NRC Publications Archive Archives des publications du CNRC

Moisture management of EIFS walls -- Part 1: The basis for evaluation Bomberg, M. T.; Kumaran, M. K.; Day, K.

This publication could be one of several versions: author's original, accepted manuscript or the publisher's version. /
La version de cette publication peut être l'une des suivantes : la version prépublication de l'auteur, la version
acceptée du manuscrit ou la version de l'éditeur.

Publisher's version / Version de l'éditeur:

Journal of Thermal Envelope & Building Science, 23, July 1, pp. 78-94, 1999-07-01

NRC Publications Record / Notice d'Archives des publications de CNRC:

<https://nrc-publications.canada.ca/eng/view/object/?id=7a65c276-619f-40be-85e2-c80ef1af8db0>
<https://publications-cnrc.canada.ca/fra/voir/objet/?id=7a65c276-619f-40be-85e2-c80ef1af8db0>

Access and use of this website and the material on it are subject to the Terms and Conditions set forth at

<https://nrc-publications.canada.ca/eng/copyright>

READ THESE TERMS AND CONDITIONS CAREFULLY BEFORE USING THIS WEBSITE.

L'accès à ce site Web et l'utilisation de son contenu sont assujettis aux conditions présentées dans le site

<https://publications-cnrc.canada.ca/fra/droits>

LISEZ CES CONDITIONS ATTENTIVEMENT AVANT D'UTILISER CE SITE WEB.

Questions? Contact the NRC Publications Archive team at

PublicationsArchive-ArchivesPublications@nrc-cnrc.gc.ca. If you wish to email the authors directly, please see the first page of the publication for their contact information.

Vous avez des questions? Nous pouvons vous aider. Pour communiquer directement avec un auteur, consultez la première page de la revue dans laquelle son article a été publié afin de trouver ses coordonnées. Si vous n'arrivez pas à les repérer, communiquez avec nous à PublicationsArchive-ArchivesPublications@nrc-cnrc.gc.ca.

<http://www.nrc-cnrc.gc.ca/irc>

Moisture management of EIFS walls -- Part 1: The basis for evaluation

NRCC-43394

Bomberg, M.T.; Kumaran, M.K.; Day, K.

July 1999

A version of this document is published in / Une version de ce document se trouve dans:
Journal of Thermal Envelope & Building Science, 23, (1), July, pp. 78-94, July 01, 1999

The material in this document is covered by the provisions of the Copyright Act, by Canadian laws, policies, regulations and international agreements. Such provisions serve to identify the information source and, in specific instances, to prohibit reproduction of materials without written permission. For more information visit <http://laws.justice.gc.ca/en/showtdm/cs/C-42>

Les renseignements dans ce document sont protégés par la Loi sur le droit d'auteur, par les lois, les politiques et les règlements du Canada et des accords internationaux. Ces dispositions permettent d'identifier la source de l'information et, dans certains cas, d'interdire la copie de documents sans permission écrite. Pour obtenir de plus amples renseignements : <http://lois.justice.gc.ca/fr/showtdm/cs/C-42>

National Research
Council Canada

Conseil national
de recherches Canada

Canada

Moisture Management of EIFS Walls— Part 1: The Basis for Evaluation

MARK BOMBERG¹ AND KUMAR KUMARAN

*Institute for Research in Construction
National Research Council
Montreal Road, Building M20
Ottawa, ON, Canada K1A 0R6*

KEVIN DAY

*Morrison Hershfield Ltd.
Consulting Engineers
4 Lansing Square
North York, ON, Canada H2J 1T4*

ABSTRACT: The Canadian approach to design accepts the presence of some construction deficiencies and calls for a multiple-line of defense. Until now, such a design has been based on the qualitative assessments rooted in experience, i.e., tradition, and involved little integration with the newly emerging analytical tools, e.g., advanced hygrothermal models. The relation between the design and climatic conditions acting on a building is not well established. Research should be undertaken to clarify the relationship between climate and the moisture performance of a given wall assembly, i.e., to enhance the predictability of moisture performance for different wall assemblies when constructed with some deficiencies and exposed to a given climate.

