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DESIGN OF MASONRY SUBSTRATES FOR EXTERIOR INSULATION AND FINISH SYSTEMS IN HOT-HUMID CLIMATES

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ABSTRACT

Exterior insulation and finish systems (EIFS) have found widespread use since they were introduced in the United States and Canada in 1969. To date, most residential EIFS applications have been surface barrier designs attached to wood framed structures. The United States' Council for Masonry Research sponsored a research study of the performance of residential EIFS applications in three locations with different climates: Houston, Texas, which has a hot-humid climate; Denver, Colorado, which has a temperate-dry climate; and Chicago, Illinois, which has a moderate-damp climate. A random analysis of applications was also performed on over thirty buildings in ten additional cities around the United States. The majority of the buildings inspected had enough water leakage past the EIFS to cause problems for their owners. Water leakage past the EIFS can cause rot or corrosion of structural components, and support mold growth in or on building materials. Historical experience from Europe, however, has shown that surface barrier EIFS perform better in certain applications when applied over properly designed masonry structures. This paper presents a summary of the research findings and offers suggestions for correctly designing masonry substrates for EIFS claddings in locations with hot-humid climates and high rainfall rates.

Keywords: claddings, exterior insulation and finish systems, EIFS, masonry wall design, water management, water leakage, hot-humid climates

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INTRODUCTION

Throughout the United States and Canada, moisture problems in buildings are a source of complaints and dissatisfaction of building performance by owners. Excess moisture in the wrong places on buildings can lead to serious structural damage. Recent discoveries of toxic species of mold which reside in or on building materials with a constant moisture supply, and their health effects, add to owners' problems. The design of walls to manage water leakage, especially that which gets into unwanted places, needs to be considered carefully.

In North America, exterior building walls generally consist of an exterior veneer or cladding that provides the weathering surface, a backup that provides the structural support for the cladding, and an interior finish applied to the back-up. Buildings from the 1800s and early 1900s had relatively massive exterior walls with multiple layers of thick absorptive materials separating the exterior surface from the interior finishes. The exterior façades were designed to promote drainage away from wall openings and the wall designs incorporated secondary waterproofing barriers of built-in flashings for long-term performance.

Recent trends in exterior wall design include the use of thin, lightweight, non-permeable, often brittle cladding materials or veneers with little or no separation between exterior surfaces and interior finishes. In many cases, especially when the wall is designed as a surface barrier design, secondary barriers and through-wall flashings are absent from the design and surface water flows freely over exposed joints, cracks and openings and finds its way into walls. As a result, the occurrence of problems from exterior wall leakage has increased. Rot of structural components in wood framed structures, corrosion of hidden metal wall components, and damage to interior finishes can occur within the first few years of service.

Since the mid-1980s studies of buildings clad with exterior insulation and finish systems (EIFS) have shown that the surface barrier designs can be problematic if they are not designed, installed and maintained properly (e.g. City of Vancouver, British Columbia, Canada 1992). The experience in Europe, however, has been that EIFS-clad masonry walls can be designed to resist the problems caused by unmanaged water inside the wall systems (European Union of Agreement, 1988). This paper will describe the results of investigations of water leakage past EIFS claddings on wood– and light gauge steel-framed structures in the United States, and will introduce the principles of proper wall design where masonry is used as the substrate to an EIFS cladding.

APPROACHES TO EXTERIOR WALL DESIGN

S. S. Ruggiero and J. C. Myers (1991) suggest that one approach to designing exterior walls for good rain water management is to shield the walls from the rain by using elements such as cornices, wide overhangs, sloped belt courses and other similar features. However, as building heights increase past one story these elements fail to shield the walls from rain and so the wall systems must be waterproofed in other ways.

