THE HIDDEN RISKS OF *Green Buildings*

Avoiding Moisture & Mold Problems in Green Buildings

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Yesterday's seal of approval for new products was "It was developed by NASA." Today the seal of approval is: it's "organically-produced," LEED© certified, "earth-friendly," or some variation of the above. Just as "NASA-developed" was no guarantee of success, neither is LEED©-certified any assurance of no problems, especially those problems related to moisture accumulation.

Although some indicators of a building's performance (such as occupant comfort, energy usage, and odors) can be ignored, you can't easily ignore water pouring through a wall assembly. We don't believe that anyone would deem a structure "sustainable" if it cannot survive the first five years without a major renovation because of moisture problems.

It's our belief that the moisture integrity of a building is one of the best report cards on the performance of its design and construction process and the correct use of materials.

After reviewing the designs of hundreds of new buildings over the past 20 years and observing the failures in an equal number of structures, the authors have found the following consistent truths:

- **Building Commissioning**—The current industry approach to building commissioning (even the LEED© Enhanced Commissioning version EA Credit 3) is unlikely to prevent moisture and similar building failures in almost any climate, except for the most forgiving climate.
- **New Materials**—The use of many new building products often has the unintended consequence of performing in unexpected ways, sometimes encouraging significant moisture accumulation and mold growth. Since wall and roof assemblies have historically been high risk areas, it should be no surprise that the increased use of new products in these areas can dramatically increase the overall potential of moisture problems within the envelope.
- **Increased Building Ventilation**—The positive benefits of increased outside air ventilation for the occupant's health and comfort can oftentimes be outweighed by the increased potential for moisture problems, some of which have caused catastrophic failures. Forensic engineers have strong evidence that buildings can perform in unexpected and damaging ways when additional air is moved through them.

Through our evaluation of various LEED© credit opportunities, we hope to establish the fact that a sustainable building must be equally designed to prevent likely moisture and mold problems. We believe that a building attaining LEED© certification does not necessarily have a low potential for failure due to moisture intrusion. However, it is our belief that it is possible to combine LEED© certification with the best practices for moisture and mold problem avoidance – but it will require extra effort from both architects and mechanical engineers.

An important aspect to avoiding moisture problems in green buildings is the inclusion of the best practices from the waterproofing/HVAC disciplines in combination with the LEED© certification principles. It is unwise to assume that LEED© certification has automatically incorporated those best practices. Green building practices must always be subservient to best design practices in areas such as exterior waterproofing, humidity control, and due diligence in selecting new construction materials.

To facilitate the dual vision of an environmentally sensitive building with a highly-durable, well-performing, moisture-resistant building, we have compressed a significant amount of data into the following discussion including a detailed analysis of specific LEED© credits that we view as examples of high risk. These credits align with the consistent truths we listed above concerning building commissioning, new materials, and ventilation issues.

These concerns are not climatically or regionally specific but are universal for all but the most forgiving climates. Forgiving climates would include those areas with very low rainfall, year-round moderate temperatures, and minimal humidity levels. Even

Green Buildings	Lower Risk Buildings
Add additional outside air (>ASHRAE by 30+ %)	*Minimizes* outside air (Does not exceed ASHRAE guidelines)
Emphasize energy conservation	Emphasize dehumidification
Stress VOC reduction --Emphasizes exhaust (>5 Pa) --Building flush out	Minimizes VOC concern --Very tight control of exhaust --Rejects building flush out
Stress new, innovative materials	Stress proven materials
Stress carbohydrate based materials	Stress hydrocarbon based materials
Stress extra envelope thermal insulation	Stress drying potential of envelope (walls and roof)

in those climates, specific building types could be expected to exhibit problems if best practices are not followed.

