THE EFFECTS AND CONTROL OF MOISTURE IN CERAMIC TILE FACADES

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SUMMARY

The purpose of this paper is to examine the common problem of moisture penetration in exterior ceramic tile facades.

Considerable controversy has surrounded the use of ceramic tile on facades, owing mostly to a lack of care in the design and construction to prevent water penetration, and subsequent deterioration and failure.

INTRODUCTION

For centuries, ceramic tile has been used to decorate and clad exterior walls of structures and buildings. Traditionally, exterior walls have provided structural support to a building as well as enclosure of the building. To serve as structural support, these walls were generally massive, providing a natural barrier to water penetration.

Ceramic tile cladding was simply decorative, allowing moisture to pass through the tile joints and also the tile itself, to be absorbed and dissipated in the massive underlying support walls, without significant deteriorating effects. Known as the «barrier wall» approach, this method of preventing moisture penetration is still in use today, but it is unreliable and not a recommended approach (figure 1).

Today, modern steel and concrete skeletal framing systems provide structural support for most buildings. As a result, thin, lightweight ceramic tile facade systems have evolved solely as enclosure of buildings (figure 2).

This relatively new application for ceramic tiles has given rise to new design considerations and construction technologies for prevention of moisture penetration which rely on methods for resisting, collecting, and discharging moisture, rather than on the absorptive properties of a massive wall.

TYPES OF CERAMIC TILE FACADE SYSTEMS

There are several types of thin ceramic tile facade systems being used today. The most popular employ the direct adhesive method of installation, where ceramic tiles are fully adhered to a variety of relatively thin underlying walls or substrates. Typical substrates may be concrete, concrete or clay masonry, or steel framing with a cementitious backer board or plaster finish. These substrates, together with the application of the ceramic tile, may be either constructed in-place (figure 3) , or prefabricated in sections, lifted in place, and connected to the building structure (figure 4) . In these systems, the ceramic tiles are typically fully adhered, with the back of the tile, and joints between, filled with a latex modified portland cement mortar and grout.

Another type of ceramic tile facade system is known as the ventilated method of installation , where the ceramic tiles are either mechanically fastened to an underlying substrate by concealed or exposed ceramic/stainless steel anchors attached to the tile (figure 5), or adhesively fastened with structural silicone adhesives to a steel substrate. In these systems, the joints between the ceramic tile, as well as the majority of the tile back surface, are left open, allowing unrestricted movement of moisture and air (figure 6).

While there are substantial differences between these systems and the methods they employ to prevent moisture penetration, they are all viable when properly designed and constructed.

CAUSES AND EFFECTS OF MOISTURE PENETRATION

Moisture penetration in ceramic tile facade systems can cause serious problems, not all of them confined to the ceramic tile itself. In addition, to familiar effects like efflorescence, freeze-thaw damage, and deterioration of interior finishes and building contents, trapped moisture can cause more subtle, but equally serious problems, such as long term expansion of substrates or condensation within the wall system.

Moisture can enter a ceramic tile facade through cracks in the grout joints between ceramic tiles, or directly through the face of an improperly selected porous ceramic tile. It can also penetrate around improperly designed or constructed coping and roof flashings, and at flashings and sealant joints at wall openings (windows, doors) and expansion joints. In addition, wind driven rain can pass through both clear coatings and the ceramic tile itself, moisture can rise up from the foundation, and moist air can condense in interstitial spaces (figure 7). In effect, moisture problems are ubiquitous; moisture can be controlled but not eliminated.

Even the most carefully designed and constructed system will have trouble preventing moisture penetration and subsequent deterioration without the proper ceramic tile selection. Technological advances in the ceramic tile industry have produced extremely low absorption vitreous ceramic tiles in large sizes with high flexural strength. The low absorption not only prevents water leakage through the tile, but also allows the tile to resist deterioration from freeze/thaw cycles, efflorescence, and long term wetting/drying cycles. The high flexural strength allows larger tile sizes such as 60 x 60 cm (24 x 24 inches) (figure 8) to resist cracking from wind loading and thermal stresses. The larger formats also make installations more economical and aesthetically pleasing.

Cracked grout joints are a primary cause of moisture penetration. Cracking, and subsequent moisture penetration, can occur as a result of 1) structural inadequacy of the substrate and /or underlying support structure to resist wind pressure (live load) and weight of the wall system (dead load), 2) lack of accommodation of thermal movement in both the structural frame and the ceramic tile cladding, 3) improper selection, mixing, or installation of grout material.

Leakage problems in ceramic tile facades have historically been blamed on cracked or porous ceramic tile or grout joints. However, it is unusual for leakage to be attributed solely to this cause; defects in facade configuration, flas hings, waterproofing (or lack thereof) and sealant joints, as well as the use of clear coatings, present more serious problems.

Once moisture is allowed to enter a ceramic tile facade system, there are numerous problems which can result, ranging from minor maintenance problems to deterioration and failure of the entire wall system.

Efflorescence (figure 9) is the most common effect of moisture penetration in ceramic tile facades, and it is typically a maintenance nuisance, with no serious consequences. Efflorescence is caused when water penetrates portland cement grout, mortar and cementitious substrates and dissolves soluble salts which are a natural by-product of cement hydration, or present by contamination by other sources such as salt water sand. These dissolved salts migrate back to the surface of the ceramic tile facade by capillary action and react with carbon dioxide in the air to form calcium carbonate, a whitish residue that does not dissolve in water. Some initial post-installation efflorescence is normal, and can be effectively removed without consequence; however, constant exposure of the ceramic tile facade system to moisture penetration will cause recurrence of efflorescence, leading to significant maintenance costs, or gross, unsightly accumulation of residue.

Latex Leaching (figure 10) is a problem closely associated with efflorescence, resulting in a whitish, rubbery residue on the face of the ceramic tile facade which is installed with a latex modified portland cement mortar or grout. In many cases efflorescence is mistaken as latex leaching; this is a common misconception in the tile industry. Latex and acrylic admixtures designed for exterior use can not re-emulsify and leach once cured.

However, exposure to copious amounts of water while the mortar or grout is still fresh prior to initial set can cause this problem. The potential for this problem is greater during cold, damp weather, which will further retard the set of latex modified mortars, requiring additional protection of the ceramic tile facade from water exposure.