Wall designs generally follow one of two primary paths. J. F. Straube and E. F. P. Burnett (1998) have classified walls as having either a perfect barrier (often referred to as a face sealed or surface barrier), or an imperfect barrier (e.g. mass walls and screened walls) (p. 74). Wall design approaches can be categorized as follows:

1. The perfect surface barrier design
2. Imperfect barrier designs
   a. The drainage plane design (sometimes called the *vented* design)
   b. The drainage plane design incorporating the rain screen principle (sometimes called a *pressure-equalized* or *ventilated design*)
   c. The mass storage design

The surface barrier design and the two drainage plane designs of the imperfect barrier approach are common to the U.S. and Canadian building industries. The fourth approach, the mass storage design, is used primarily in Europe.

In the United States, the two most prevalent exterior wall finishes that incorporate the surface barrier design are wood sidings (including hardboard and fiber-cement board sidings), and exterior insulation and finish systems (EIFS). The primary design criteria for a surface barrier wall is that water must not be allowed to get behind the exterior materials of the surface barrier design (Iano 1991). With this approach, the goal for the building envelope, including all the openings in it for doors, windows, piping, wiring etc. is that it be sealed to a watertight condition and kept that way for the life of the building. For illustrative purposes, Figure 1 shows the components of the perfect surface barrier type of exterior insulation and finish system.

The drainage plane design consists of a moisture barrier such as felt paper which is applied behind the cladding. Wood and hardboard sidings with shiplaps almost always include a drainage plane behind them, especially in the hot-humid climates, for redundancy in case water leakage occurs in the outer cladding of the envelope. Even with the drainage plane for redundancy, every effort is made with laps, sealants, and flashing pieces to keep water on the outside of the structural components of the wall. This is a good system for wood or hardboard siding because every effort should be made to keep water from getting behind these materials. Wood and wood-based cladding materials are hygroscopic (porous and contain cellulose) and will deteriorate from the fungi supported by constant sources of moisture.

Most EIFS manufacturers now offer their products with drainage planes. Figure 2 shows an EIFS design incorporating a drainage plane.

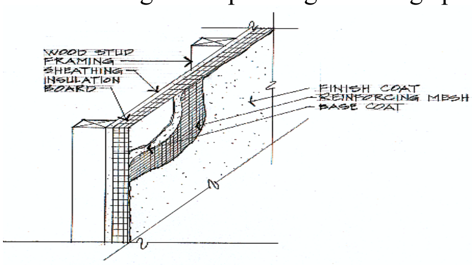

Figure 1. Components of a Surface Barrier

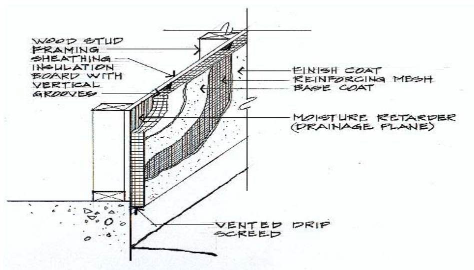

Figure 2. Drainage Plane Design EIFS

Wall Incorporating EIFS

The third type of system is a drainage plane design incorporating the rain screen principle. These are sometime called pressure-equalized or ventilated designs. There are three predominant features of walls that incorporate the rain screen principle. These systems have the exterior face (the rain screen); the pressure-equalized cavity, and a waterproof air barrier system. The rain screen is the first line of defense in the wall cladding for keeping water out of the building. However, the operational assumption in designing this type of wall is acknowledgement that minute amounts of water will get past the rain screen

The pressure-equalized cavity, a component of the rain screen system, is responsible for the ventilation necessary to balance the wind-induced pressure differentials between the outside of the rain screen and the interior components of the wall system. This "shock absorber" mechanism helps to reduce the potential for wind-driven rain to enter the wall behind the outer cladding by releasing air at the top and bottom of the walls. Rainwater that gets past the rain screen drops out of the air in the cavity. The cavity, with the aid of a waterproof barrier and flashing, directs any water leakage back to the exterior of the building.

The waterproof barrier system (drainage plane) provides the redundancy necessary to keep any air and water leakage that may occur from entering the interior of the wall. Drainage plane designs incorporating the rain screen principle have been provided in commercial construction in the United States for a number of years, but recent research in Canada has brought it to the foreground as a redundant system for EIFS installations on residential and commercial building construction (Canadian Home Builders Association 1997; Day 1994). Figure 3 shows the drainage plane design EIFS incorporating the rain screen principle.

