Potential Pitfalls of a Green Building Material: A Case Study of Cellulose Insulation

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ABSTRACT

Using recycled products to build green is rapidly gaining momentum in the construction industry; however, these materials must be incorporated correctly within building envelope assemblies to avoid potential pitfalls. In this paper, we address problems that can arise when an incompatible combination of materials is used and construction defects occur. This paper presents a case study demonstrating the detrimental effects of construction defects on a masonry cavity wall assembly that incorporated vapor retarders and cellulose insulation, a green building material.

CASE STUDY

Introduction

The subject structure was an approximate 9000 square foot single-family two-story residential wood-framed structure built in North Texas in 2004. The exterior of the structure was clad with natural stone veneer. Windows were wood-framed. The interior surfaces of the exterior walls were covered with 5/8" gypsum board. Interior finishes included latex painted gypsum board, enamel-finished wood trim, and varnished hardwood paneling. The exterior stud wall assemblies were insulated with wet-spray cellulose insulation.

The subject structure was located in a hot-humid climate (USDOE 2007). In a hot-humid climate, high exterior levels of humidity and cool interior surfaces exist for extended time periods during the cooling season, and moisture migration from exterior to interior is of greatest concern.

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Shortly after the homeowners moved in, suspect fungal growth appeared on the interior surfaces of the exterior walls at gypsum board and wood paneled wall surfaces. Testing of air and surface samples confirmed the presence of mold within the structure. The gypsum board and wood paneling was replaced twice after recurring conditions and attempted repairs to both the stone veneer and windows. Yet the mold growth continued to reappear.

The authors were tasked with determining the source of moisture migration for the recurrent exterior wall distress.

<u>**Observed Distress**</u>

General observations were made at the exterior and interior of the structure. Select interior demolition of wood trim, hardwood paneling, and gypsum board had occurred prior to the investigation making observations of the stud wall cavities easier. The following distress was observed:

- Efflorescence on the exterior stone veneer typically below window sills.
- White staining on the hardwood wall paneling ***behind*** the clear finish.
- Mold on the gypsum board ***behind*** the painted wood trim (**Figure 1**).
- Mold on the exposed gypsum board ***behind*** the hardwood paneling (**Figure 2**).

Figure 1. Mold behind removed wood trim

Figure 2. Mold on gypsum board behind removed wood paneling

GENERAL DISCUSSION

<u>**Building Envelopes and Moisture Migration**</u>

A building envelope is the assembly of materials that separate the exterior environment from the interior of a structure. The envelope serves as the outer shell or "skin" that protects the building from the elements and facilitates climate control within the same. Typical components of a building envelope include exterior walls, roof, doors, and windows.

Building envelope components must be designed and constructed to shed or drain water to the exterior and away from the skin of the structure. Moisture movement across the building envelope can occur through four transport mechanisms: liquid flow, capillary suction, air movement (convection), and vapor diffusion (Lstiburek and Carmody 1994). Liquid flow normally involves water breaching the building envelope through openings and penetrations. Capillary suction is the result of adhesion or surface tension of water in porous materials such as brick, natural stone, and mortar. Convection can transport moisture-laden air through unsealed openings and penetrations. Vapor diffusion allows moisture in the vapor state to travel through the permeable materials in the building envelope when subjected to vapor pressure differentials.

<u>Masonry Veneer Cavity Wall Systems</u>
In residential construction in a hot-humid climate, a masonry veneer cavity wall system typically consists of the following components, listed in order from exterior to interior: brick or natural stone masonry veneer, air space, weather barrier and/or vapor retarder, load-bearing wall (such as wood framed stud wall with sheathing as discussed in this paper); and interior wall finish. Insulation is used within the wood framed stud wall. Together, these cavity wall system components must act to minimize moisture movement across the building envelope from liquid flow, capillary suction, air movement (convection), and vapor diffusion, as discussed below.

Brick or Stone Veneer
The brick or stone veneer sheds the bulk of the rain water impinging onto the wall system. However, these materials are not waterproof. Brick, natural stone, and mortar are porous materials and absorb moisture from the air and rain water. In addition, separations between the mortar and the brick or stone due to differential expansion and contraction of the materials, as well as intrinsic imperfections in the brick or natural stone, will further allow water penetration through the veneer.