Cryptoflorescence (figure 11) is a little known problem in ceramic tile facades constructed with porous ceramic tiles, especially in those facades treated with clear, silicone water repellent coatings. Similar to efflorescence, dissolved salts get trapped below the surface of the tile or grout joint by silicone water repellent coatings, while carbon dioxide and evaporating water transpire through the «breathable» coating, allowing salt crystals to form internally. The formation of salt crystals exerts even higher pressure than the formation of ice crystals, resulting in cracked or spalled ceramic tile and grout joints, or even delamination of the ceramic tile from the substrate. Ironically, if a ceramic tile is properly selected and installed, clear silicone based water repellent coatings are not necessary.

Freeze/thaw damage (figure 12) can occur to a ceramic tile facade when the ceramic tile, grout, or bonding mortar absorption rate is greater than 10% by weight. Internal pressures caused by the formation of ice crystals can result in cracking, spalling, bulging or complete failure of the ceramic tile.

Permanent moisture expansion (figure 13) of ceramic tiles, mortars, and substrates can result from long term exposure to moisture. Clay ceramic tiles, concrete, concrete masonry, and portland cement mortar expand and contract with wetting and drying cycles. Most of this movement is reversible and not sufficient to damage the ceramic tile or bond of the ceramic tile to the substrate. However, frequent wetting or continuous soaking can cause permanent expansion of these materials. Consequently, the wetting cycles of a ceramic tile clad concrete wall may cause some of the wall components to expand permanently. This permanent expansion could produce tensile stresses between the concrete wall and the ceramic tile mortar, leading to bond failure. It is important to note however, that these tensile stresses are typically not sufficient enough to cause problems with a low modulus type mortar such as latex portland cement adhesive mortar. These mortars have a low modulus of elasticity which make them flexible and able to accommodate, rather than resist, the permanent expansion of concrete walls, mortars and ceramic tiles.

Corrosion (figure 14) of metal structural supports and anchors for ceramic tile facade systems is a common problem. While specification of stainless steel components is recommended, it is not always economically feasible or readily available. Alternate use of galvanized coatings over steel is an acceptable alternative, but inevitable damage to protective coatings during construction can expose steel to corrosion and possible failure.

Condensation (figure 15) of moisture vapor within interstitial spaces of a ceramic tile facade is an often ignored consequence of an improperly designed and constructed system. In warm climates, moist exterior air can condense in interstitial spaces of air-conditioned buildings, and in cold climates, moist interior air of heated buildings can also condense. Condensation can lead to mold growth, noxious odors, and deterioration of building finishes. Of even more significance though, is that the movement of moisture vapor through the wall, and its restriction at inappropriate locations, can cause vapor pressure accumulation and result in deterioration and delamination of waterproof membranes, grout joints, sealant joints, or the ceramic tile itself.

Deterioration (figure 16) of interior building finishes and building contents is the most obvious consequence of moisture penetration, and perhaps the most fundamental concern, along with safety of occupants. Because this problem does not directly affect the performance of ceramic tile facades, it will not be examined in detail.

CONCEPTS OF MOISTURE MOVEMENT

Before examining recommended methods for controlling moisture penetration, it is helpful to have a conceptual understanding of the dynamics of moisture movement through building materials.

The first concern is the source of moisture, some of which are not obvious. Sources of moisture are as follows:

External - Rain or Snow

1. Accumulates on horizontal surfaces (roofs, balconies) or at ground level
2. Striking vertical wall surfaces
3. Seeping into ground - temporarily trapped
4. Seeping into ground - permanently contained

Internal/External

1. Moisture vapor condensation
2. Building Systems (Leaking pipes)

There are basically four types of forces that can cause moisture to penetrate and move through building materials. They are as follows (figure 17):

Gravity
Capillary Action
Kinetic Energy
Air and Vapor Pressure Differentials

Gravity will allow water to penetrate any opening that slopes downward to the interior of the wall system. Capillary action can draw water through small cracks in grout joints or through the microscopic pores of grout or the ceramic tile itself. Kinetic energy refers primarily to wind driven rain forced through openings in the ceramic tile facade. An even greater, and often misunderstood force, is air pressure differential between the wet side and opposite dry side of the ceramic tile facade.

CONCEPTS OF MOISTURE CONTROL

There are two basic approaches to controlling moisture penetration in thin, lightweight ceramic tile facades:

-eliminating openings
-controlling the forces (described above) acting on the openings

Both of these approaches are used in variou combinations depending on the type of ceramic tile facade system being considere.

The first method of moisture prevention, and probably the least successful, is sometime referred to as the «face-seal» approach. This method involves the elimination of openings by use of as many low or non-porous components as possible, such as a porcelain tile, epoxy grout joints sealant/caulk joints at all openings and intersections, and even water repellent coatings in an attempt to provide a complete barrier to moisture at the face of ceramic tile facade.

While this method is an important component to resisting water penetration, it can not, and should not be relied upon as the only barrier to water or moisture. Structural movement, thermal cycling (expansion/contraction), and normal porosity of materials will eventually allow some moisture penetration to be forced into the system by the four forces described earlier. Water will penetrate unless effort is made to control the forces transporting water through the facade.

The most effective approach in preventing moisture penetration then, is to combine the control of forces that cause water leakage, together with the «face-seal» method of eliminating openings in the facade system. This approach involves designing and constructing joints and other facade elements to accommodate, rather than resist the four mechanisms of gravity, capillary action, kinetic forces, and air-vapor pressure differences.

The first and most fundamental step in controlling the forces that propel moisture or water is to control rain water that flows down the facade of a building. In order to minimize water on the face of a building, the facade must have properly designed facade features such as drips and flashings at all door/window openings, underlying waterproof membranes, copings, roof parapets , ledges, and balconies (figure 18). Sound architectural design and engineering practices still play the most significant role in preventing moisture problems in a ceramic tile facade system.

As a result, gravity can be controlled simply by sloping all openings in a ceramic tile facade to the outside so that water runs out of instead of into the facade envelope.

Capillary action can be minimized by proper ceramic tile selection described earlier, and careful design and installation of joint filling materials in direct adhesive ceramic tile facade systems. Latex modified portland cement grout is the optimum joint filler for use in ceramic tile facades. This material, when properly installed, produces a dense, watertight joint (less than 4-5% absorption). Most important though, this joint filler allows the joint to transpire any trapped moisture. This material also has superior bonding strength to the ceramic tile edges and flexibility to withstand thermal expansion/contraction and wind loading movement typical of thin, lightweight ceramic tile facades. These attributes control movement of water by capillary action either through the pores or between hairline cracks in the grout. Capillary action of moisture is also a concern in ceramic tile facades which terminate at or below ground level. Trapped or temporarily trapped ground moisture can rise up by capillary action from building foundations to the ceramic tile facade system.

