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The Physics of Mold

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The physics of mold.

1. INTRODUCTION.

The recent upswing in legal claims against architects, builders and developers has helped to focus on the performance of the building envelopes in various climatic conditions.

It also forced the building scientists to learn more about the microorganisms that develop their habitats inside the wall structures, namely mold and mildew. Previously this was the domain of industrial hygienists. Today, architects and engineers involved in the design of building envelopes must also understand the complexities of the process of vapor migration and the resultant problems of mold in building structures.

It was not until recently that new materials applied to building construction resulted in new and different conditions, creating almost airtight structures. One needs only think of the impact of silicon caulking applied so generously to buildings today. What was the technology of sealing, for example, the base plate to the foundation walls before the invention of caulk? In most cases, nothing. Imagine the air movement between the base plate and the top of the foundation then!

Was the fact that there were loose connections, and ill fitting doors and windows before the use of caulking became universal, a bad thing or a good thing?

The answer is: bad and good at the same time.

From a thermal envelope’s point of view, the movement of air through those imperfections is definitely bad.

For the removal of any impurities inside the building (by natural ventilation or leakage) or from the wall structure itself, the leakage is a good thing.

When walls became so tight that the natural ventilation of the structure was eliminated, a multitude of problems never before experienced started to surface.

Take the case of a nationally recognized architect, specializing in historic preservation. The Board of Directors of a museum, which operates in the homestead of one of our earlier presidents, hired him to fix the problem the museum building was experiencing. The original building was built in the eighteen century, and survived until the later part of the twentieth century.

The walls were plaster interior, wood balloon framing and wood clapboard exterior. There was no insulation. With the requirements of today’s museums, the humidity control required the addition of humidifiers to the central air conditioning system (installed earlier by another contractor). Suddenly, the plaster walls started to discolor due to moisture condensation inside the wall cavity.

The architect, realizing that the higher humidity created condensation inside the open wall cavity, specified blown-in insulation to be installed by drilling holes into the exterior clapboards and filling the cavities. His theory was that by raising the cavity temperature, he would eliminate the condensation problem. He intended to solve the vapor retardation problem by applying oil based paint to the interior surface of the plaster.

Unfortunately for the architect (and for the museum Board), in trying to save money, they followed the advise of the insulation supplier and allowed him to install cellulose blown-in insulation.

Just a few years later, the museum noticed that the discoloration of the (newly painted) plaster walls had returned, but this time it was worse than before. When the museum staff removed a section of the exterior clapboard, they found the cellulose insulation fully collapsed at the bottom of each cavity and caked into rock solid paper mache. The insulation had to be jack hammered out after removing the entire exterior of the building. The cost was extremely high.

What can we learn from this episode?

By applying a new component to a building wall (which stood well for almost 200 years) without a thorough analysis to adjust for the new requirements, the integrity of the structure was compromised, and eventually the building may have been destroyed.

In another example, a client asked to go to see his brand new house, which had just been completed the previous summer and was experiencing the first cold weather. The owner was complaining that despite the “super insulated” house, he was experiencing condensation everywhere to the extent that constant moisture started mold growth in the carpet under the windows.

The “super insulated” house was a typical wood frame structure. In addition to the standard wall cavity insulation and the visqueen vapor retardant, polyurethane foam had been applied over the entire exterior surface, including the walls, ceilings and basement walls. The thickness of the foam varied from 1.5” to 2”.

Upon entering the residence, a large number of potted plants were noted throughout the house. To the question of “how often are the plants being watered”, the owner answered, that his wife had been pouring about 15 gallons of water on the plants each day. The smell of high humidity was easily perceived. It was clear, that in addition to the moisture generated by normal activities, the house was suffering from abnormally high humidity levels due to the inability of moisture to escape from the building. Moisture was being trapped inside by the extremely tight construction.

The first advice given to the home owner was to open the doors and windows each day for a few minutes. The owner readily rejected this idea, stating that he did not build a super insulated house to waste the energy by allowing outside air to enter the building. Fair enough. The second suggestion was to bring outside air into the furnaces. The owner had the same response. The third recommendation was to buy a small heat wheel type heat exchanger for a make-up air system utilizing the exhaust air to recapture the wasted heat. Because of the cost of such equipment, the owner also rejected that idea. The author does not know what methods the owner eventually took to mitigate the humidity problem or what the state of the structure is today.