One way of distinguishing the two drainage plane designs is that the drainage plane design is vented at the bottom of the wall to allow gravity discharge of water leakage back to the exterior. On the drainage plane design with a rain screen, the cavity is ventilated at the top and bottom of the wall

The fourth system is what is referred to as the mass storage wall. The mass storage system used in Europe incorporates a perfect surface barrier design EIFS cladding on masonry or concrete substrates instead of the gypsum board, plywood, or oriented strand board substrates of the surface barrier design in the United States.

In mass storage wall systems, it is expected that water will get past the surface coatings, but that such moisture will be in minute quantities that can be stored by absorption in the concrete or masonry substrates, which are usually quite thick (200 – 300 mm, or 8" – 12" is common). This water will have time to evaporate back to the exterior, or, from gravitational forces, will drain towards the base of the wall and be diverted to the exterior with the use of flashings and weeps.

Because the masonry and concrete substrates are non-deleterious in nature the presence of limited quantities of moisture in them normally does not support growth of rot-inducing fungi or attract destructive insects such as termites or carpenter ants as readily as it does in wood. Freeze-thaw and other problems may occur, but experience has shown that the water storage capacity of these wall systems helps to alleviate the problems that occur when water leaks into walls framed with wood or light gauge steel materials. Figure 4 shows the components of a mass storage wall design.

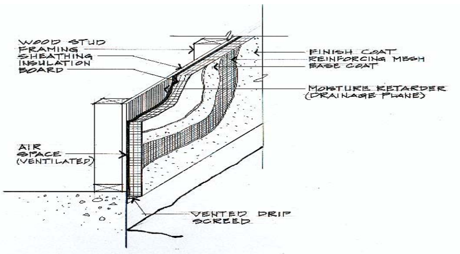

Figure 3. Drainage Plane Design EIFS with a Rain Screen

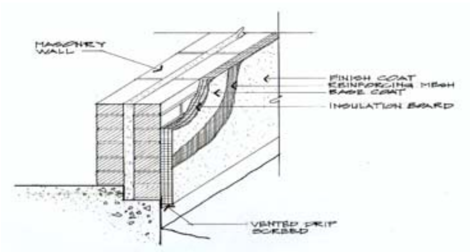

Figure 4. Mass Storage Wall Design EIFS with Masonry Substrate

FINDINGS FROM FIELD INVESTIGATIONS

The Review of the Literature

The goal of this research was to find the causes of water-related damage to building envelopes in the United States. An extensive review of the literature on moisture problems in building envelopes was conducted to see what the knowledge base was about the causes of and solutions to problems caused by moisture penetration in buildings. The literature review included analyses of works from laboratory-based research projects and field investigations in the United States, Canada, and a number of countries in Western Europe. Contacts were made with laboratories in these areas to see what kinds of moisture research were underway in the institutions of higher learning, or in government and industry laboratories.

Field Inspections

The buildings inspected in the study were located in states bordering the Gulf of Mexico and the Atlantic seaboard. Approximately 4,000 buildings were inspected in North Carolina, South Carolina, Georgia, Florida, Alabama, Mississippi, Louisiana and Texas during the period of 1995-99. Buildings were also inspected in Tennessee and Kentucky, areas with climates that closely resemble the Gulf states because of their high rainfall rates and temperate climates. Most of these buildings were inspected in support of research or investigations in support of litigation involving hard board siding, EIFS, brick or other cladding materials.

The Council for Masonry Research, made up of representatives of the masonry industry in the United States, also funded a controlled study of buildings in Houston, Texas; Denver, Colorado; and Chicago, Illinois (Graham 1999). Five single-family properties in the Houston, Texas area and one home in the Plano, Texas area were inspected during the summer of 1997. Three houses and a church were inspected in Denver, Colorado. Eight houses were inspected in Chicago, Illinois.