Building Commissioning

Energy & Atmosphere Prerequisite 1 and Credit 3

Building commissioning (even the enhanced version of commissioning in LEED© EA Credit 3) is not likely to prevent catastrophic moisture and mold problems. Traditional commissioning fails to accomplish two primary requirements in avoiding moisture problems:

1. The design review is not likely to be a "standard of care" technical peer review, but is often a review intended to determine if the constructed building, once built, can be commissioned and if the design meets the owner's intent. In our experience, the typical design review will not predict the potential for moisture and mold problems. Without this prediction, it cannot offer specific solutions to avoid them.
2. These reviews are not required to incorporate an analysis of the building envelope's performance—the acknowledged component that fails the most frequently and usually the most dramatically.

What the building science industry has known for some time is that moisture and mold problems are often very predictable, even in the early design stage. However, for this analysis to be successful, the review team must be very savvy about what combination of design choices create a high risk of causing problems and what other choices are lower risks.

Concepts that should be included in building commissioning to reduce the possibility of moisture and mold problems include:

- During the design phase, a technical peer review of the document should identify issues that will likely be a major cause of moisture and mold problems in the operating building. This review may need to be accomplished by someone other than the traditional commissioning agent since they may not have the requisite skill set to conduct this type of analysis. It's our opinion that this review needs to specifically identify which building components and systems have a high potential for moisture problems and offer alternative solutions to the design team.
- The commissioning process needs to consider the interrelationship of the building envelope and the HVAC system. This area is often overlooked because it involves the dynamic interaction between two separate technology areas.
- The building envelope needs to be commissioned in a manner that would avoid rainwater leaks, excessive air leakage, and condensation problems. In cases where the envelope is commissioned, both individual envelope components (like windows) should be tested, as well as assemblies of multiple adjacent components. Testing individual components does not address the connection points and intersections between various envelope components where most of the failures occur. Assembly testing can include a mix of qualitative and quantitative testing, such as ASTM tests.
- Construction phase commissioning of envelope components may require adjustment of installation methods based on test results. Checklists should be developed that allow for certification that such adjustments are implemented.

New Materials

Multiple Materials & Resources Credits

New green materials can often meet requirements in several LEED© credits. Many new materials and concepts can also fall under the Innovation & Design Process credit requirements for developing new solutions, employing new technologies, or realizing exemplary performance.

We believe that it is reasonable to assume that if we are relatively unfamiliar with a new material's individual performance, then we probably know even less about the material's interaction with other adjacent components. Our ignorance about the performance of new materials should not be disregarded because the manufacturer of these materials assures us that the product is appropriate for LEED©-certified buildings. The recognition of additional risk in the use of innovative products (especially in the envelope and HVAC systems) by the development team should demand a higher degree of rigor in the evaluation of these products.

As previously mentioned, the interaction between the HVAC system and the envelope creates an unusually high-risk area. The impact of this condition is that any deficiency in either system can cause dramatic building-wide moisture problems.

It may be only a slight overstatement to state that there is no wall system that a creative architect can envision that a poor HVAC system cannot destroy. Conversely, a very well-performing HVAC system can often compensate for a marginally-designed (or constructed) building envelope to the point where many moisture problems may never be noticed. However, there is a point where even an exceptionally well-performing HVAC system cannot compensate for a poorly-designed wall system, especially a wall that allows rainwater intrusion or is excessively leaky to air movement.

Although new wall system products are often intended to provide better thermal insulation, reduce air movement through walls, or allow enhanced drying of the wall assembly (via vapor diffusion), they can also perform in unanticipated ways. These new products can dramatically change the way moisture flows through wall and roof systems and the potential for condensation within these cavities. Their use mandates that the designer implement several additional steps to avoid problems:

1. Better understand the performance characteristics of these new products. This may require a more rigorous evaluation of these materials. As with any product – but more so with new products – the performance answers may not be found in the product data sheets but may require experiments and mockups. This type of evaluation may be beyond the scope and expertise of the design team—but it should nevertheless be implemented.

2. Analyze the vapor retarder, air barrier, and bulk water retention properties to better understand where the material should be placed, if at all, within the wall system.
3. Model the wall systems for performance during the early design stages to predict the potential for water vapor transmission through the wall assemblies and potential for condensation to occur. Minimally, this modeling should predict the dew point location and the vapor transmission profile during the most extreme season for the location.
4. Perform a three-dimensional analysis of rainwater barrier geometry, especially at complex joints and changes in plane.