Studies have shown that the kinetic energy of wind-driven rain at 28.6 mps (64 mph) can penetrate virtually any water repellent coating or latex modified cement grout. Water must be stopped by an underlying waterproof membrane and be allowed to discharge or transpire back through the grout joint in a direct adhesive ceramic facade system. In a ventilated type ceramic tile facade system, water is allowed to drain freely down the back of the ceramic tiles, collected by proper flashings, and diverted back to the exterior by weep holes or other drainage channels.

Air pressure differences across the ceramic tile facade system can be controlled by designing openings into the facade such that the cavity behind the facade is equalized to outside surface pressure. This is commonly referred to as a pressure-equalized rain screen, and has been used successfully for many years in other types of thin, lightweight facade or curtain wall systems. (figure 19).

The ventilated type of ceramic tile facade system relies primarily on the pressure equalized rain screen approach to prevent moisture penetration (figure 20). Certain types of direct adhesive ceramic tile facades such as a ceramic tiled pre-cast concrete panels can also employ this method of water control. Air pressure differentials are caused by the flow of wind over the exterior of a building, or simply by the operation of a heating, ventilating and air conditioning systems inside a building. Air pressure differentials can literally suction significant amounts of water through tiny pores, cracks and openings in a ceramic tile facade.

PRACTICAL RECOMMENDATIONS FOR DIAGNOSIS AND REMEDY OF MOISTURE PROBLEMS

Efflorescence can be minimized primarily by use of low absorption, vitreous ceramic tiles, quality controlled mortar/grout powders and liquid additives, and carefully prepared and uncontaminated substrates. It is also recommended to avoid use of clear silicone base coatings which can trap moisture and soluble salts, and avoid use of acid based cleaning products, whose unrinsed residue can contribute to efflorescence. Most important, though, is reducing and controlling the degree and frequency of water exposure.

Latex Leaching can be prevented by proper specification of latex/acrylic admixtures designed for exterior use, and strict compliance with protection from water exposure during curing. Factors to consider are the specific setting/curing characteristics of different latex / acrylics under different temperature and humidity conditions, as well as the size and porosity of the ceramic tile which can further retard the cure of latex modified bonding mortars.

Cryptoflorescent deterioration can be eliminated by avoiding use of clear silicone based coatings. These coatings trap or retard drying of moisture and soluble salts, thus promoting localized accumulation and crystallization and possibly causing spalling of the ceramic tile and grout joints.

Waterproof membranes are a critical component of both the direct adhesive and ventilated types of ceramic tile facades. Both of these systems require membranes which can resist, collect, and discharge water back to the surface, but most important, these membranes must be permeable to moisture vapor to prevent condensation within interstitial spaces, as well as allow transpiration and drying of trapped moisture from other sources.

Durable through-wall flashings must be provided at each floor level and at the heads and sills of all wall openings. Similarly, proper design and execution of flashings at roof-wall intersections and parapets/ copings are critical to the prevention of moisture penetration. Recommended types of flashing are stainless steel and lead-coated cooper. Flashings constructed of metal pans joined to rubber or copper fabric flashing can also be used. Flashings should terminate outside the outer face of the wall in a drip edge configuration. Thin, unreinforced PVC flashings are not recommended; they tear and puncture easily, can not be formed to provide a drip edge, and can become brittle.

Sealants can be effective in resisting water movement through expansion joints or in joints adjacent to dissimilar materials such as metal window frames. It is imperative that sealants be properly specified for the type of application. Sealant joints and tile edges must be properly cleaned, primed, prepared with foam backer rods and tooled to allow proper adhesive and movement characteristics of the sealant.

Weep holes and other types of drainage channels are only effective in allowing discharge of collected water in systems which provide a drainage cavity. Weep holes should be located directly above flashings, and be spaced a maximum of 60 cm (24 inches) on center. The most important type of weep holes are open joints, louvered vents, rope, wicks, tubes, and cellular vents.

Condensation problems can be particularly acute in ceramic tile facade systems employing steel suds, screws and anchorage systems. Vapor transmission and air leakage can be controlled by use of vapor barriers and air barriers, as well as use of vapor permeable grouts, mortars, waterproof membranes. Impermeable epoxy or sealant joint fillers are not recommended because they can trap moisture and cause deterioration by condensation or vapor pressure build-up.

CONCLUSION

Every ceramic tile facade system requires a unique approach to the control and remedy of the effects of moisture penetration. An understanding of the concepts of moisture movement and control, together with a logical application of sound architectural and engineering principles, will result in a beautiful, problem and maintenance-free ceramic tile facade.

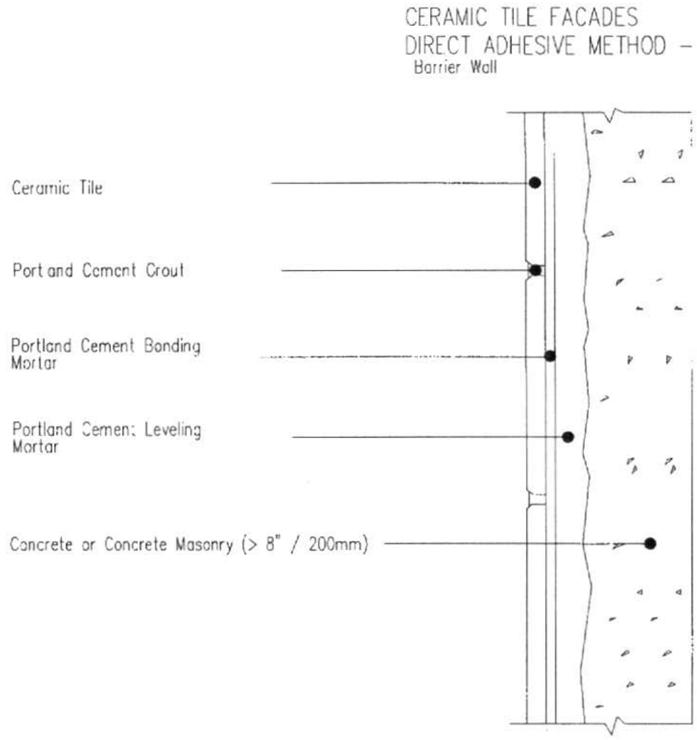

FIGURE 1 DIRECT ADHESIVE METHOD (Barrier Wall)