To improve the correlation between climatic conditions and design practice, moisture management of a building envelope must involve the flow-through principles. The flow-through approach is, however, much more difficult than the currently used approach with barriers. The flow-through approach requires performing computer calculations of moisture balance of all layers of the wall with regard to heat, air and moisture transport over an entire year. This is the critical element of the integrated moisture management strategy.

Four papers are being written to facilitate the use of analytical tools into EIFS wall

¹Author to whom correspondence should be addressed.

design process. This paper provides the background and sets the stage for a rational evaluation of moisture performance of cladding systems. The next paper will define the classification of EIFS with respect to moisture management. The third paper will discuss the selection of EIFS and the fourth paper will review the critical aspects of quality assurance.

INTRODUCTION

ONE HAS ONLY to look at the list of papers published during the past few years to appreciate the wide consideration given to the topic of long-term performance of Exterior Insulation and Finish Systems (EIFS). Research resulted in various new designs and new technical solutions. To enhance a systems approach for evaluating long-term performance of EIFS, the authors decided to review the emerging systems with respect to the potential moisture management strategies inherent in these new designs.

This task is accomplished in four parts, published as separate papers. The first paper provides background for moisture management concepts; it neither evaluates the performance of the systems nor provides comparative ranking; it only aims at providing the frame of reference in which such systems are evaluated. The second paper lists the actual moisture management strategies, and the last two review the approach to EIFS selection and quality assurance. Thus, for each EIFS type the moisture management strategies and details critical for EIFS construction are discussed and documented with a view to ensuring field performance.

DESIGN FOR ENVIRONMENTAL CONTROL

In designing for environmental control (heat, air, and moisture transfer), professionals integrate two very different conceptual approaches. One involves specific testing and analysis; the other encompasses broad qualitative assessments based on experience, judgment and knowledge of what makes a building envelope function.

On the analytical side, there is a complex array of tools: hygrothermal models, banks of material properties, analysis of environmental factors relating to the building envelope. On the qualitative side, a particular building envelope is seen from a functional point of view.

For example, a vapor barrier is classified at one perm, a unit that represents sufficient retardation of moisture flow for wood-frame housing. However, when calculations were made using an advanced model of heat, air and moisture transport for various climatic conditions in Canada, barriers ranging from 0.2 to 7 perms were found suitable for various combinations of materials and climates (Karagiozis and Kumaran, 1993).

A significant effort was made to measure vapor transmission through many construction materials during the last four decades. Yet, this effort did not enhance the reliability of moisture management in construction. The benchmark of one perm, introduced about 50 years ago, is still only a benchmark (even though many building codes present this benchmark as an important criterion).

To advance moisture management in construction, we cannot restrict our discussion to one concept at a time. Over the last two decades, construction industry in North America went through three "campaigns" for (1) vapor retarder (called vapor barrier in Canada), (2) air barriers, and (3) pressure equalized rain screen. Each campaign was thought to establish a panacea for moisture management. While all the three elements (vapor barrier, air barrier, and rain penetration control) are important, none of them can be discussed without the others. Only the holistic and comprehensive approach to moisture management, such as the one expressed by Hutcheon in 1963—to control heat, air and moisture flows—withstood the test of time.

Experience tells us that most of the traditional wall assemblies will perform well in a dry, mild or moderately cold climate. The more extreme the climate, the smaller is the selection of walls with proven long-term performance. It is expected that on-going research will enhance the understanding of the relationship between climate and moisture performance of a given wall assembly. The outcome of research is expected to enhance predictability of moisture performance for different, not necessarily perfect wall assemblies, in a given climate. How imperfect these walls are may depend on many factors.

Reliability of the Design

Through experience, the Canadian precept for building envelope design incorporates precautionary measures to avoid harmful accumulation of moisture in critical parts of the envelope. Theoretically, building professionals—be they designers, specifiers or builders—can design and construct a perfect structure. Yet, in practice, sooner or later the imperfections will reveal themselves. Water enters, for instance, because the roof drainage does not lead water away from the building but directs it right to the basement, or caulking in a face-sealed design is not maintained during the service life and therefore leads to water penetration. We know that eventually some moisture finds its way into the building envelope. So the walls are constructed to permit draining and drying of any incidental moisture accumulation. But how long would it take to dry out, and what effect would the moisture have on various materials? As there are not many quantitative answers, designers must look to logic and experience.