There are many ways that moisture can enter a building. Rainwater can enter due to gravity, wind, leaky building components, imperfect installation, etc. Other sources of water in the building could be from penetration of ground water, leaky pipes, and osmosis. The purpose of this course is to identify the causes of moisture condensation inside the wall cavities and the resulting mold problems due to vapor migration and condensation. The study of other reasons for moisture penetration belong to the field of construction technology and are not covered in this course.

2. CHARACTERISTICS OF MOLD

As mentioned in the introduction part, new construction technologies, the application of air conditioning systems, the use of new materials – especially in composite walls – have created conditions which are conducive to condensation and eventually can result in unhealthy buildings and unhappy occupants.

Remember the hotel in Philadelphia where the Legionnaire’s Disease first surfaced? The cause, as it turns out, was the introduction of air into inhabited spaces through a dirty air conditioning duct containing mold growth combined with the population in the hotel of elderly people who had compromised immune systems. This combination proved to be deadly. Without the air conditioning system, one can argue, this tragic incident would not have occurred. (A better argument would be that without a dirty duct this tragic incident would not have occurred).

The Philadelphia Legionnaire’s Disease tragedy illustrates that there are two components that must be present to cause a health problem in any building (sick building): a vehicle to create a preferable environment for the mold to become viral and the presence of people to react to the toxicity of the mold.

To understand the first component, one must recognize the fact that mold is a part of our natural environment. Mold, either alive or in a dormant form as spore is all around us, both inside and outside of buildings. The vehicle to activate the spores and to allow them to become active is to have the right environment: they need the right temperature, they need food and they need water. When those conditions exist, mold starts to grow and in the process they produce toxic materials. The production of mycotoxins (the toxic agents that attack the human nervous system) can happen in less than 24 hours after exposure of the mold to the right conditions for growth.

Not every mold is toxic. (The use of molds in the production of cheese, salami, fermentation of wine and beer goes back to centuries. Molds are also basic components in the production of antibiotics). Not everybody reacts to mold toxicity the same way.

Although quantum leaps in development were made during the past decade, the study of human toxicology is still in its infancy and has a long way to go to identify all the connections between toxic mold and human health and to establish acceptable threshold levels for exposures. There is one consensus, however: people with a compromised immune system are more vulnerable to mold toxicity than others. These are the people who are most likely to suffer from rashes, flue- like symptoms and respiratory diseases in the presence of airborne or surface grown mold while others happily go on without any symptoms in the same environment. And that is the second component of the equation: the human body.

The wide variety of molds in nature makes it even more difficult to categorize their effects on people. (Today, several thousands of different mold species and sub-species are identified, a large percentage of them toxic). The technical literature so far has concentrated the studies on the"warm weather" mold (thermal tolerant molds), since this is the area from which most complaints have originated. Yet there are molds that grow and thrive in cold environments. (Cryophytic molds). We have no information so far on the toxicity of the cold molds. We know in tropical areas the high temperature mold (thermophyllic mold) is in abundance and there is data that suggests that people in hot climatic zones are getting sick from them. The moderate climate mold is characteristic in the majority of the continental United States.

The most common molds in the moderate climate are the fungi Penicillium, Aspergillus flavus and Aspergillus parasiticus. The mycotoxins produced by these molds are the most toxic and carcinogenic that have been identified. Stachybotrys chartanum (black mold) belongs to the same category. Upon entering the human body either by inhaling, digesting or through the skin, they can begin to colonize in the sinuses and spread throughout the body, including the digestive track, lung and eventually to the brain.

The U.S. Environmental Protection Agency has published guidelines on basic mold cleanup methods, identifying typical reactions and causes. The following list of "Ten things you should know about mold" is a loose quote from their brochure:

1. Potential health effects and symptoms associated with mold exposures include all kinds of reactions, rash, lesions, asthma or other respiratory complaints.
2. There is no practical way to eliminate all mold and mold spores in the indoor environment; the way to control indoor mold growth is to control moisture
3. If mold is a problem in your home or school, you must clean up the mold and eliminate the sources of moisture.
4. Fix the source of water problem or leak to prevent mold growth.
5. Reduce indoor humidity (to 30-60%)
6. Clean and dry damp or wet building materials and furnishings within 24-48 hours.
7. Clean mold off hard surfaces with water and detergent, and dry completely. Absorbing materials that are moldy might need to be replaced.
8. Prevent condensation: Reduce the potential for condensation on cold surfaces by adding insulation.
9. In areas where there is a perpetual moisture problem, do not install carpeting.