FIGURE 2 SKELETAL STRUCTURAL FRAMING SYSTEM

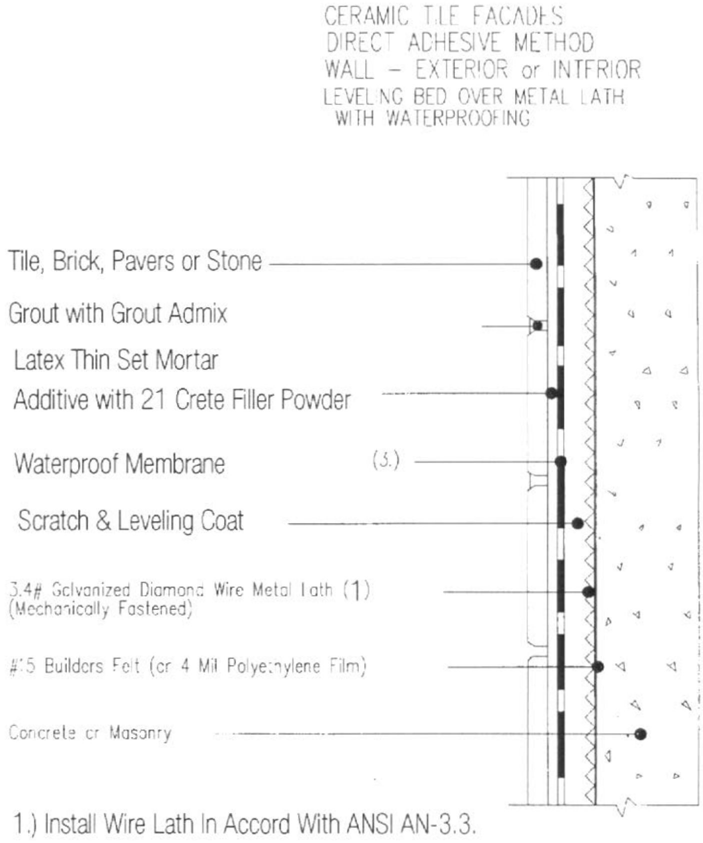

FIGURE 3 DIRECT ADHESIVE METHOD (In-place construction)

FIGURE 4a DIRECT ADHESIVE METHOD (Pre-fabricated panels)

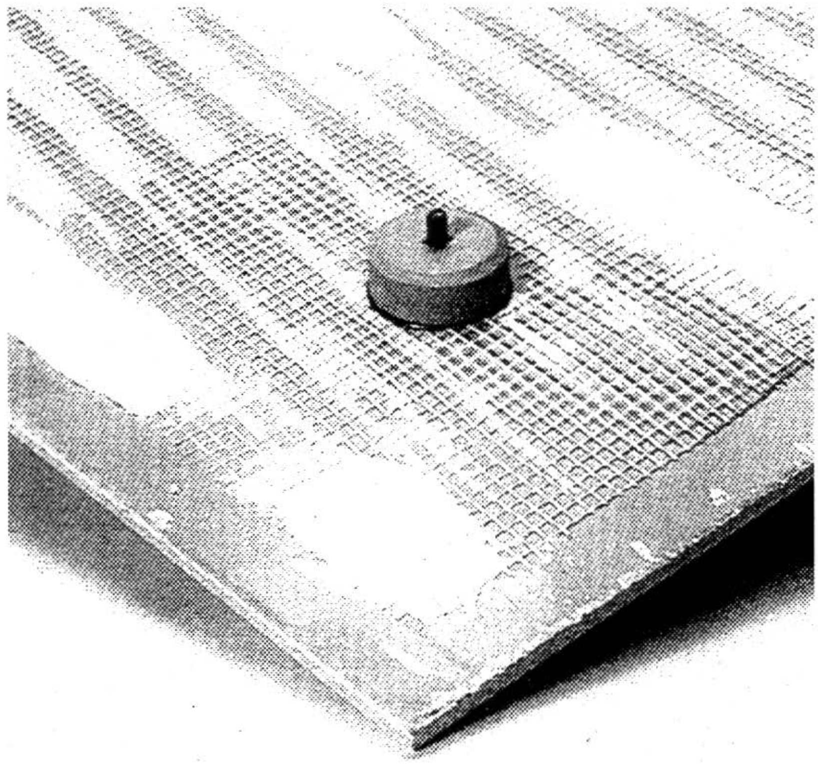

FIGURE 5a VENTILATED METHOD (ceramic/metal anchor)

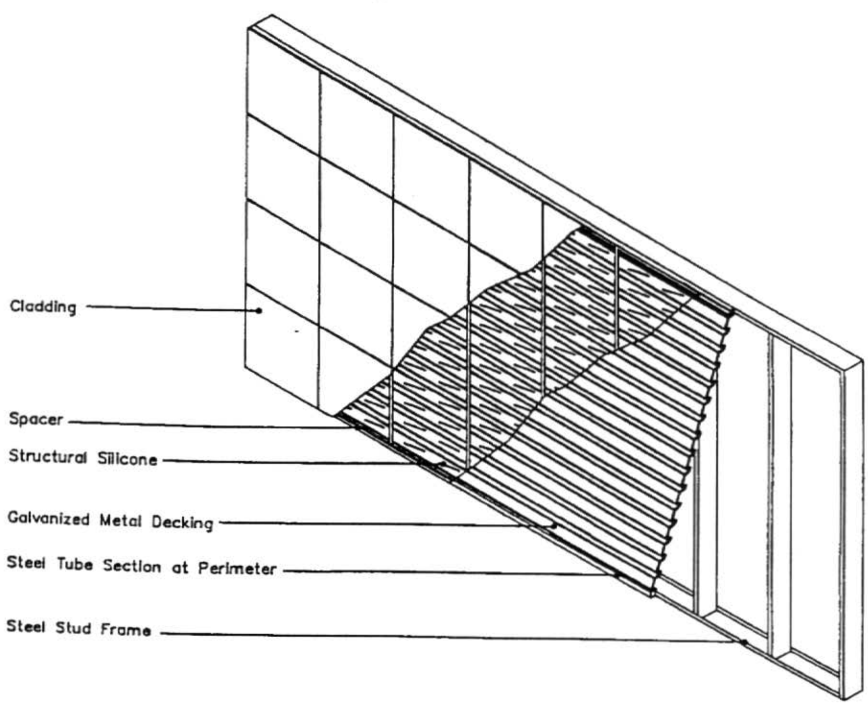

FIGURE 5b VENTILATED METHOD (structural silicone adhesive system)