A detailed sampling procedure following the recommendations included in a report entitled "Moisture Assessment Guidelines," by the NAHB Research Center (1996) and modified by the author (Graham 1997), was used on the home inspections in Texas. In these inspections, areas known to be leak-prone with EIFS claddings from the NAHB Research Center studies in Wilmington, North Carolina, were tested, as well as at least ten statistically random locations on each building

In addition to the detailed home inspections in Texas, during the same period approximately 30 buildings, including commercial office buildings, hotels and shopping centers, were surveyed in the following cities which are located in states with hot-humid climates: Mobile, Alabama; Orlando, Florida; Pensacola, Florida; Austin, Texas; San Antonio, Texas; Gulfport, Mississippi; and, Washington, DC. Inspections of these commercial buildings did not utilize the destructive testing procedures recommended by the NAHB Research Center. Instead, they were performed with field observations and photographic recordings.

Data Analysis

The research plan was to compare the data from all of the sources to see if there was a chain of evidence that would be consistent with the proposition that damage to building materials in the building envelopes inspected, either in this research or by others, was caused by water infiltration. Robert Yin (1984) has discussed the use of a case study research methodology where the investigator wants to know the "who," "what," "where," "how" and "why" about a situation. The case study research methodology is also appropriate when the investigator has no way of applying an experimental treatment to subjects or when the research cannot be conducted in the controlled environment of a laboratory. The investigator's goal is to use the widest possible range of sources of information to see if a pattern of evidence exists. This comparison of findings from different sources of information establishes the chain of evidence that Robert K. Yin (1984, 80) says is necessary to draw conclusions back to the original hypotheses or propositions.

Findings of Field Investigations

Joseph Iano (1991) has noted that "A prudent assumption is that a wall will always admit some water, and many assemblies are designed to capture moisture and redirect it back to the outside" p. 18). Kevin Day (1994), an executive with one of the EIFS manufacturers in Canada, has acknowledged that "…water infiltration into an exterior cladding is inevitable. Hence, a means of drainage must be provided, and more importantly, the venting to allow this drainage must be designed to balance the pressure between the interior and exterior of the wall assembly" (p. 34).

The chain of evidence found in this study supports the proposition that surface barrier wall designs without drainage planes behind their outer claddings have a high probability of allowing leakage to damage structural components behind the claddings in hot-humid climates. While an extensive review of the failure mechanisms will not be provided here, two examples from the field investigations will serve to demonstrate the value of drainage planes behind claddings.

Figure 5 shows what happens when water gets past the rain screen of a surface barrier design wall cladding that does not have a drainage plane behind it. In this case, a surface barrier EIFS is shown. Water that got behind the insulation boards was absorbed in the oriented strand board wall sheathing and after only 18 months rotted the sheathing. This level of decay can greatly reduce the structural capacity of structural framing and sheathing if widespread.

Figure 6 illustrates what happens when another type of surface barrier cladding, in this case, hard board lapped siding, gets water behind it at the lower corners of a window, a common leak location. Thirty pound felt paper was installed behind the siding and although the siding itself rotted, the rot did not advance into the structural sheathing and framing behind it because the moisture barrier blocked its penetration into the wall system. This is a surface barrier design cladding system with a redundant drainage plane behind it.

Figure 5. Water Damage Behind Surface Barrier EIFS without a Drainage Plane

Figure 6. Water Damaged Hard Board Siding

WALL DESIGN RECOMMENDATIONS FOR EIFS ON MASONRY SUBSTRATES

Basic Principles

A number of basic principles must be followed when designing walls with masonry substrates and EIFS claddings. In short, the masonry wall should be designed as if some moisture will get past the outer surfaces of the cladding and so a water management system in the masonry substrate must be in place.

R. L. Quirouette and J. Rousseau (1998) have noted that there are three means by which water can penetrate masonry. These are: direct, gravity, and capillarity. All three means of penetration must be addressed in the wall's design. J. F. Straube and E. F. P. Burnett (1998) have described the characteristics of water penetration in masonry. Direct water entry occurs during rainfall and is aided by wind pressure. Gravity water penetration results from hydrostatic pressure that forces water, drawn and trapped in cracks and voids in the masonry, to flow back out of the material at a lower point in elevation. The water usually follows cracks to a point of exit. Capillary action is a function of water penetration caused by suction forces in the masonry materials.