Air Space
In a drainage wall system such as a masonry veneer cavity wall, the air space provides an interstitial space between the exterior veneer and framing. This creates a drainage path to shed, by gravity, any water that enters the cavity and allows it to drain to the exterior and away from the skin of the building at the base of the wall, typically through weep holes. It also provides a capillary break between the masonry veneer and the wood framing to prevent the movement of moisture by capillary action into the wall framing. The air space must be kept clean and free of mortar to provide this capillary break and a functioning drainage path.

If the water cannot shed properly from and through the air space, it will collect in the air space, locally increasing the humidity inside the building envelope and eventually finding another path to escape the air space such as migrating towards the interior of the structure. **Figure 3(a)** illustrates a properly constructed cavity wall where moisture that has traveled through the porous veneer drains down the drainage plane within the air space to the exterior. **Figure 3(b)** illustrates a non-functioning air space filled with mortar. The moisture absorbed by the veneer migrates across the mortar by capillary suction and into the wood framing and insulation.

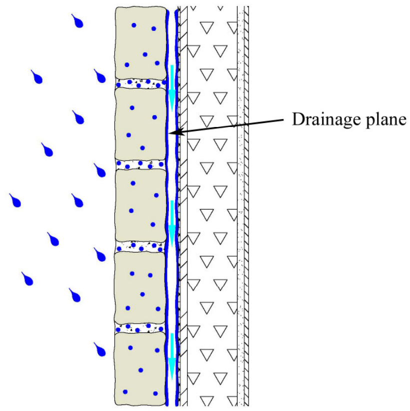

Figure 3(a). Properly constructed wall cavity

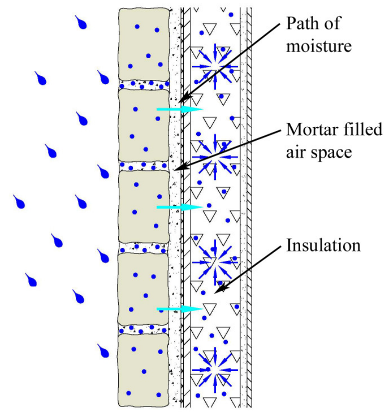

Figure 3(b). Improperly constructed wall cavity

Weather Barrier

The weather barrier minimizes the passage of moisture-laden air by convection. It is also resistant to liquid water by shedding of the moisture; however, the weather barrier is both breathable and permeable.

Vapor Retarder

The vapor retarder limits the diffusion of water vapor driven by water vapor pressure differentials. Many construction materials have a published vapor permeance rating. A high perm rating means that the material allows easy diffusion of water vapor through its thickness. A low perm rating means that the material resists the passage of water vapor. A vapor retarder is generally defined as a material with a vapor permeance rating of 1.0 perm or less (Odom 2000). **Table 1** below provides a summary of approximate vapor permeance for select building materials commonly used in residential wall construction.

Table 1. Approximate Vapor Permeance of Select Building Materials
(DuPont 2007, Beall 1999, MHRA 2011, Odom 2000)

Material	Vapor Permeance (perm*)
DuPont™ Tyvek® Home Wrap	58
Brick Veneer	40
1/2" Gypsum Wall Board with 2 Coats of Latex Flat Paint	19.54
Oriented Strand Board (OSB) Sheathing	2
1/4" Plywood, Douglas Fir, Interior Glue	1.9
Oil-based Paint on Wood (3 coats)	0.88
0.004" Polyethylene Sheet	0.08

*A perm rating of 1.0 represents 1 grain of water (1/7000 of a pound) passing through 1 square foot of material in 1 hour.

Building materials can be further separated into three general classes based on their permeability: vapor impermeable (less than or equal to 0.1 perm), vapor semi-impermeable (greater than 0.1 to 1.0 perm), and vapor semi-permeable (greater than 1 perm) (Lstiburek 2004). Vapor permeable (also referred to as breathable) represents materials with more than 10 perms.

Wall Sheathing
Sheathing typically consists of a layer of sheet material applied to the exterior side of the wood framing. It serves to strengthen the structure and act as a base for the weather and/or vapor barrier. Common exterior wall sheathing materials include plywood and OSB. These materials typically have a low permeance and can, by themselves, provide a degree of vapor retardation when properly installed and sealed.