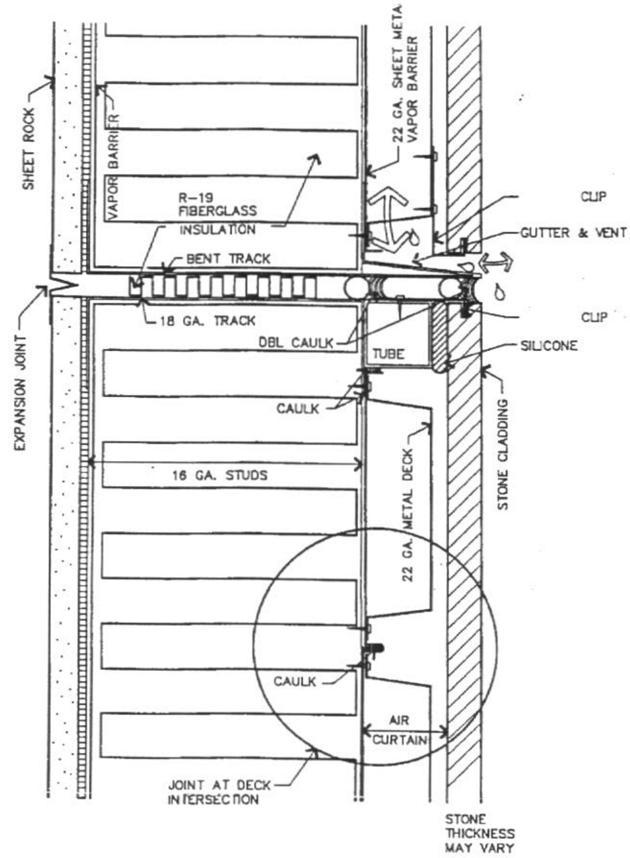

FIGURE 6 VENTILATED METHOD (air cavity system)

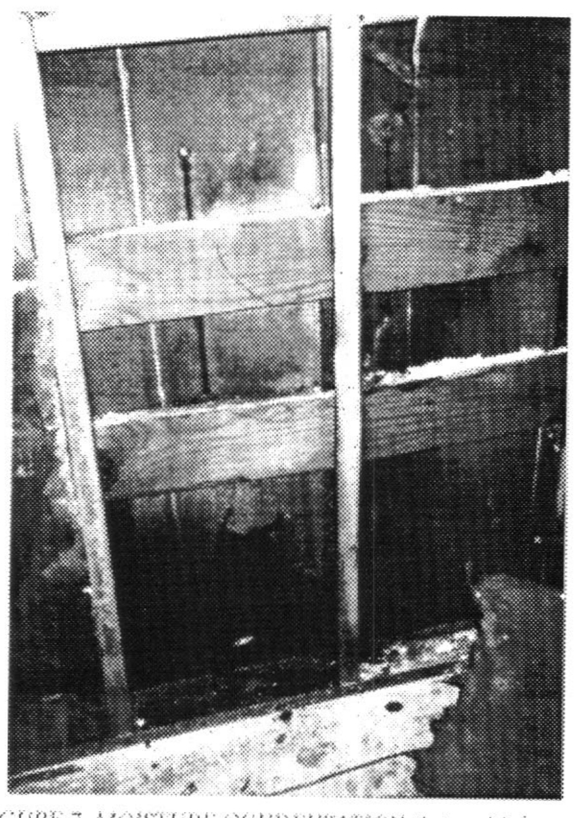

FIGURE 7 MOISTURE CONDENSATION (interstitial space)

