Most sealant joint failure is caused by adhesive or cohesive failure of the sealant itself.

Adhesive failure occurs when the sealant does not bond to the substrate. Lack of adhesion is usually due to improper preparation of the substrate surface. Failure is virtually guaranteed if the substrate is dirty, damp, improperly primed, or contaminated by other construction materials. The exact cause of failure must be determined first, however, to make sure the problem is solved before re-sealing. If no cause can be determined, start from scratch by field-testing the various cleaning and priming combinations with the selected sealant until the right mix is found.

Cohesive failure is the failure of the sealant to bond to itself, as evidenced by cracks and splits in the center of the applied sealant. This type of problem is clear evidence that the joint's movement was more than the sealant could handle.

Roofing

Roof assemblies are made up of two principal elements: the substrate (framing, deck, and insulation) and a continuous membrane barrier used to protect the substrate from water entry.

These continuous roofing membranes fall into three categories:
• Built-up membranes: successive layers of bitumen and felt, often with a gravel or mineral granule surface.
• Liquid-applied membranes: sprayed or rolled-on elastomeric coatings.
• Single-ply membranes: sheets of synthetic rubber, plastic, or modified bitumen.

Rust has formed on the steel supportive structure behind this leaking bronze-and-glass curtain wall.

Cohesive failure of the sealant in a brick masonry expansion joint.

Roofing problems

Premature failure of roofing membranes is more often a problem of incorrect design decisions and improper material installation, rather than that of defects in the material itself. Moisture damage, the leading cause of roof decay, usually appears first as wrinkles, blisters, or ridges that show up long before any actual leaks occur. One cause may be faulty flashing around roof penetrations and mechanical systems. Others include poor repair efforts in the past, age, or simply neglect.

How does moisture get in?

• Through absorption and retention by felts or insulation before installation.
• Through migration of water vapor through open joints or cracks in the substrate, which then condenses at lower temperatures in the felts.
• Through leakage problems at penetrations and interruptions of roofing layers.
• Through splitting, cracking, etc., on the exposed side of protective coatings or on the top ply of felts due to weathering, solar radiation, water ponding, freeze-thaw cycling, flow-off, alligatoring, or damage from foot traffic, falling objects, and temporary placement of equipment or tools.
• Through trapping of moist air between plies of felts due to incomplete coatings of bitumen or embedment of felt into bitumen. Blistering occurs when moisture is trapped between or within the plies of felt or under the membrane itself.
• Through fish mouths or edge wrinkles in felts where they overlap other felts, a problem caused by improper membrane installation.

Premature roofing failure may also be due to:
• Splitting due to tensile stress (resistance depends on the strength of the membrane and the fastening method).
• Slippage due to inadequate anchorage; using bitumen with too low of a softening point; high roof surface temperatures; or the excessive coating of bitumen between plies of layering or aggregate surfacing.
• Uplift resulting from air movement at high velocities over the roof surface, which can move and separate roof layers.

When Problems Occur

Any building owner planning to repair a deteriorating building envelope must first make the commitment to discovering the underlying causes of the decay. Unless those causes are found and fixed, any repair effort will be wasted money.

In planning a retrofit project, a specifically qualified architectural or engineering firm can provide a comprehensive package of renovation services. These include a preliminary survey of existing conditions, bidding documents, bid evaluation, contract administration, and on-site representation to monitor the repair work. Given the extent and expense of the average repair project, it is well worth the cost of the professional fees to make sure the job is done correctly the first time. Patching and re-doing poor rehabilitation work is an endless cycle that only gets more expensive over time.

One reason owners and managers often run into difficulties in solving building decay problems is that they immediately turn to a specific contractor who specializes in the building area that's leaking. For example, if the roof leaks, owners will typically call in a roofing contractor. The problem is that each contractor will only develop a solution that is specific to his trade. If the owner consulted a masonry contractor, every aspect of the problem would be a *masonry* problem, and so on. A qualified rehabilitation architect or engineer, however, has a more in-depth knowledge of all possible sources of deterioration and will take the broader view to find the root of the problem.