Wall Insulation
Thermal insulation is provided inside the exterior stud wall to slow the ***rate*** of heat transfer across the exterior wall. Common types of insulation in residential construction include fiberglass batt insulation and cellulose insulation.

Fiberglass Batt Insulation. Fiberglass batt insulation has been used in the construction industry for many years. The main advantages of fiberglass batt insulation include low cost, fairly high R-value, and ease of installation (Allen 1999). Fiberglass batt insulation is tolerant of moisture due to the characteristics of the insulation fibers. Fiberglass, due to its inorganic composition, does not decompose readily, rendering it a poor choice for the environment.

Cellulose Insulation. Cellulose insulation is made from recycled paper and treated with mold retardants and fireproofing chemicals. There are two kinds of cellulose insulation application methods: dry and wet-spray. Typically in residential wall construction, cellulose is wet applied. Two advantages include low cost and fairly high R-value (Allen 1999). Cellulose insulation is hygroscopic, meaning it is very effective at absorbing and retaining moisture. Wet-spray cellulose insulation has two important application limitations: it requires an experienced installer and it must be allowed to dry properly before it is covered up.

According to the North American Insulation Manufacturers Association (NAIMA), proper curing time of the wet cellulose insulation before enclosure of the stud wall is vital to the overall performance of the insulation. A study performed on cellulose insulation in Newfoundland, Canada, a humid climate, revealed that gypsum board installation prior to the proper dry-out period of wet cellulose insulation resulted in the cellulose and the wood framing having a moisture content of 60% after two years (NAIMA 2011). Typically, wood used for residential wall construction is untreated. As long-term moisture contents above 19% are conducive to wood rot and mold growth, improper curing of the wet cellulose insulation can therefore result in material degradation.

According to NAIMA, other studies have been performed under various humidity conditions. These studies also analyzed the impact of vapor retarders and drying times of the cellulose after allowing it to cure for two days (considered consistent with field practice). The shortest dry time was 1 month in a dry climate without a vapor retarder in the assembly. With vapor retarders on both sides of the system, it took more than 1 year for the insulation to dry in humid, moderate, and dry climates.

Other sources of liquid moisture include interstitial condensation. Within a wood-framed wall condensation is dissipated differently depending on whether cellulose insulation or fiberglass "batt" insulation is used (Lstiburek and Carmody 1994). The cellulose insulation is more prone to hold the condensation than fiberglass insulation.

Interior Finish

Interior finishes typically include painted gypsum board, vinyl wall covering, hardwood paneling, and wood trim. Many of these materials function as unintended vapor retarders. Examples include oil-based paints, vinyl wall coverings, and hardwood paneling.

Fenestration

Fenestration units such as doors and windows create discontinuities/openings in the envelope's moisture resisting system; therefore they must be designed and constructed to control moisture intrusion within the cavity wall assembly. Water intrusion is controlled around these openings with flashing and sealant.

The authors have found that most instances of water intrusion at door and window openings in cavity wall systems is the result of construction deficiencies, including incorrect manufacturing and/or installation of the fenestration unit, incorrectly applied or missing flashing, and/or a weather barrier that is not properly installed or sealed to the fenestration unit.

DESIGN CONSIDERATIONS OF MASONRY VENEER CAVITY WALL SYSTEMS

Masonry veneer is considered porous or absorptive, and both liquid water and water vapor will penetrate the masonry into the air space. The masonry cavity wall assembly must be designed and constructed to drain this moisture and prevent it from migrating past the air space and into the stud wall where it can damage the insulation and interior finishes.

Water vapor will migrate from a region of higher vapor pressure to a region of lower vapor pressure. Since cooler air typically has a lower vapor pressure than warmer air, a masonry veneer cavity wall system should be designed and built to address inward migration of moisture in a hot-humid climate where the cooling season is dominant.

The proper location for the vapor retarder within the wall cavity depends on the climate where a structure is located. Typically moisture will condense on the colder side of a wall system. In warm climates, where moisture travels from the outside to inside, the vapor retarder is typically located on the outside of a wall system (wall sheathing).