The need for additional precaution forces designers and builders to prepare for the eventualities they cannot predict, such as material changes caused by aging or weathering, flaws in workmanship issues or even design flaws that may escape their notice. Typical, unnoticed leakage paths occur when air travels through more than one building component, e.g., air passing through a part of masonry where wall parging is not finished, or behind radiator cabinets, or through holes used to pass wires to the suspended ceiling or corrugated roof decks. The list of leakage paths also includes large masonry partition walls that stretch above the roof, openings cut for electrical heating, ventilation and plumbing services, cladding materials that are not drawn tight to metal studs and furred partition walls connecting with a suspended ceiling. Air leakage is likely to occur if the drywall is carried just above the ceiling plenum and does not meet the floor to form continuous and airtight connection.

Buildability

Similar to the precautionary measures, buildability relates more to judgment and knowledge of the professional than to mathematical analysis. Buildability reflects whether a specific design can be constructed on site, by various trades, without compromising the functional requirements of the wall. Contrary to a frequent misconception, buildability is more related to a good design than to superior workmanship. As experience indicates, only a good design can combine responses to all the environmental factors and produce an easily assembled construction sequence. For the most part, it is the designer who attends to the aspects of buildability such as material installation under different weather conditions, level of skill required for installation, and construction tolerances. Often buildability problems are caused by the interaction and sequencing of different trades. As a rule, none of the following: window manufacturer, window installer, interior finish/drywall installer would consider the window/wall interface as their responsibility.

Other Key Design Considerations

The design of building envelopes for environmental control requires a number of iterations. Each material must be examined with regard to its compatibility and interaction with the adjacent materials and components. Each modification of the performance requirements or change in the material selection must be followed by a review of architectural details. These issues highlight the importance of a review (in a sense, troubleshooting) of drawings of the assembled system and of the design details. To maintain a high standard

of quality and clarity, some specifiers prefer to have one section of the specification addressing the joints and junctions of various sub-assemblies within the overall building envelope system. In this respect, it is difficult to draw the line between concepts of buildability and the precautionary measures. Both address aspects of the system during both its construction and its service life. Yet, so often, the key to good and long-term performance of the system depends on the performance of the architectural details.

A HISTORIC VIEW OF MOISTURE MANAGEMENT OF EIFS CLADDING

Walls with EIFS contain a substrate (the supporting system) and the cladding system. The latter is composed of an insulation board (attached with adhesive and/or mechanical fasteners), a synthetic coating system consisting of one or more layers of a base coat with an alkali-resistant reinforcing glass fibre mesh, and a finish coat. The synthetic coating system is commonly called the lamina. Each of these components has a clearly defined function such as mechanical support (strength and rigidity), reduction of heat flow, bonding (adhesion), resistance to crack initiation, resistance to water ingress, and appearance.

EIFS-type claddings have been classified as Polymer Based (PB) and Polymer Modified (PM) systems. Formerly these systems were classified as soft coat, thin and flexible for PB, and hard coat, thick and rigid for PM. The words, soft, thin, and flexible are attributed to the high polymer content in the base coat that results in a flexible thin coating, while the words hard, thick, and rigid are attributed to the relatively low polymer content that result in a less flexible coating. The cement content does not exclusively separate these two systems. Most PB base coats contain cement, yet some do not. The components of the two systems are largely identical, except for the thickness of the base coat and the method of attachment. The performance characteristics are inherently different. The critical difference of the base coat thickness and hardness of the PM systems traditionally required that control joints be provided.

Traditionally, wall systems with EIFS cladding were considered face-sealed (barrier) walls, which means that the exterior face is expected to provide most of the functional requirements of the wall and, in particular, to act as the primary (and often the only barrier) to rain ingress. The exterior face, however, includes also fenestration, penetrations, and connections (joints and junctures) between all the components of the building envelope. All these penetrations must be equally impermeable to water, if the face-seal approach is to work.