D. Sauve et al. (1999) describe the influence mortar quality, both in terms of mix design and application to the masonry, can have on water penetration. Less porous mortar and good workmanship at application result in less water penetration potential. L. R. Baker and F. W. Heintjes (1990) have described how the permeance of the masonry materials can effect resistance to water penetration. C. T. Grimm (cited in Borchelt 1982) had conducted an earlier review of the literature on water permeance in masonry walls. Baker and Heintjes (1990) found that there is a relationship between moisture penetration time and the monthly Driving Rain Index and that satisfactory performance of masonry walls must take these into account. Water repellant admixtures in the original manufacturing of the masonry units, or applied in the field, may also affect the water penetration characteristics of the masonry (e.g. see Sauve, D. et al. 1999; Salonvarra, M. H., Karagiozis, A. N. 1998). Changes in the physical shape of the masonry units, such as the addition of grooved webs and beveled edges of face shells, also effect the water penetration performance of masonry (op cit. 1999).

The designer must also remember to account for thermal and moisture-induced movements in the masonry. In the hot-humid climates, experience has shown that concrete masonry units will shrink when placed in service, while fired clay brick or tile units will expand. The addition of heat or moisture at any time during service will cause the units to expand. Lowering the temperature or reducing the moisture in causes masonry to shrink. Expansion and shrinkage occurs in all three directions of the axes – x, y, and z – of the masonry units. Movement control joints must therefore be placed in the appropriate locations to relieve the stresses in the masonry induced by these physical changes. If they are not provided, both the masonry substrates and the claddings adhered to them will be damaged.

Wall Design Considerations for the Masonry Substrates

C. T. Grimm (1982, cited in Borchelt 1982) has said that there are six approaches to masonry wall design that resist water penetration. These are:

1. Masonry cavity walls with a net air space of at least 50 mm (2”);
2. Single wythe walls, 200 mm (8”) thick, of hollow concrete masonry units, hollow brick, or vertical cell or divided bed horizontal cell structural clay tile, each layed with only mortar face shell bedding with an exterior coating of stucco and paint or with an exterior coating of stucco or paint and interior furring;
3. Solidly grouted single wythe walls, 150 mm (6”) thick, having a solidly grouted core at least 50 mm (2”) in width;
4. Masonry wythe veneer, 150 mm (3”) thick, over concrete or water-resistant sheathing and studs of sufficient rigidity to prevent flexural cracking of the veneer, with a minimum of 50 mm (2”) wide cavity between veneer and sheathing; or,
5. Composite masonry walls, 175 mm (7”) thick, having a brick exterior wythe and a

hollow masonry unit interior wythe, with the interior vertical longitudinal (collar) joint solidly filled with mortar or grout with a 10 mm (3/8") parging (p. 175).

The masonry wall should incorporate through-wall flashing at the heads and sills of wall openings (Ruggiero, S. S., Myers, J. C. 1991). This is essential to the successful waterproofing of walls. Ruggiero and Myers also note (p. 31) that a slight outward slope should be provided on all horizontal elements projecting out from the wall to prompt drainage off the wall.

Figure 7 shows how a typical wall section for an EIFS-clad wall over a masonry substrate would be detailed. Note that as per P.E. Nelson and M. E. Waltz's (1996) recommendations, through-wall flashings are provided in a number of key locations in the wall system. At the base of the wall flashing is provided to minimize the potential for rising damp and to divert water leakage to the exterior. This barrier could be either physical flashing as shown or a chemical barrier as described by A. Oliver (1988). Through-wall flashings are provided at locations above and below window openings, and at the coping at the top of the wall. Horizontal projections have outward slopes of at least 22.5^o to be consistent with the EIFS manufacturers' recommendations. Most masonry institutes recommend slopes of at least 15^o on masonry projections. The polystyrene insulation boards for the EIFS adhered on the outside of the wall will inhibit evaporation of water penetration that gets past the surface barrier so the design must allow for evaporation to the interior. Paint coatings or other finishes on the interior of the wall must not block moisture vapor from passing through them. Interior finishes must have a high vaporization potential. Movement joints, though not shown in the figure, must be installed according to good design practices for the materials used.