10. Mold can be found almost anywhere; they can grow on virtually any substance.

3. CLIMATIC ZONES.

The continental United Sates has basically four different climatic zones:

1. Cold - the Northern tier States
2. Moderate – The central part of the country
3. Hot and humid – The Southern States
4. Arid – The Southwestern States.

Each zone and each region requires different approaches to the design of the building envelope to avoid condensation and the consequent troubles associated with condensation. However, prior to discussing the different construction techniques, we must investigate the mechanisms of moisture collection due to water vapor condensation in the building components.

Our study will focus on the physics of vapor transmission and condensation in buildings. The moving forces acting to guide moisture into the building components are different in the different climatic zones.

Water vapor is always present in the air. The air, being made up of mostly oxygen, nitrogen, and water vapor as the main gaseous components, gets its molecular pressure from those components. Every gas present in the air has its own pressure, independent from the others. The pressure exerted by each of the component gases is called the partial gas pressure. The sum of the partial gas pressures is the total air pressure.

Since the component molecular gas pressures are independent from the others, each component moves by its own pressure differential. Therefore, water vapor can move independently from the remaining (mostly oxygen and nitrogen) pressure. This thesis is very important to understand the basic reason why vapor can move in any direction despite any other pressures being present. The fact that in any vessel, the gases automatically form perfect mixtures illustrates the concept of independent partial pressure.. (Just like oxygen moves from the higher pressure area, such as from an oxygen supply outlet, to occupy the room volume evenly by its own partial pressure).

4. VAPOR MIGRATION

Water vapor always moves from the higher vapor pressure area towards the lower pressure zone. Higher vapor pressure generally occurs on the higher temperature side of the wall, however, that is not always the case. Lower temperature and very high absolute humidity can produce a condition where vapor moves from the colder side towards the warmer side.

The level of partial vapor pressure, of course, is a function of the amount of moisture in the air. Low levels of absolute humidity will result in low levels of partial water pressure. (Absolute dry air has no water molecules; therefore it has zero partial water vapor pressure). At any given temperature, the maximum water vapor pressure occurs at the saturation conditions. (On any good psychrometric chart, the vapor pressure scale is indicated along the absolute humidity scale.)

Vapor can enter the building wall due to air movement. High levels of air velocity can result in an increased level of vapor delivery . However, one must understand that water vapor can and will move against the movement of the air if the partial vapor pressure acting in the opposite direction is higher than the velocity pressure of the air. This fact is often overlooked in the technical literature. To help the release of the water vapor from the inside of the wall, a structure preventing easy air movement is a basic necessity.

Psychrometrics is a key knowledge in understanding vapor migration and condensation in building structures. Since the interior and exterior air conditions across the wall, roof, etc. are always changing, the vapor pressure differentials are also in constant flux. That's what makes the calculations difficult in practice. To further complicate the issue, condensation might or might not occur even if moisture moves through the structure in the form of vapor, depending on the climatic conditions. Remember, if there is no condensation and liquid water, mold will not have one of the key components required to grow.

So, there are two possible ways to reduce or even eliminate mold growth:

1. Eliminate moisture from the building structure
2. Eliminate condensation where it can cause problems.

In theory, moisture entering the building structure can be eliminated if the building is wrapped in a 100% effective vapor barrier.

Let's say the building in question is in the cold zone, where the problem is that vapor usually migrates from the warm and humid interior towards the cold and dry exterior. The challenge is to install a vapor barrier on the warm side of the wall, preventing the moisture from entering the structure. The problem is that, in reality, a 100% efficient vapor barrier does not exist. Even if a contractor could install a vapor barrier perfectly sealed at the edges, there would still be the need for pipe, conduit penetrations, and window and door frames to penetrate the walls. (Not to mention electrical outlet boxes, switch boxes, ductwork, light fixtures, drywall screws, etc.). In practice, there is no such thing as a perfect vapor barrier. That is why some experts in the industry started to use the term "vapor retardants" in place of "vapor barriers". And rightfully so.

When vapor enters the wall in a cold climate, sooner or later it will hit a layer of the construction where the temperature is at or below the dew point condition which is the point at which the vapor changes phase from gas to liquid. While this itself is not cause for concern (remember, the dew point is probably well below the temperatures most spores like to germinate), the continuing process of collecting water in the wall cavities will result in accumulation of water. Because of gravity, water will flow to the bottom of the cavity. It eventually will find its way to the warmer regions of the wall, where now all of the three components required for mold growth will exist, since organic material is always present in building materials.