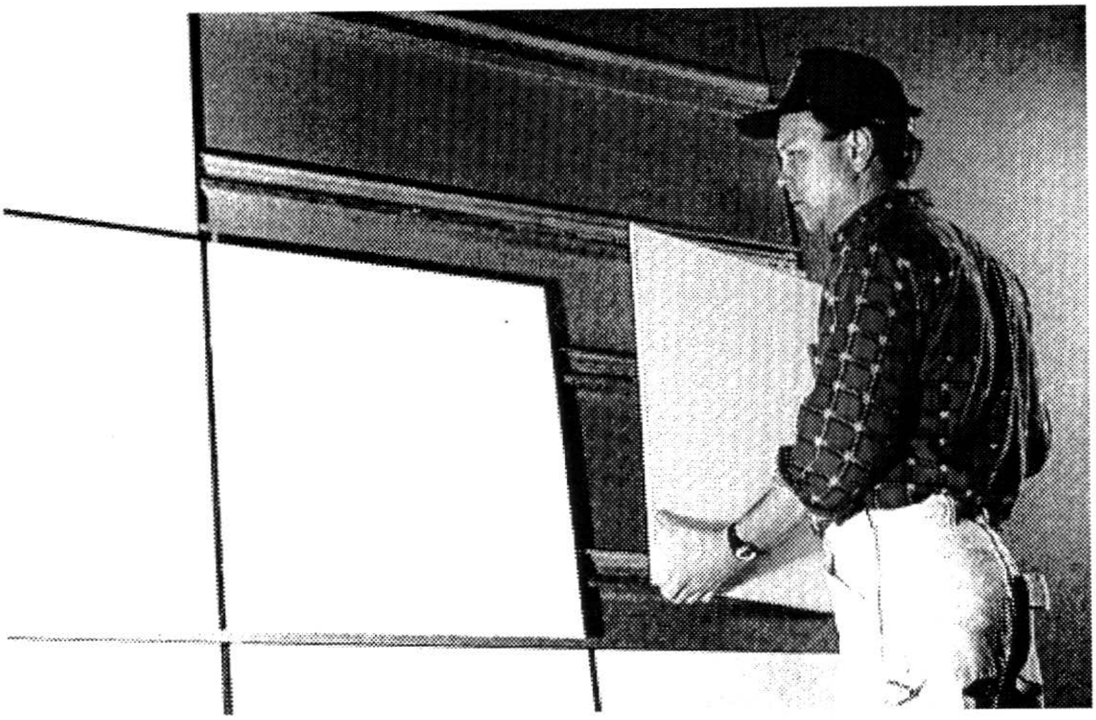

FIGURE 8a LARGE FORMAT CERAMIC TILE

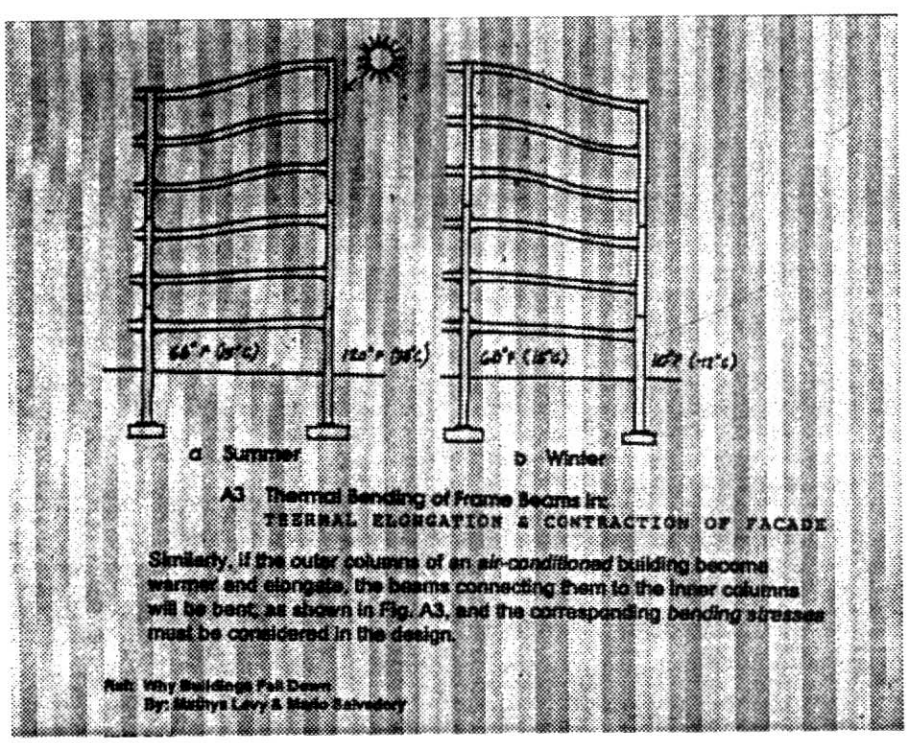

FIGURE 8b THERMAL MOVEMENT (Structural frame)