The rain barrier created by the EIFS lamina must remain impermeable to water during its expected service life. The effects of weathering, aging of materials, cracks in the lamina, and the possible deterioration of the wall substrate, as well as service penetrations through the wall, must be included in the evaluation. Therefore, not only the initial performance of the wall system but also its long-term performance under service conditions must be evaluated:

Although examples of satisfactory long-term performance of EIFS abound, there have been also failures of walls with EIFS, notably failures of the substrate once rain water has penetrated through the joints and junctures and become trapped within the wall system. Sealant joint failures have been reported frequently during this decade, e.g., Williams and Lamp-Williams, 1990; Meyers and Ruggiero, 1991; STP, 1995. Recent moisture problems in Wilmington, NC, and Vancouver, BC, which led to prohibition of field-applied, face-sealed systems in Vancouver (1995) and North Carolina (1995) were well publicized. Note that these types of regions have particularly adverse climatic conditions.

The central issue of EIFS system evaluation is the management of moisture to ensure system integrity during many years of adverse climatic conditions. During this evaluation, one often faces the dilemma whether EIFS is a component evaluated in the context of an entire wall, or a separately evaluated cladding system. Cladding is a component of the wall and the functional requirements of cladding need not be as extensive as those for the entire wall. Exterior cladding is defined as "those components of a building which are exposed to the outdoor environment and are intended to provide protection against wind, water and vapor"² or "the non-load bearing clothing of the walls and roof of a building, the skin used to keep the weather out."³

The commentary on Part 5 (dealing with large buildings) of the 1990 edition of the National Building Code (NBC) of Canada states:

"When the sealants of a face-sealed cladding fail, the walls lose their water tightness and air tightness; this translates into severe disability of the envelope in performing its intended functions. As a consequence, face-sealed walls require frequent and costly maintenance during the life of building. The approach has little to recommend it and is considered impractical for buildings in Canada."

Brown⁴ reviewing Part 9 (dealing with housing and small buildings) of the same NBC stated:

²National Building Code of Canada, 1990 edition.

³Scott, J. S., Dictionary of Building, Penguin Books Ltd., Harmondworth, Middlesex, UK, 1974.

⁴Private communication.

"Part 9 of the Code also generally accepts that cladding alone cannot be expected to provide protection from rain penetration. The intended performance of exterior cladding, as outlined above, to prevent the passage of water and provide drainage if there is a likelihood of penetration is essentially covered within Part 9 by listing acceptable sidings (section 9.27) and requirements for a sheathing membrane (subsection 9.23.17) beneath siding. The requirement for self-furring devices to hold stucco lath 6 mm from the backing (9.28.4.4) is essentially a requirement that stucco be constructed with a drainage layer⁵; in other words, the probability that the cladding will leak is presumed to be not zero."

Thus, in Canada, most experienced designers do not rely on sealants as the long-term measure of controlling rain penetration. A single-stage sealant joint, as in one bead of sealant with a closed cell backer rod, was once the norm. However, other solutions, such as drainable two- or single-stage joints with secondary protection (expanding foams and gaskets, etc.) are becoming increasingly more common.

In summary, while the Canadian approach to design appeared to be on the safe side, accepting the presence of some design or construction deficiencies and calling for a multiple-line of defense, it has been entirely based on the qualitative assessments rooted in experience, i.e., tradition. It did not require any integration with the analytical side of the design process.

With such failures as the stucco walls in Vancouver, or the EIFS walls in North Carolina, the North-American approach to moisture management of a building envelope did not provide for adequate relations between design practice and climatic conditions. This situation must be changed. To achieve this objective, the incorporation of the analytical side of moisture management—with its vast array of tools, models and quantifying methods for structural and environmental factors relating to the building envelope—may be needed. Furthermore, we need to make the design process more transparent and focussed on suitable means for quality assurance. Such changes are necessary to accommodate a growing supply of new construction materials and components.