Exterior walls should be limited to a single vapor retarder to allow a path for moisture that enters the cavity to escape. If vapor retarders are installed on both sides of the wall, moisture can be trapped in the wall insulation and prevent the wall cavity from drying. Materials should be selected with an increasing perm rating in the intended direction of drying. For example, in a predominantly cooling climate, the masonry veneer cavity wall component with the lowest perm rating should be installed closest to the air space and each component toward the interior should have a higher perm rating to facilitate incidental moisture migration toward the interior. It is important to recognize that some commonly used materials will function as vapor retarders or barriers when they are not intended to. Examples include interior finishes such as enamel paints and hardwood paneling.

In addition, exterior wall assemblies constructed with wet lumber (greater than 19% moisture content by weight) or employing wet-applied insulation (for example, wet-spray cellulose) require special attention. These assemblies must be designed and built so that they can dry to the exterior or interior, and/or the materials must be allowed to dry prior to enclosure (Lstiburek and Carmody 1994). Most cellulose insulation manufacturers recommend against the use of vapor retarders in walls insulated with spray-applied cellulose.

Flashing is critical to a successful masonry veneer wall cavity system design. Proper flashing of all wall fenestration units should be clearly specified and detailed in the construction documents. Once installed, flashing should be verified for proper installation by the general contractor/builder and/or prime design professional prior to installation of the masonry veneer.

CASE STUDY – TESTING AND ANALYSIS

Testing

High moisture readings of the interior finishes at the exterior walls led to performing additional testing at the exterior walls to determine the source(s) of the moisture and path of moisture migration.

Water Testing and Exterior Stone Veneer Removal

Water spray tests were conducted at various locations around the structure using a nozzle at a controlled pressure of 30 to 35 psi at a distance of 1' away from the stone veneer. Sections of walls were sprayed for a period of 5 minutes. After water testing, sections of stone veneer were removed and revealed that the air space was filled with mortar and the mortar was packed against the Tyvek weather barrier. In addition, at the removed stones adjacent to windows, the Tyvek weather barrier was not sealed around the window frame. Galvanized metal ties and nail fasteners were corroded. The Tyvek weather barrier was then cut to observe the OSB sheathing. The sheathing was saturated with water (moisture content greater than 19%).

Additional Stone Veneer Removal

Additional stones were then removed from various locations on all sides of the structure in areas corresponding with observed interior distress, both in the field of the wall and adjacent to windows. The stone removals revealed a general lack of an air space behind the stones, with mortar packed against the Tyvek barrier. At the exposed window locations, improper or missing flashing was observed.

Gypsum Board Removal

The interior gypsum board was removed at the exterior walls to evaluate moisture and moisture distress inside the stud wall. At one location away from the windows that exhibited elevated moisture readings, a section of wall finish was removed, revealing mold growth and moist cellulose insulation to the touch.

Analysis

Our investigation revealed deficiencies in the construction of the building envelope, including the mortar-filled air space and missing and deficient window flashing. These deficiencies resulted in water intrusion and high moisture conditions within the stud wall, which manifested into deterioration of the materials in the wall assembly and promoted an environment for mold growth.

Evidence of Moisture
High moisture conditions were noted at all exterior walls. High moisture readings were recorded around windows and at areas away from windows. The fact that moisture readings were elevated away from windows indicated that the causes of moisture intrusion were not limited to window-related deficiencies. Additional evidence of water intrusion through portions of the building envelope include observed mold at wall finishes.

Pattern of Distress
The mold growth on the interior wall surfaces was noted behind the finished hardwood and painted wood trim, but not at the exposed painted gypsum board walls. The relevant difference between the gypsum board and the enameled wood trim and varnished paneling is that the latex-painted gypsum board is vapor permeable, while the enamel-finished wood trim and varnish-finished plywood paneling act as vapor retarders.

Moisture was trapped at the back side of the varnished and enameled materials because these finishes are vapor retarders and prevent the wet cellulose insulation from drying to the inside of the structure. Moisture passed across the vapor permeable painted gypsum board surfaces. **Figure 4(a)** represents the walls with painted gypsum board finish. **Figure 4(b)** represents the walls covered with hardwood paneling and painted trim.