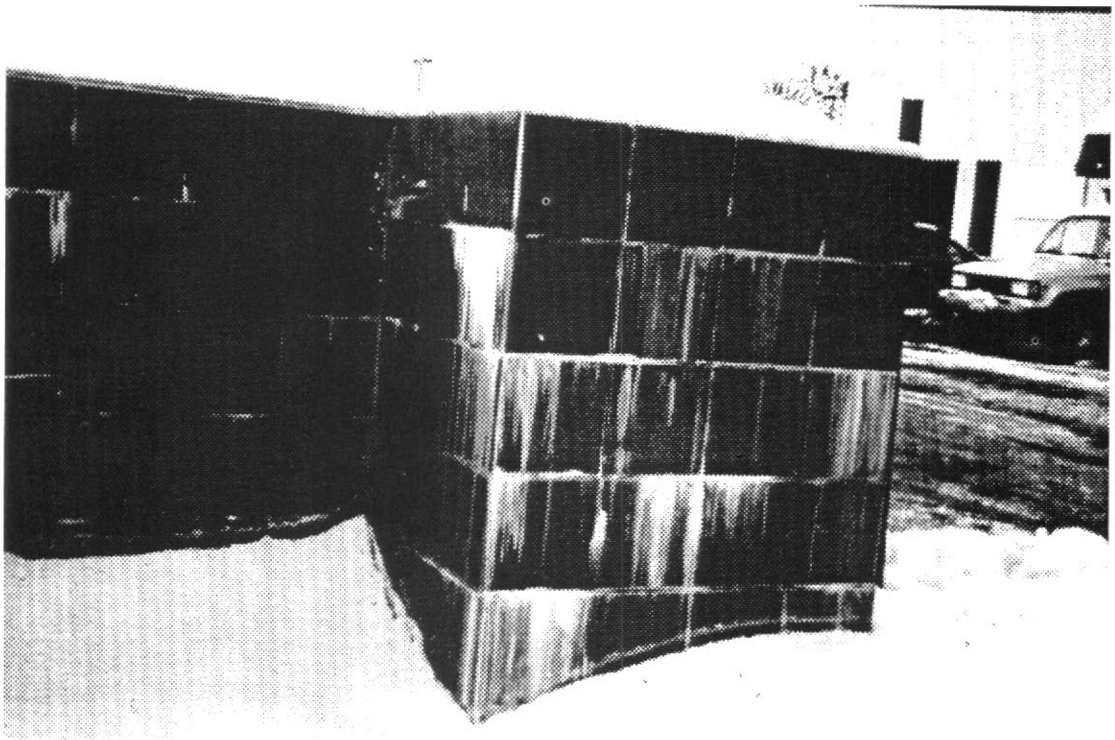

FIGURE 9 EFFLORESCENCE - FIGURE 10 LATEX LEACHING

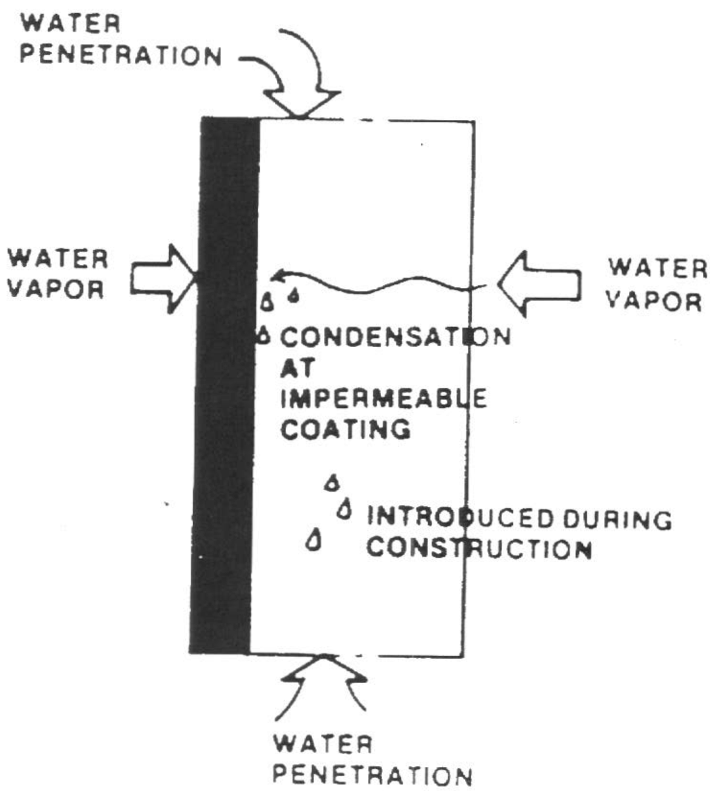

FIGURE 11 CRYPTOFLORESCENCE

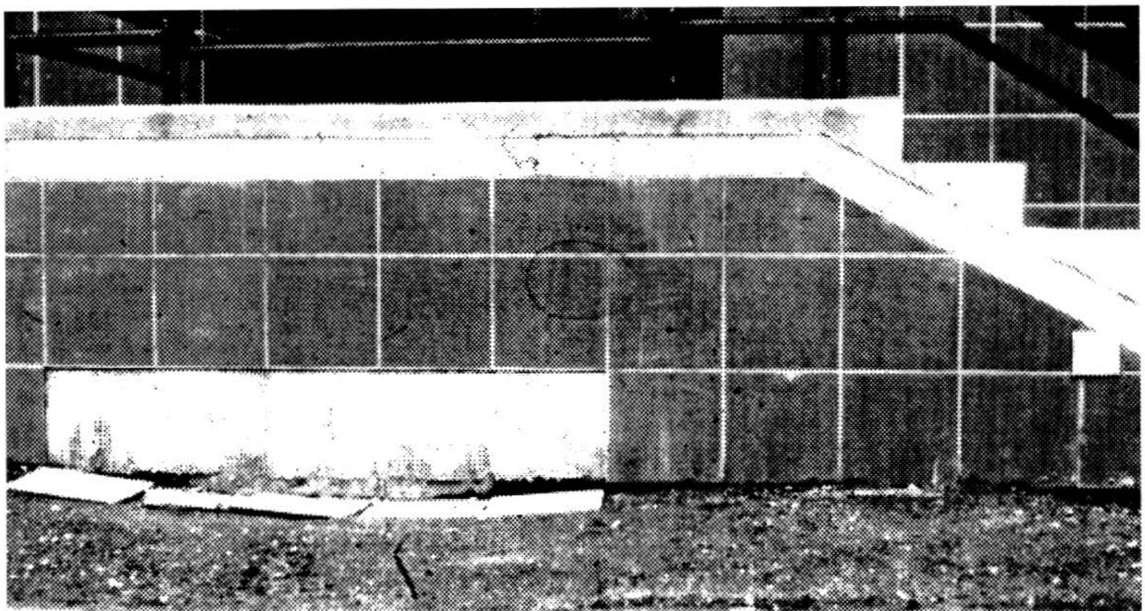

FIGURE 12 FREEZE/THAW DAMAGE

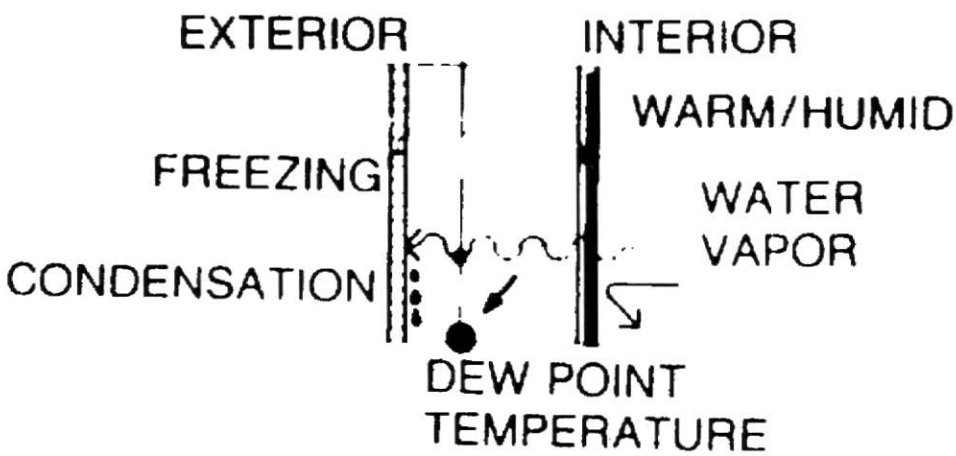

FIGURE 15 CONDENSATION

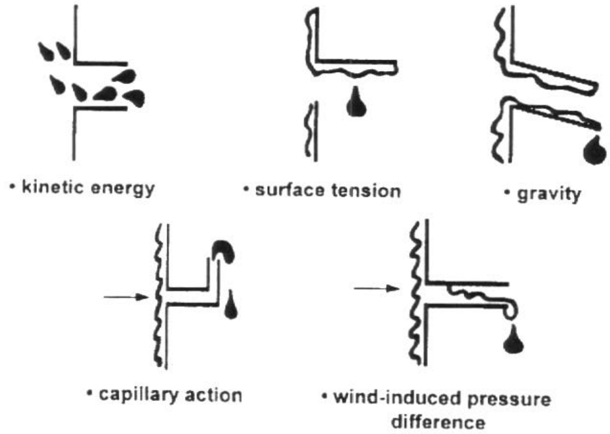

FIGURE 17a MOISTURE PENETRATION - DRIVING FORCES

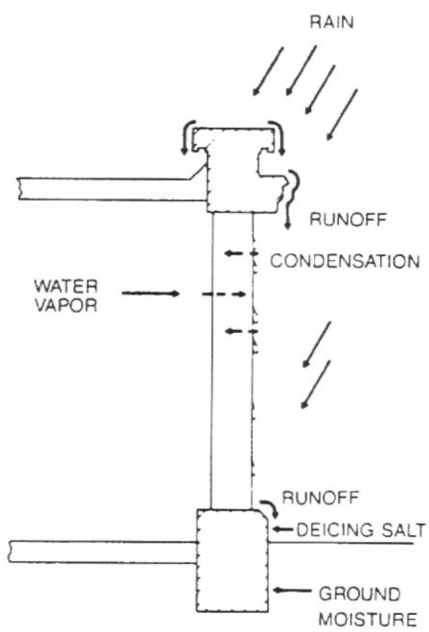

FIGURE 17b MOISTURE PENETRATION (Sources of moisture)

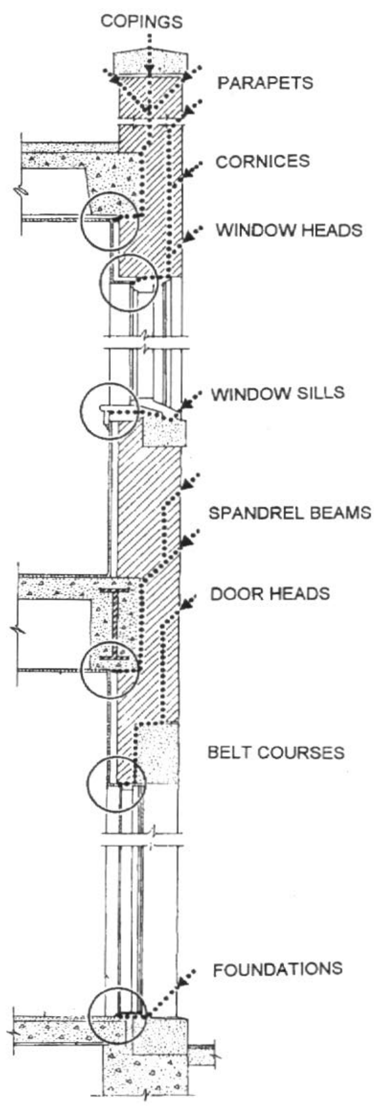

FIGURE 18 CONTROL OF WATER (Typical flashing locations)