Increased Building Ventilation

Environmental Quality Credit 2

For decades there have been competing arguments within the mechanical design community on whether to increase or decrease the amount of outside air that is introduced into commercial and institutional buildings. Although there are sound arguments on both sides of the debate, today's emphasis on increased building ventilation to achieve LEED© credits has given an added incentive to increase the amount of outside air to buildings. The experience of many forensic building experts (especially in the eastern half of the country) does necessarily support the theory that adding more outside air creates a better performing, more sustainable building—sometimes quite the opposite.

What is known about ventilation air is that in regions with ambient high-dew-point conditions and elevated relative humidity levels, there is a direct correlation between the number of moisture problems and increased rates of mechanical building ventilation. This can occur for obvious reasons, such as the additional moisture load that is introduced into the building along with the outside air. However, more obscure reasons can also increase the risk of adding outside air to a building. Unbalanced (or partially depressurized) buildings can be the result of moving large amounts of air around a building. When this condition occurs, moisture problems become more prevalent. These unbalanced conditions happen when air is trying to flow from the supply side of the air handler equipment to the return side but is restricted by structural or architectural barriers.

Florida Solar Energy Center (FSEC) of Cocoa, Florida, called this condition the "Smart Air Syndrome" concept—that air is supposed to be smart enough to get from one place to another in spite of barriers. Additional ventilation air should always be designed in conjunction with considering the impact of the distribution of the ventilation air. This requires identifying parts of the building that could become depressurized with respect to outside conditions, thus potentially drawing humid outside air into the envelope cavity or occupied spaces.

FSEC's research has demonstrated the relationship between building complexity (architectural and structural complexity), the intensity of the HVAC drivers (air volumes and pressures), and the risk of building failures. The solution is not to build simpler, less ventilated buildings but to insure that the ventilation air is effectively delivered to the space. This means that ventilation must be distributed so that it not only reaches the desired breathing zone but does so in a manner that does not adversely affect the building.

The HVAC system that introduces ventilation air must also do so in a manner that properly dehumidifies the air. The "golden rule" of moisture control is that under no circumstances should adequate dehumidification be sacrificed for increased ventilation. In many regions of the country during summertime conditions, the moisture load contributed by the outside air can exceed the amount of moisture that the airconditioning system can effectively remove.

The solution is to address these risk factors in several ways:

- Insure the correct distribution of air flows within buildings (to avoid pressure imbalances). This can usually be accurately predicted during design.
- Increase the verification of HVAC system performance by adding additional elements to the building startup and commissioning programs. This post-construction verification includes detailed pressure mapping of the building to confirm proper air distribution and using temperature and relative humidity (RH) dataloggers to confirm conditions during the first year's operation. This pressure mapping and data logging needs to also include the building cavities—areas that are often ignored. Many of these elements are frequently absent in today's standard HVAC system startup and building commissioning programs.

What experience demonstrates is that increased amounts of outside air can be safely added to a building if the known causes of increased risk (such as proper air distribution) are addressed during design and verified after construction.

Indoor Air Quality Management Plan

Environmental Quality Credits 3.1 and 3.2

During construction there can be increased pollutant load in a building because of various factors: heavy particulate load and the off gassing of formaldehyde and volatile organic compounds (VOCs) from newly installed products. There are various methods of controlling this additional pollutant load, such as additional air filtration, the use of temporary air handlers for heating and cooling, and flushing out the building with additional amounts of outside air.

As proposed by LEED© Credit 3.2, building flush out can occur either late in the construction phase or after the building is occupied. While the use of outside air to flush out the building may reduce the concentration of off gassing, it can also inadvertently cause moisture problems. Although the moisture problems may be short-term (decreasing after the flush out is finished), the resultant mold problems could be long-lasting.