NEED FOR THE SYSTEMATIC APPROACH TO MOISTURE MANAGEMENT

The review of the scientific basis for moisture management in a building

⁵As Straube points out in the private communication to the authors, the 6 mm requirement is there to ensure that the lath gets well keyed into the stucco, as it should be placed in the middle of the plaster; the drainage comes from the requirement for a capillary break at the building paper or sheathing membrane that is required beneath the stucco.

envelope must start with rain penetration control. Rain falling on the wall surface can flow down (be shed), stored (absorbed by material or attached by surface tension), or transmitted into the wall. Some of the water flowing onto the wall surface may be removed from the surface by features such as drips and ledges.

Rain Control and Design Strategy⁶

Straube and Burnett (1997) discuss three design strategies:

- face-sealed (barrier wall) or perfect barrier system
- moisture storage system
- screened and drained systems

FACE-SEALED (BARRIER WALL)/PERFECT BARRIER SYSTEM

A multi-layer enclosure assembly may contain a single layer where the amount of rainwater transmitted inward must be zero. The water-impermeable layer is often located on the exterior face of an assembly. Such a rain control strategy has been termed “face-sealed” or “barrier walls.”

In principle, drainage and storage within the assembly do not play any role in providing rain control in functional face-sealed (perfect barrier⁷) systems.

MOISTURE STORAGE SYSTEM

When there is enough moisture storage to absorb all rainwater that is not shed from the outer surface, the wall assembly can also prevent moisture penetration through the wall.

Although envelopes employing this strategy might be termed “moisture storage” systems, “mass walls” are often used to denote a large mass required for providing sufficient storage. The water transmission of the various layers and interfaces can play a critical role in the performance of mass systems. Straube and Burnett (1999) give an example of a 300-mm thick, solid-brick masonry wall. By applying 15-mm thick, PM cement rendering, the storage capacity is only marginally increased, but the water transmission of this outer layer, even when cracked, is so low that the rain penetration control of the system is vastly improved. In effect, performance of mass walls depends

⁶This section is based on the work of Straube and Burnett (1997, 1999).

⁷It may seem that “perfect barrier” is a redundant term, but the building industry almost always uses the term “barrier” in a relative, not absolute, sense, e.g., vapour barrier and moisture barrier. Therefore, it is deemed necessary to qualify the barrier as being perfect.

on the moisture storage and water transmission characteristics. Finally, the ability of materials to dry is critical for the performance of such a wall.

The performance of mass walls depends heavily on weather conditions. If a series of rain events occurs and drying conditions are poor, the storage capacity may be exceeded, resulting in the failure to limit water intrusion. While theoretically speaking, the mass walls do not require any drainage capability, these are routinely provided in masonry construction.

SCREENED AND DRAINED SYSTEM

Straube and Burnett (1999) state:

"Another approach to controlling rain is to accept that some water will penetrate the outer surface (hence the cladding "screens" rain) and to provide drainage to remove it. The drainage need not be provided at one layer only. In fact, if all the drainage was provided by one layer only, the wall would be acting as a perfect barrier system. Screen and drained walls control rain penetration by reducing the amount of water transmitted at each of several layers.

The drained enclosure systems control rain penetration by reducing the successive fractions of water that are transmitted inward. Almost without exception, functional rain screen walls provide several additional drainage layers, for example, the front and back of the sheathing paper. Modern windows, car doors, and two-stage joints are exceptions, in that they typically have precisely two layers (hence two stage control mechanism). Although these types of joints provide an "almost" perfect inner layer, the intent of the outer layer is to significantly reduce the potential for any water on the second layer."

In principle, the screened-drained wall system does not require any storage capability.

Finally, there are two special cases of screened and drained system, where the transmission fraction of the screen is reduced by modifying air pressure. These systems are called "pressure-equalized" or "pressure-moderated" rain screen.

Rain Control Performance of Actual Walls

While the classification of the rain control strategy in itself does not benefit the architect or designer, it brings, however, into focus some fundamental issues involved in the process of design. First, it explains why many face-sealed wall systems function despite the documented existence of cracking and penetrations through EIFS lamina. As Straube and Burnett (1999) state:

"This is not necessarily because the lamina (the plane assumed by designers to be perfectly watertight) allows no transmission, but rather that the substrate has

sufficient storage to store the small fraction that penetrates. In other cases, this storage capacity may act in conjunction with drainage that is inadvertently provided by interface layers and large pored or fibrous insulation materials. In most reported cases, EIFS fail because of very high exposure and poor detailing of the joints and penetrations, e.g., windows.