So far we have not taken into account the other potential damage that can result from vapor condensation.

Let’s assume a wall construction consisting of a wood frame with drywall, visqueen vapor retardant, 3-1/2” fiberglass insulation in the wall cavity, some kind of backboard (let’s assume plywood, more about this later), and a 4” exterior brick facing. This is a typical house structure.

Once vapor condensation starts inside the fiberglass insulation (because that’s where the first condensation will occur), the original insulating value of the fiberglass is lost and the condensation zone will be moving towards the interior surface. As the insulation collapses, a large portion of the wall’s heat insulating capacity is ruined. At the same time, condensate will freeze and the structural integrity of the wall is now in danger.

The above scenario will play out for any wall construction. The amount of damage might be more or less, but damage will be done. But in a cold climate where the outside temperature can be below zero degrees F, the temperature gradient will always cross the condensation line and the freeze line. Thus, condensation and freezing will occur.

The techniques used to minimize the effect of the moisture condensation involve
a) selecting insulating materials that do not react to the presence of water by changing the physical characteristics of the insulation and b)selecting insulation materials that allow the (inevitable) vapor to escape from the structure before it creates the favorable conditions for the spores to get activated.

Closed cell type insulation can be selected to ensure that the presence of water does not change the physical characteristics of the insulation. When condensation has no place to collect inside the insulation layer, it will not ruin the insulating value of the material, the vapor pressure (due to the higher level of absolute humidity) will increase and the moisture will try to move on.

This is the area where the designer has the responsibility to assure that the moisture can move freely.

In the aforementioned example, we used plywood as a backboard for laying the face brick up. Because the plywood is not water tight (neither is the fascia brick), code officials often instruct designers and builders to install water barriers on the outside of the backboard. The most frequently used water barrier is tarpaper. Tarpaper is not only a water barrier, but is also vapor retardant. If some other form of backboard is utilized, care must be taken to avoid selecting a product that could act as a vapor barrier or even a vapor retardant. A good example of such product is a frequently utilized “black board”, a petroleum impregnated particle board which is advertised as a non-vapor barrier component. One manufacturer claims that their board has a permeability of 2.5 perms. (One perm equals water transmission of 1 grain through 1 sf surface in 1 hour under 1in mercury pressure differential. 7,000 grains equals 1 lbm water).

Industry standard says that a material that has a permeability higher than 1.0 perm is not a vapor retardant. The problem is that the manufacturer of this particular product changed their manufacturing standards, but did not retest the new product. An independent test showed that the new board had a permeability of 0.7 perm, placing it into the category of vapor retardant. The result was that several hundred homes built with this material have experienced mold growth and had to be stripped of the exterior finishes and properly rebuilt.

By applying a second layer of vapor retardant at the point where it could restrict the movement of vapor toward the (low vapor pressure) outside zone, we are creating conditions that will become detrimental to the health of the wall. In other words, we are ruining the chances for the water vapor to escape the structure. If the vapor condenses into liquid form, then under favorable conditions it could re-evaporate or, if it froze, it could sublimate and leave the wall That is the natural way of solving the moisture accumulation problem. (Sublimation is the change of phase from solid to gas, without going through the liquid phase. This can be observed in the ice storage bins inside the household refrigerator’s freezer section, where the ice “evaporates” without first turning into liquid).

One should think of the building wall as a bottle that accepts water trough a funnel on the top and simultaneously drains it at the bottom through a control valve. The designer of the structure has to try to keep the inflow and the outflow in equilibrium by adjusting the outflow valve. If the outflow valve is too restrictive water will accumulate inside the bottle. The difficulty is that the inflow rate is constantly changing. Maintaining equilibrium is difficult under these conditions. The best chance of avoiding accumulation of water inside the bottle is to open the outflow valve as wide as possible. The analogy for designing walls for elimination of water accumulation is to design the composite wall structure to be well ventilated to allow water to escape from the wall.

5. WALL CONSTRUCTION.

Creating a well ventilated, but protected, airspace under the outside surface goes a long way to provide a release zone. Some literature calls this zone a “pressure equalization zone”. Although the vapor pressure inside this space eventually will equalize with the outside vapor pressure, the real function of the airspace is to allow the flow of water vapor from the inside to the outside, which means that there is still a pressure differential between the airspace and the outside air. The key is, however, that the airspace must freely communicate with the outside air. Interestingly enough, the standard clapboard or vinyl siding does an excellent job of providing this function. The same is true for the standard, ventilated attic space. (Ever wondered why ceilings do not have vapor barriers?)