Where To Start

There are no simple answers to water infiltration and building deterioration problems. In older buildings, the problems most often result from age or neglect, or some alteration to the waterproofing system. In newer buildings, the problems arise most often from poor design, poor construction, poor materials, or some combination of these.

Any repair effort should begin with a review of the original plans and specifications, and a physical inspection of both the building's interior and exterior. This can help determine whether system failure was due to age, poor materials, or faulty design and installation.

A building envelope is a complex system of interacting components, with ample opportunity for things to go wrong. Expert preparation and execution of the construction contract will help keep the repair project on track. ■

The Facility Manager's Bookshelf: **The Building Envelope**

A. Basic References

1. *AAMA Technical Reference Center.* $450.00
   Volume 1: Windows and Sliding Glass Doors
   Volume 2: Metal Curtain Walls
   Volume 3: Aluminum Storefront and Entrance Manual
   Volume 4: Skylight and Space Enclosures
   To order: The American Architectural Manufacturers Association (AAMA), (708) 202-1350.
2. *ASD Manual of Steel Construction, 9th Edition.* $72.00
   To order: American Institute of Steel Construction, Inc. (AISC), (312) 670-2400.
3. *BIA Technical Notes.* $75.00
   To order: Brick Institute of America (BIA), (703) 620-0010.

B. General Reading

1. Ahuja, Hira N., S. P. Dozzi, and S. M. AbouRizk. *Project Management: Techniques in Planning and Controlling Construction Projects, Second Edition.* John Wiley & Sons, Inc., 1994. 560 pp. $59.95.
2. Hoffmann, John J. and Alan P. Eddy. "The Building Envelope." Chapter 4 of *The Design, Operation, and Maintenance of Building Systems, Part I.* Building Owners and Managers Institute International, 1521 Ritchie Highway, Arnold, MD 21012.
3. Sohl, Duane, Bruce Kaskel, and Susan Greenwald. "Specifications Series: Glazed Metal Curtain Walls/Structural Performance." *Architectural Record.* May 1992, p. 38 (3).
4. *Water in Exterior Building Walls: Problems and Solutions. STP 1107.* Thomas, J. Schwartz, Editor. 1992. 240 pp. $47.00.
   To order: ASTM, 1916 Race Street, Philadelphia, PA 19103-1187, (215) 299-5585.

C. Construction Specifications Institute

1. Beall, Christine. "Selecting and Specifying Caulking and Sealants." *The Construction Specifier.* March 1990, p. 54.
2. Dworkin, Joseph F. "Evaluating Roofs Using Non-Destructive Methods." *The Construction Specifier.* November 1990, p. 82.
3. Grimm, Clayford, T. "The Hidden Flashing Fiasco." *The Construction Specifier.* June 1994, p. 134.
4. Quirouette, Rick. "Rain Penetration Control." *The Construction Specifier.* November 1994, p. 48.
5. Raeber, John A. "Roofing and Waterproofing Pre-Installation Conferences: Wishful Thinking?" *The Construction Specifier.* November 1989, p. 31.
6. Rogers, Tyler Stewart. "Is It A Leak, Or Is It Condensation?" *The Construction Specifier.* September 1966, p. 26.
   To order: $4 each from *Specifier Reprints,* 601 Madison Street, Alexandria, Virginia 22314-1791, (800) 689-2900

D. Past issues of Hoffmann Architects' JOURNAL

1. Accurso, Dominick, Jr., AIA, and Alan P. Eddy, CDT. "The Care and Preservation of Sealant Joints." Volume 12, Number 2, 1994.
2. Sanders, Arthur L. "Solving Glazed Brick Deterioration Problems." Volume 11, Number 1, 1993.
3. Kadlubowski, Richard P. "Avoiding Added Wear and Tear to Roofing." Volume 10, Number 2, 1992.
   To order a complimentary copy: call Brian W. Schafer or Emily D. Dowden at Hoffmann Architects, (203) 239-6660.

Compiled by Alan P. Eddy, Technical Information Specialist ■

REPRESENTATIVE PROJECTS

Building Envelope Rehabilitation

Hoffmann Architects specializes in the rehabilitation of existing facilities. A primary focus of the firm's work is on the diagnosis and resolution of building envelope problems, from roof leaks to curtain wall deterioration to foundation decay.