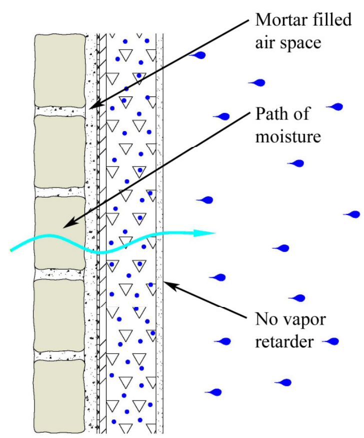

Figure 4(a). Moisture passes through wall

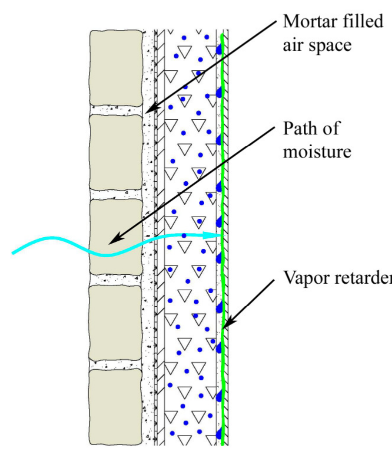

Figure 4(b). Moisture blocked by vapor retarder

Construction Deficiencies
Properly constructed cavity wall air space, weather barrier, and window flashings should keep the exterior wall cavity dry. The construction defects at the subject structure, including the mortar-filled air space and missing and deficient window flashing permitted moisture to penetrate past the air space. The moisture then accumulated in the cellulose insulation due to its hygroscopic nature. Other construction deficiencies include the use of incompatible building materials for the regional climatic environment. Incompatible materials include the cellulose

insulation (a hygroscopic material), in conjunction with the wood paneling and enamel-painted wood trim (both vapor retarders) installed at the interior of the wall system, as discussed below.

Incompatible/Multiple Vapor Retarders

In the subject structure, moisture was trapped between the exterior vapor semi-permeable OSB and the interior vapor retarders (varnished hardwood paneling and enamel-finished wood trim). Water condensed behind these interior elements when the dew point of the moist air was reached within the stud wall. The use of vapor barriers in walls insulated with cellulose is not recommended (CIMA 2011).

Impact from Cellulose Insulation

The high moisture readings recorded near windows and at wall areas away from windows indicated that the causes of moisture intrusion were not only limited to window related deficiencies. The moisture intrusion came from two sources; capillary suction across the mortar packed in the masonry wall cavity and liquid water across the deficient window flashing. The moisture migrated to the cellulose insulation where it accumulated due to the hygroscopic nature of the material. While mold growth would have still occurred behind the finished hardwood and painted wood trim with the use of a nonhygroscopic insulation, the absorptive tendency of the cellulose insulation added to the severity of the condition by retaining moisture and not allowing the cellulose insulation to dry out as quickly as a nonhygroscopic insulation. In addition, the cellulose insulation may not have been adequately dried before it was enclosed with gypsum interior finishes. Further, whether moisture infiltrated post-construction, or was present in the wall since construction, the moist insulation was not able to dry because of the use of materials that, in essence were vapor retarders on the interior sides of the wall assembly (varnished hardwood paneling and enamel-finished wood trim) and the exterior sides of the wall assembly (vapor semi-permeable OSB wall sheathing).

CONCLUSIONS/LESSONS LEARNED

When specifying material components, the project designer must consider the materials' tolerance for common construction defects or imperfections, and the implications thereof. In residential construction, often there is no designer and the builder is responsible for integrating the various components. Whether the designer or the builder is responsible for specifying material components, the following should be addressed:

1. Masonry cavity wall moisture intrusion is inevitable and drainage of the cavity wall is an intrinsic design requirement. It is imperative that cavities are kept clean of mortar droppings during construction.

2. Cellulose insulation should be allowed to dry in at least one direction. Installation of cellulose insulation between two materials that perform as vapor retarders in an exterior wall is not recommended. The same recommendations should be considered when vapor semi-permeable materials are used.

3. Designers and builders should be thoroughly familiar with both the requirements and limitations of green building materials. For example, care should be taken to ensure wet-spray cellulose insulation is allowed to dry and independently verified prior to enclosing the insulation in the wall system. Additionally, care should be taken to ensure additional moisture is not added to the cellulose insulation by means of condensation or moisture intrusion.

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