It is likely that many rain control failures of EIFS are the result of extreme exposure conditions and insufficient safe storage capacity behind the (often) somewhat less-than-perfect lamina. The inability of some types of EIFS systems to dry once rain penetrates often results in other serious performance and durability problems (for example, the well-publicized cases in Wilmington, North Carolina)."

Typically, we recognize failure in two cases:

1. when water penetrates through an entire assembly to the inner surface of the wall
2. when the transmission of rainwater reaches a sensitive layer of the wall assembly and is likely to cause damage, degrade performance, or affect its durability.

While in modern construction, the first type of failure is extremely rare, the second type highlights the question: what level of moisture is acceptable? Evidently, moisture management involves not only the environmental conditions and material hygrothermal properties, but also the "moisture sensitivity" of different construction products. (The concept of moisture sensitivity has evolved with time. Originally, it involved only the moisture effects on durability. Now, it also includes other moisture effects such as mold or fungus growth, i.e., phenomena affecting indoor environment.)

With discussing screened and drained-wall systems, Straube and Burnett (1999) highlight that storage also plays an important role in those walls. For example, only during extended rainy periods and intense rain events, when the veneer may become saturated, the drainage function becomes critical. The storage capacity of such walls suggests that in most exposure conditions, they are actually behaving as mass walls aided with water-retarding layers, e.g., building paper. While these walls may be functional in some weather conditions, this may not be so in a different climate. With more driving rain deposition—e.g., near the top of high-rise buildings—or less drying potential—e.g., Halifax, Vancouver or other rainy, coastal climates—the storage capacity can be exceeded, resulting in the leakage of water into the wall assemblies.

In effect, Straube and Burnett (1999) do not accept the simplified picture of rain penetration control where one or two layers provide all the necessary controls either through drainage or through barrier functions. They postulate that even when one fraction dominates the design, all fractions (drain-

FIGURE 1. Schematic of environmental functions in a frame wall used in cold climates.

age, storage and transmission) play an important role in almost all wall systems. If some storage and drainage is possible in walls considered designed as barrier walls, these walls may not fail even if the barrier is imperfect. In the same way, many drained-screened walls may, in fact, have poor drainage and therefore can only function when sufficient storage is available.

Introducing moisture storage into rain penetration control broadens the scope of our analysis. Moisture storage is affected by such phenomena as thermally driven redistribution of moisture as well as air leakage. In effect, moisture storage brings all environmental parameters into consideration. The following section will provide a brief overview of the complexity of this field of concerns.

Environmental Control Functions: Example of a Wood-Frame Wall

The environmental control functions of the frame wall construction are schematically shown in Figure 1. After the rain screen, the next environmental function⁸ shown in Figure 1 pertains to a cavity, the air gap. It contributes to two aspects of moisture performance:

- control of rain penetration by reducing the intensity of rain carried across the air gap

⁸Each environmental function may or may not be fulfilled by one specific material or component of the building envelope.

- removal of residual rain and summer condensation of vapor (with wall surface temperature varying between day and night, the direction of thermal gradient in the outer layer of the wall changes and may cause moisture to move back and forth), unless it is removed through the air gap.

The drainage function of the air gap is often underestimated. There is a history of proven performance of the cavity space in frame walls and in masonry walls (double-wythe brick veneer). Only recently, when completely filling these cavities with foams or fibrous insulation and causing moisture problems in renovated walls, have we started to appreciate more the importance of a free of obstructions, drainable air space. The air space may or may not be ventilated.

Whether this air gap is ventilated or not is often much less important, since its main purpose is to serve as a capillary break. (Figure 2 illustrates the power of an air gap in this respect.)

Figure 2 shows a large difference in the rate of moisture transport caused by a break of direct contact between two materials. The same moisture content was reached either in 20 or in 2000 hours. Obviously, this ratio is not a constant but depends on the capillary nature of both materials, yet it is evident that moisture is moved in its liquid phase much faster than in its vapor. Even a small break in continuity breaks the capillary flow of water and presents a dramatic reduction in the rate of moisture transport. One can also infer from Figure 2 that drainage is the most powerful method of moisture removal.