Design of the EIFS cladding must follow the manufacturer's requirements precisely and must incorporate good design and application practices for the use and location of the facility. Again, the proposed wall design is for a hot-humid climate with heavy rainfall rates. As noted on the drawing, a preferred design would incorporate a drainage plane.

CONCLUSIONS

The EIFS-clad masonry wall, based on European experience, might find acceptable usage in certain locations in the United States and Canada. The professional opinion of the author, after having looked at many water penetration problems on buildings, is that this combination has certain limitations. The EIF systems are prone to impact damage in high pedestrian and vehicle traffic areas and so heavier reinforcing meshes and heavier coatings should be used in these locations. There is evidence in Florida that EIFS do not perform as well as other cladding materials during hurricanes and high wind storms. A knowledgeable structural engineer needs to design the system used to fasten the EIFS to the substrates to resist the pull-off forces and potential impact damage during storms.

In very high rainfall areas along the Texas Gulf Coast and Atlantic Seaboard water leakage through the perfect surface barrier could be more than the redundant components of the masonry substrate can properly manage. In other words, leakage through cracks in the cladding could be faster than the flashings and evaporative effects can overcome. The result will be high levels of moisture saturation of the masonry upon which fungi might be able to grow. In coastal locations, leakage of salt water through openings in the outer cladding could contribute to rapid corrosion of metals in the masonry, or attached to it. Once again, preference in these locations would be to utilize a drainage plane behind the EIFS for redundancy.

As with any building design, professional judgment will be necessary when making materials selections and designing wall systems. Experts who are knowledgeable of masonry and exterior insulation and finish systems in hot-humid climates with high rainfall rates should be consulted.

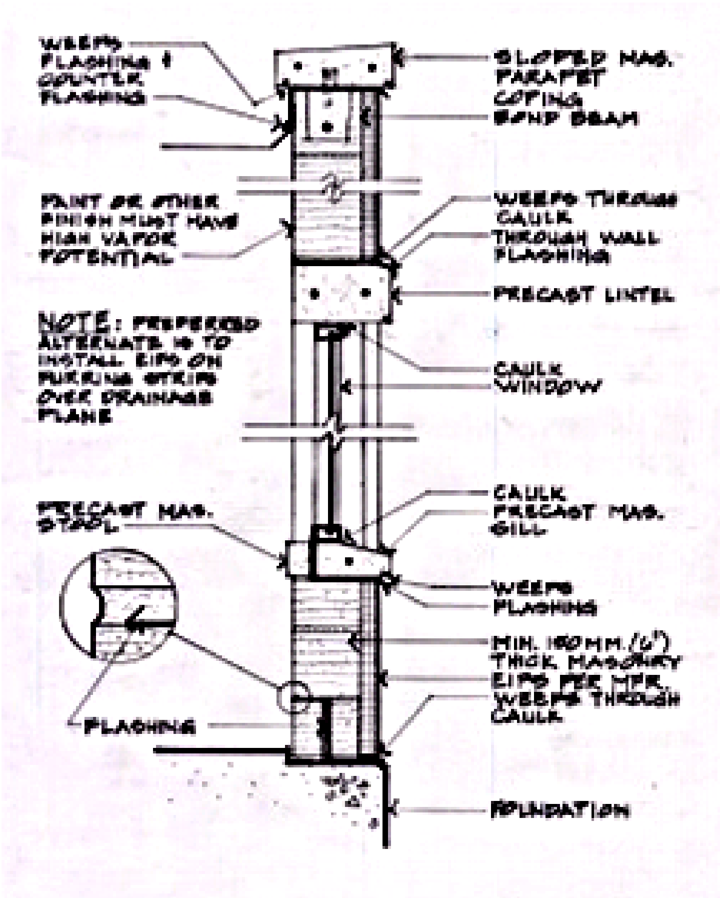

Figure 7. Wall Section Showing EIFS Cladding on a Masonry Substrate

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