The EQ Credits related to the Construction IAQ Management Plan allow for two separate approaches to building flush out, one during construction and an alternative plan after occupancy. Both approaches involve a substantial amount of outside air volume—14,000 cubic feet (cfm) per square foot (sf) of floor area. Whether this flush out occurs rapidly over a several-week period (during the late stages of construction) or more slowly over several months (during post construction), moisture problems are likely to result in many parts of the country during the summertime.

Increased building ventilation over the design amounts can create a range of problems, such as inadequate sizing of the air filters and an inability of the air conditioning equipment to handle the increased moisture (or latent) load. While the LEED© credit mandates a 60 percent RH maximum level during this flush out period, this requirement may not be feasible with the building's equipment. Since final building finishes should be in place prior to flush out (otherwise there are no materials to off gas), it makes the entire building susceptible to mold growth problems. If building flush out occurs after occupancy, then even the furnishings are susceptible to moisture problems.

In a typical 100,000-sf building, the amount of outdoor air required to meet the flush out portion of this credit is 1.4 billion cubic feet. This amount of air volume in the eastern portion of the U.S. during the humid summer months can be equivalent to over 200,000 gallons of additional moisture introduced into the building. This moisture is in addition to the normal moisture load from construction activities, cleaning liquids, or construction-related moisture from curing concrete, paint drying, etc.

One of the additional risks with conducting building flush out (especially in an occupied building) is that it is usually done in the evening when the heat load (sensible) is the lowest and the moisture load (latent) is the highest. This can result in even greater relative humidity levels in the building because the unfavorable ratio of sensible to latent load can cause overcooling (resulting in flash condensation). The additional likelihood that the HVAC system might still be unbalanced at the time of the flush out increases the potential for moisture problems as the result of this process.

Indoor Pollutant Source Control

Environmental Quality Credit 5

Depending on the climate where the building is located, it may be important to utilize different types of ventilation approaches to control indoor air quality degradation and indoor chemical and pollutant source control. In climates with outdoor air conditions that carry large summer moisture loads (which includes much of the eastern portion of the country), ventilation approaches should include a combination of exhaust and make-up air to achieve the pressure differentials required by the credit.

Conclusions

The green design movement is transforming the design and construction marketplace like no other innovation in the lifetime of most designers. Green design has brought to the forefront of the design and construction community a holistic view of how to design, build, and operate higher performing buildings. As such, the noble goals espoused by sustainable development and green buildings are certainly worth aggressively pursuing — but it must be done with significant care, especially in the areas of high risk for moisture and mold problems. It seems that some of the "best practices" and "lessons learned" in other fields are not applied in a precise manner when it involves green construction, at least as that applies to moisture control.

To summarize our recommendations, we believe that the following should occur in an effort to enhance green designs:

- A technical peer review of the design should be implemented that attempts to predict the building performance with the new materials and products. At a minimum, this review would focus on the HVAC and building envelope systems that are most exposed to moisture-related failures. This should provide a more climatologically and regionally accurate green design.

- The design team must be confident that they have incorporated institutional knowledge in the fields of humidity control, waterproofing, and building envelope performance. Processes that have already lost favor in the indoor environment field, such as "building flush out," should not now be incorporated into green construction as "best practices." These processes have historically shown little benefit and have demonstrated high cost, high risk, or both.
- The acceptance of new products with specific "green" benefits should be scrutinized. Gaining performance in one area often means sacrificing performance in another. If the sacrifice is a critical parameter (such as the water absorption qualities of wall insulation), then the risk may be too great, no matter what the benefit is. It may be unrealistic for a design team to make all of these required assessments, but without it building failure seems more probable.

Liberty Building Forensics Group, LLC (www.libertybuilding.com) is a firm that specializes in forensic building investigations and expert witness/litigation support. Its staff has led the correction and cost recovery for some of the largest building failures in the country, including the $60 million defect claims in Hilton Hawaiian Village in Honolulu and the $20 million Martin County Courthouse problems. Its staff has performed green building-related services on over $3 billion in new construction since the late 1990's and has authored three manuals and over 100 technical publications.

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