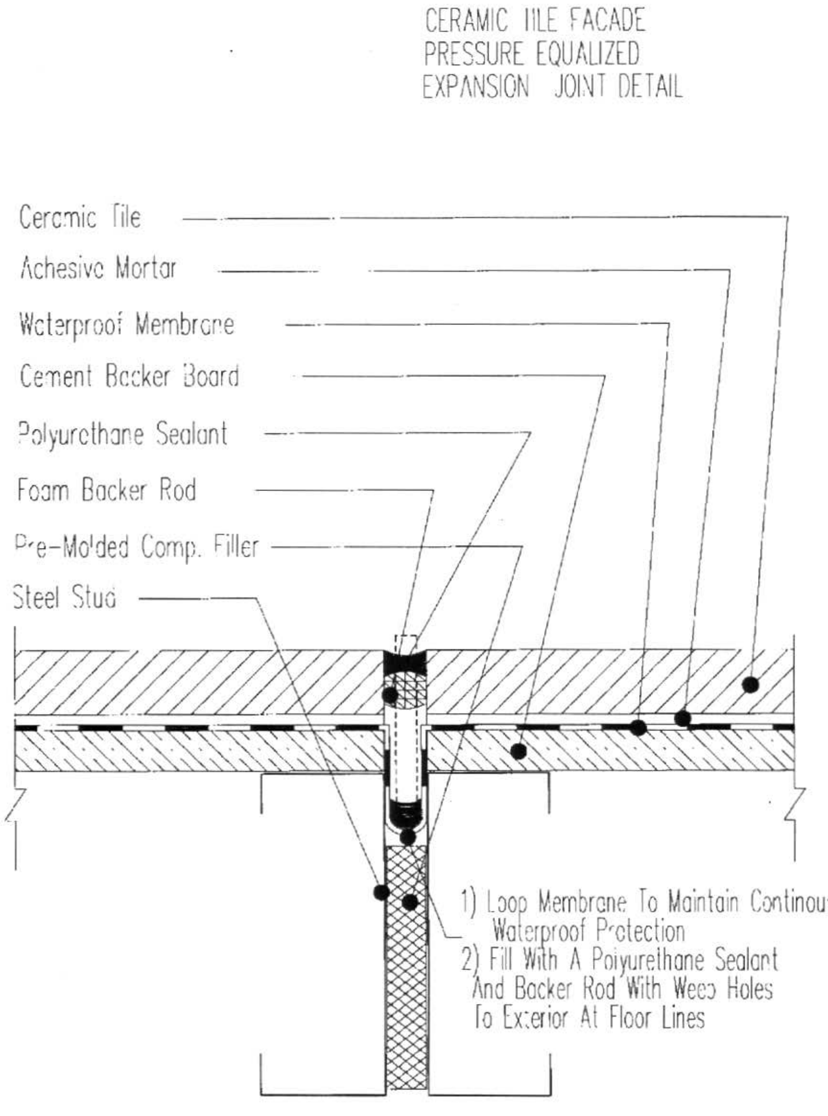

FIGURE 19 PRESSURE EQUALIZATION

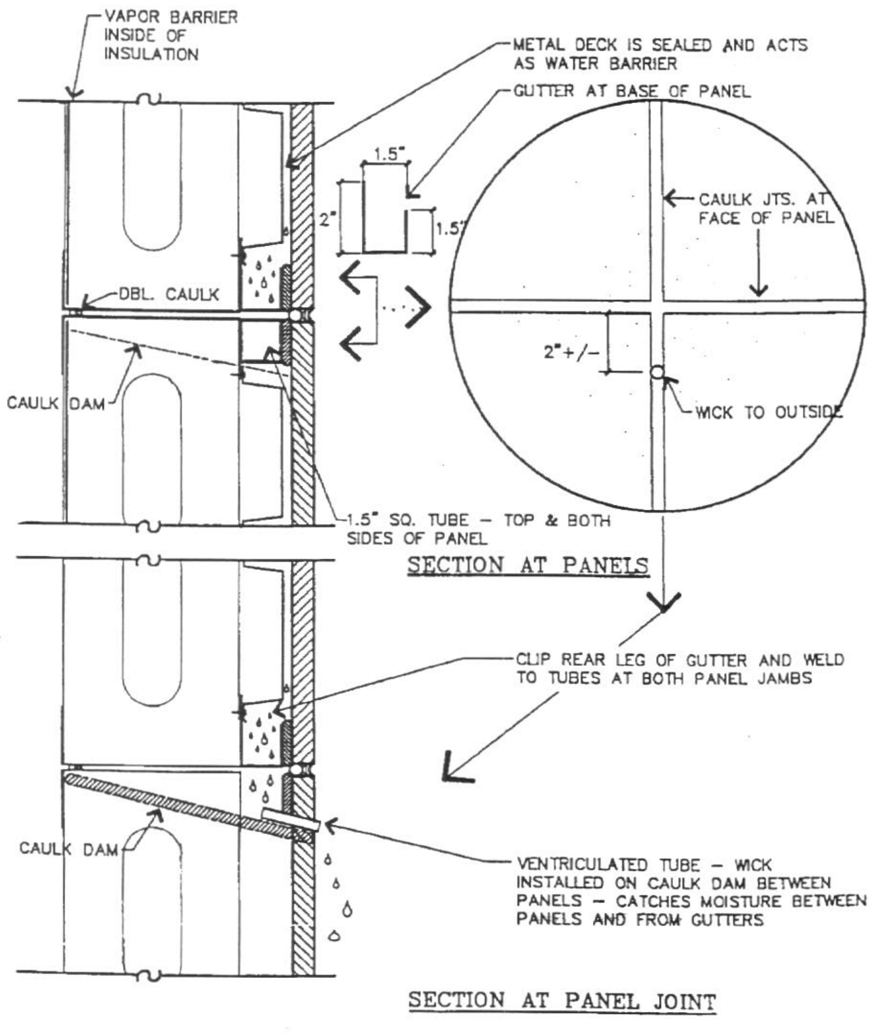

FIGURE 20 PRESSURE EQUALIZATION