In helping clients resolve these problems, Hoffmann Architects investigates existing conditions, prepares construction documents to guide the work, and administers the construction contracts for all renovation and restoration services.

The firm's architects and engineers take a three-part approach to building envelope rehabilitation: identifying the root cause of deterioration, developing a comprehensive program for repair, and providing expert guidance and recommendations for long-term maintenance of the restored building. Each project is approached with an eye toward building life cycle costs and other budget issues, as well as the unique characteristics of the facility.

Hoffmann Architects has provided building envelope rehabilitation services to numerous corporate and institutional clients. Among these are the following:

North Point Office Complex
Cleveland, Ohio
(North Point Management/The Equitable)

Trinity College
Various buildings
Hartford, Connecticut
(Trinity College)

Pfizer, Inc.
Buildings 126 and 156
Groton, Connecticut
(Pfizer, Inc.)

General Electric Headquarters
Fairfield, Connecticut
(General Electric)

563 Eleventh Avenue
New York, New York
(NYNEX)

Southern Connecticut State University
Buley Library
New Haven, Connecticut
(State of Connecticut DPW)

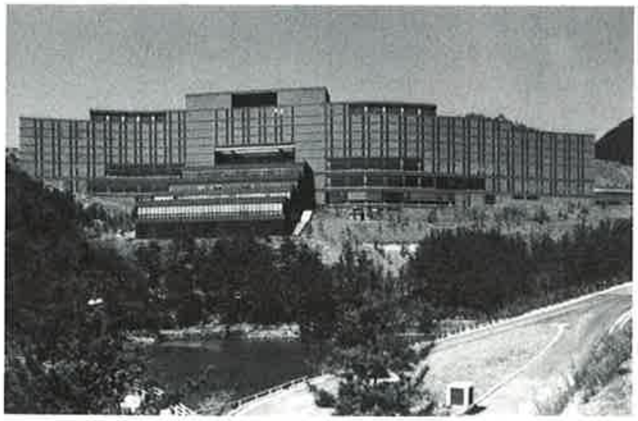
New London C.O. # 2
New London, Connecticut
(SNET)

Borough Hall
Staten Island, New York
(New York City, Department of General Services)

Rockefeller Center
Building # 7
New York, New York
(Rockefeller Center Management Corporation)

Sheraton University City
Philadelphia, Pennsylvania
(Met Life/Continental Companies)

Hunters Woods and Triangle Park
Reston, Virginia
(LaSalle Partners) ■



The Kyesongwon Training and Education Center in Chonan, Korea.

Homer D. Babbidge Library, University of Connecticut at Storrs.

Waterproofing Tips

The first step in making a wet building dry is to find out why the waterproofing system failed to begin with. The following three steps will help in that investigation:

1. Pinpoint the exact location of the interior leak. This is a relatively easy task for floor and wall leaks, but more difficult when it comes to ceiling leaks. For example, stains on suspended ceilings may not always be immediately under the leak. Instead, water might flow along a beam or joint for some distance before dripping onto the saturated ceiling area. Unfortunately, pinpointing the location of the interior leak doesn't guarantee that you've found the entry point. Water may enter the building at one location and travel laterally under the waterproofing before causing evidence of leakage at another location.

2. Review the original building plans and specifications for possible clues. What type of waterproofing system was used? Are there components that might be incompatible? Are there any questionable design details which may have interfered with good waterproofing practices? Are there problems in the expansion joints, or simply a lack of necessary expansion joints? Are drains properly located? This review can help establish a probable cause for the leakage and guide further actions.

3. Exploratory openings are required for a reliable understanding of the leakage problem. Results from steps 1 and 2 above will help in developing a plan for this investigation. In the case of underground leaks, excavation, removal of overburden, and inspection are required. Care should be taken during this investigative work. Under the best of conditions, it may be difficult to clearly ascertain the cause. If the source of water entry is not found, further excavation will be needed. ■

Courtesy of W.R. Grace and Company

JOURNAL is a publication of Hoffmann Architects, specialists in investigative and rehabilitative architecture/engineering, including the analysis and solution of problems within roofs, exterior walls, glazing, and structural systems of existing buildings, plazas, and parking garages.

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