In another case, the introduction of new materials without thorough analysis once again created problems for the construction industry: the synthetic plasters (dryvit, sto, etc.) applied directly to closed cell insulation have been shown to create a vapor barrier on the outside layer of the wall structure. By slowing down the pace of moisture exiting (or trying to exit) the wall, condensation and moisture accumulation can occur. In a cold climate, moisture migrating from the inside can collect under the insulation and cause damage in a winter freezing and thawing. In warm, humid climate moisture can collect on the wood framing or just inside the structure and contribute to the start of mold development. The producers of the synthetic plaster quickly recognized the problem, and developed a product that allowed for the ventilation of the zone under the insulation layer thus eliminating the vapor collection problem.

In a hot and humid climate, the problem is somewhat different than the cold climate conditions. In the mid-to-late 1970's the US Park Service found a puzzling problem with their historic structures that were restored just a few years earlier: they started rotting. Historic structures were mostly of wood frame construction in the South. The best way to save historic buildings is to make them habitable and put them back to use. That meant installing air conditioning, which required insulation in the walls. Of course, a good vapor barrier under the inside drywall was a necessity per the current construction guidelines.

Unfortunately, again, application of a new technology without proper evaluation proved to be disastrous. A short analysis of the thermal gradient in the wall would have shown that at the inside surface or just below, the (new) drywall finish lower than dewpoint conditions could exist if the temperature and the humidity on the outside were consistently high. Because the analysis was not performed, condensation and water collected on the outside facing side of the vapor barrier. This resulted in the wood structures starting to develop dry rot that eventually led to the structural disintegration of the building.

In hot and humid climates, most of the time, the higher vapor pressure is on the exterior. Water vapor is being pushed inward where the dryer conditioned air has lower vapor pressures. The vapor retardant should be placed on the outside (higher dominant vapor pressure side), not on the inside. Better yet, instead of putting a vapor barrier on the wall, select one that will have some breathing capacity to reduce the flow of the vapor, but allow it to escape during the night when the pressure relationship might be reversed. No cookbook solution can be assigned, since each climatic area is different. Each area needs careful evaluation before the composition of the wall is settled upon. Where conditions are such that no pressure reversal is expected and the outside vapor pressure remains higher than the inside due to air conditioning, it is usually best to eliminate all vapor barriers from the wall, and allow the wall to breathe freely.

Unfortunately, this option is not applicable to cold climate structures. Some in the professional literature advocate the total elimination of vapor barriers from wall structures. Anyone who lives in the cold climate areas of the US or in Canada will challenge the notion to go that way. Moisture condensation in the wall will result in more structural damage than any mold and mildew can ever create. As stated earlier, vapor will enter the wall structure. That is not debatable. The debate should center on how to reduce or eliminate the accumulation of the condensed vapor. As the previous examples show, the only natural way is to allow free, unrestricted movement of the vapor so that it can flow out of the wall structure.

During the past few years newer materials have been introduced that allow practically unrestricted vapor movement, yet they are excellent water repellant building wraps. Most widely used is the Tyvek by DuPont, but there are others on the market. Tyvek has a permeability of 62 perm, which provides an almost invisible barrier to the vapor flow, yet it repels water 100%. As such, it meets the requirements for water protection, yet it does not create a second vapor barrier, and it does not trap moisture inside the wall.

On a recent trip to the hurricane –stricken region of Florida, I noticed that almost all new construction was being framed with plywood backboards and Tyvek wrap on the outside. Unfortunately, the inside revealed that the builders - once again – were not evaluating the local conditions They were installing visqueen vapor barriers on the inside of the fiberglass insulation and covering it with drywall.

In Florida's warm, humid climate, the water vapor will be moving from the outside towards the (air conditioned) inside surface. The Tyvek will stop rainwater from entering the wall, but it will not stop the vapor from migrating toward the interior. If the humidity level is high, the wall temperature under the drywall will be below dew point. At this layer, condensation will occur and mold growth will start. It would have been cheaper and immeasurably better if the builders had used the visqueen on the exterior of the plywood backboard, allowing it to perform both the water protection and vapor barrier functions.

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