FIGURE 2. Moisture gained by initially dry, aerated concrete specimens from wet gypsum specimens. Two levels of moisture content in gypsum and two different conditions at the interface between specimens: (1) Samples in contact and (2) samples separated by 1-mm air gap (Bombrerg, 1974).

The next functional element shown in Figure 1 is the drainage plane which, in addition to drainage of rain that may find its way to the inner surface of the air gap, reduces the so-called wind-washing effect. When the plane of air tightness in the air barrier system is on the internal side of the wall, wind could enter and exit from the external side of the wall.

The next functional element (see Figure 1) is a thermal insulating sheathing placed on the cold side of the wall frame. Its role is particularly important in highly insulated wood- or steel-frame walls. In the latter case, metal studs act as powerful thermal bridges when insulation is inserted between the studs.

The next functional element shown in Figure 1 on the warm side of the cavity insulation is an air barrier plane (plane of air tightness). Section 5.4 of the 1995 National Building Code of Canada describes performance requirements for an air barrier system. The plane of air tightness must reduce the air leakage to less than $0.02 \text{ l}/(\text{s}\cdot\text{m}^2)$ when tested at a 75-Pa pressure differential.

Finally, the last functional element, the vapor retarder, has received a disproportionate amount of attention. One explanation is that the vapor diffusion is one of the few moisture transport mechanisms that are easy to calculate. Nevertheless, these calculations can only be used to establish the onset of condensation. Because the condensation process makes these simplified calculations invalid, they cannot be used to determine the quantity of condensed moisture.

Often, to be on the safe side, practitioners do not allow any condensation within the building structure. This type of approach is called moisture design with barriers.

Conversely, moisture design with a flow-through approach permits moisture accumulation on an intermediate basis. This approach requires performing experiments or calculations to estimate how much moisture will accumulate within the building envelope during the critical season. Then, one must assess the potential effects of this moisture on the structure durability. If the durability of materials and components is not adversely affected, one must check whether the drainage and drying capability over the remaining part of the year will exceed the condensed amount. Moisture is allowed to accumulate during the heating or cooling seasons, but it is not allowed to accumulate from one year to another.

Normally, the use of the flow-through approach is more difficult than that of the barrier approach. Flow-through approach requires computer calculations of the moisture balance over the entire year during which the wall assembly is exposed to the worst set of probable climatic conditions.

Figure 3 illustrates these two different design principles with an analogy to a barrel. No liquid is delivered to Barrel A and none is flowing out (design

FIGURE 3. Two approaches to moisture design: (A) design with barriers and (B) design on the flow-through principle.

with barriers). The same quantity flows into Barrel B as it flows out and the balance does not change (flow-through on a yearly basis).

Note that the moisture flow is seldom one-dimensional, and that flow-through invariably involves both the liquid flow and the vapor diffusion. Actually, the more drainage occurs during phase changes of moisture⁹ entrapped within the enclosure, the more efficient is the flow-through design. The name flow-through was selected to emphasize an important aspect of the design, called moisture tolerance of the building system. A well-designed building system is not significantly affected when some moisture enters the structure because of mistakes or unforeseen circumstances. There is no damage to materials, and the system allows for subsequent drainage and drying.

Environmental Control Functions of the Wall—A Summary

An old adage states that the “proof of the pudding is in the eating.” Similarly, the example of environmental control functions of the wall highlighted a few critical issues.

First, we observe the role of air gap as the capillary break. Reducing or eliminating capillary flow of water significantly reduces the rate of moisture

⁹Phase changes may occur daily because of solar or night radiation.

transmission through the wall. The air gap also facilitates drainage. For the purpose of capillary break and drainage, the rule of thumb requires the cavity depth is about 6 mm.

Where removal of moisture from the air cavity is concerned, a distinction has to be drawn between four different types of air cavities:

1. closed (non-vented)
2. vented (through openings or porous materials)
3. ventilated
4. pressure-moderated (pressure-equalized)

The difference between 2 and 3 is vague. The ventilated cavity is assumed to have a "significant" amount of airflow.

Secondly, we observe multi-dimensional character and strong interactions between heat, air and moisture flows. When we talk about control of water vapor, we think about moisture coming from indoors, in cold climates; or from the outdoors, in hot and humid climates. We rarely think about moisture entering the wall from rain. Yet, sometimes the presence of deficiencies provides a coupling between rain ingress and vapor movement. In one case study, rain penetration into the leaky masonry walls coincided with negative indoor pressure created by the HVAC (Lstiburek, 1995). The water evaporated and vapor was carried inward with moving air.

Finally we observe that the design with barriers belongs to the tradition of prescriptive design. To correlate climatic conditions and design practice, moisture management of building envelope must be quantified. Similarly, to Straube and Burnett (1999), who argued that screened and drained walls control rain penetration by reducing the amount of water transmitted at each of several layers, we must consider performance of all layers of the wall with regard to heat, air and moisture. This is the critical element of the moisture management strategy.

CONCLUSION

To be on the safe side, the design must accept some deficiencies and use a multiple-line of defense. So far, however, the design has been entirely based on the qualitative assessments rooted in experience, i.e., tradition, and involves little integration with the newly emerging analytical tools, e.g., computer models.

This situation must be changed to improve the relationship between the design and climatic conditions. This change may require incorporation of the analytical side of moisture management, with its vast array of tools, models and quantifying methods that relate environmental factors to the build-

ing envelope. Furthermore, the design process needs to become more transparent and focussed on means suitable for quality assurance. Such changes are necessary to accommodate a growing supply of new construction materials and components.

To facilitate the correlation between climatic conditions and design practice moisture management of building envelope must be quantified. To this end, one must consider the flow-through that involves performance of all layers of the wall with regard to heat, air and moisture. The flow-through approach is, however, much more difficult than that of the barrier approach. Flow-through approach requires performing computer calculations of moisture balance over an entire year on the wall assembly that is exposed to the worst though probable climatic conditions. This is a critical element of the moisture management strategy.

This paper provides a background for moisture management strategies for EIFS. The next paper will provide a moisture management classification for EIFS, which later form the basis for incorporation of analytical tools into EIFS wall design process.

ACKNOWLEDGEMENTS

The authors are grateful to Peter E. Nelson, Simpson Gumpertz and Heger Inc., Arlington, MA; John Straube, University of Waterloo, ON and Fadi Nabhan, Canadian Construction Material Centre, National Research Council, Ottawa, ON for their contribution to this paper.

REFERENCES

- Bomberg M., 1974. "Moisture Flow through Porous Building Materials." Ph.D. thesis at the Lund Institute of Technology, Report 52, LTH, Lund, p. 188.
- Karagiozis A. N. and M. K. Kumaran, 1993. "Computer Model Calculation on the Performance of Vapour Barriers in Canadian Residential Buildings," *ASHRAE, Transactions Vol. 99(2)* pp. 991-1003.
- Lstiburek, J. W., 1995. "Two Case Studies with Failures in the Environmental Control of buildings," *Journal of Thermal Insulation and Building Envelopes*, Vol. 19, pp. 149-160.
- Meyers J. C. and S. J. Ruggiero, 1991. "Building Facade Watertightness," *ASTM STP 1107*, pp. 11-39.
- STP, 1995. "Development, Use, and Performance of Exterior Insulation and Finish Systems," *ASTM STP 1187*, M. Williams and R. Lampo, Eds., American Society of Testing and Materials, Philadelphia, several papers deal with moisture performance of EIFS.

- Straube, J.F. and E.F.P. Burnett, 1997. "Rain Control and Screened Wall Systems," *Proc. of the 7th Conference on Building Science and Technology*, Toronto, Mar. 20-21, pp.17-37.
- Straube J. and E.F.P. Burnett, 1999, "A Review of Rain Control and Design Strategies," *J. of Thermal Env. and Build. Science*, Vol. 22, July (in press).
- Williams, M.F and B. Lamp-Williams, 1990. "Sealant Usage for EIFS," *ASTM STP 1069*, pp. 175-194.