"For a long time, I have been frustrated that water activity could not be conveniently measured on building materials and contents. Now that has changed thanks to Decagon Devices."

Ian Cull, P.E.
Indoor Sciences, Inc.

Water Activity:

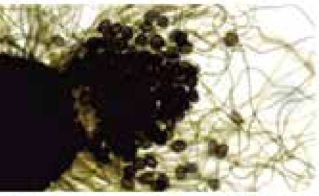
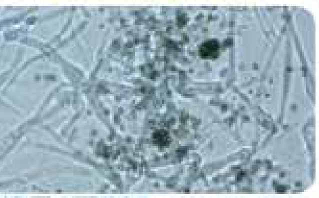
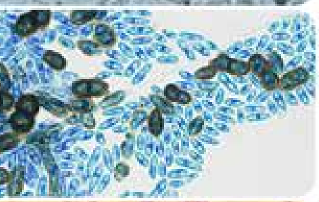
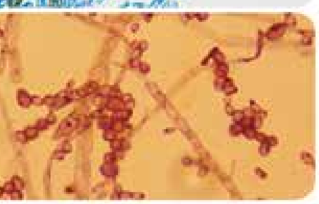
A Scientific Metric for Structural Drying

Water activity is a powerful drying metric because:

- It measures **how much water is available** to support mold growth.
- It **predicts** whether or not a porous material will mold.
- It can **reduce over-drying** by letting you **confidently determine** not just when a material is dry, but **when it is safe**.
- It has **strong scientific credentials**–over 70 years of research back the relationship between microbial growth and water activity.
- It can help **monitor a remediated site** after the fact to assure that building materials stay in the **safe zone**. ▶

AQUALAB®
BY DECAGON

Water Activity and Growth of Microorganisms*

Range of a_w	Microorganisms Generally Inhibited by Lowest a_w in This Range
1.00–0.95	Pseudomonas, Escherichia, Proteus, Shigella, Klebsiella, Bacillus, Clostridium perfringens, some yeasts
0.95–0.91	Salmonella, Stachybotrys, C. botulinum, Serratia, Lactobacillus, Pediococcus, some molds, yeasts (Rhodotorula, Pichia)
0.91–0.87	Chaetomium, Trichodermo
0.87–0.80	Most molds (mycotoxigenic penicillia), Staphyloccocus aureus, most Saccharomyces (bailii) spp., Debaryomyces, Cladosporium, Alternaria
0.80–0.75	Most halophilic bacteria, mycotoxigenic aspergilli, Penicillium
0.75–0.65	Xerophilic molds (Aspergillus chevalieri, A. candidus, Wallemia sebi), Saccharomyces bisporus
0.65–0.60	Osmophilic yeasts (Saccharomyces rouxii), few molds (Aspergillus echinulatus, Monascus bisporus)
0.60–0.00	No microbial proliferation

* Adapted from L.R. Beuchat, Cereal Foods World, 26:345 (1981).

Damp Building Materials: The Molecular Story.

After flood waters recede, carpet, drywall, wood floors, cabinets, cushions, and other building materials will still be wet. Water remains bound to the matrix of these materials by hydrogen bonds, capillary forces, and van der Waals - London forces. It can only be removed by expending energy--extraction, heating, blowing air.

But there's no way to get all the water out. Natural, un-flooded materials still contain water. So how much drying is too much?

Knowing When it's Dry Enough

Moisture content can't answer this question. Different types of materials contain different percentages of water, and the point at which materials are "dry enough" is at best a guess.

Water activity is the scientific way to measure whether or not there is enough available water to support mold growth.

Water Activity Predicts Mold and Microbial Growth in Foods

Water activity is not a new measurement. It has been used in many branches of science for decades.

In food science, it is part of USDA and FDA regulations. Every company that makes potentially hazardous foods uses water activity to determine whether or not a product is susceptible to mold and microbial growth.

The Connection Between Drywall, Carpet, and Cake

Molecularly speaking, drywall and carpet are not so different from jerky, crackers, and cake. All of them are porous materials that contain water.

Water activity measures how much of that water is available to mold and microbes.

Understanding What Water Activity Is

You can use a thought experiment to understand what water activity measures. Imagine dipping a sponge--a porous material--into a glass of water. The water in the glass will move into the sponge.

It's the same amount of water but its energy has changed.

How can you tell? Because you would have to perform work--squeeze the sponge--to get the water out.

Water Activity: Measuring Energy

The Energy State of Water

The water in the glass has higher energy. It's available. The water in the sponge has lower energy, and is less available. Both the sponge and the glass have the same water **content**, but the water in the sponge is measurably different.

This difference is a difference in the energy state of the water. Water activity expresses this difference as a number between 0 and 1.0, with 1.0 being defined as pure, free water.

Where Microorganisms Come In

William James Scott studied food spoilage during World War II, and later focused his research on the relationship between water and microorganisms.

In 1953, he showed that microbial growth in food is governed not by water content, as most people thought, but by water activity. Four years later, he established the concept of a minimum water activity necessary for microbial growth.

Water Activity Growth Limits

In other words, he showed that each microbe and mold spore has a water activity growth limit--a water activity below which it will not grow.

Scott's work was done on food, but has proved relevant to every porous material. It applies equally to products from fresh tree nuts to tree bark, from hand lotion to carpet and insulation.

Different Organisms Have Different Limits

Different organisms cope with osmotic stress in different ways. That's why there are different growth limits for each organism.

If you measure the water activity of any building material, you will know which bacteria, molds, and fungi can grow on it. By reducing water activity, below a certain level, you can preclude the growth of anything at all.

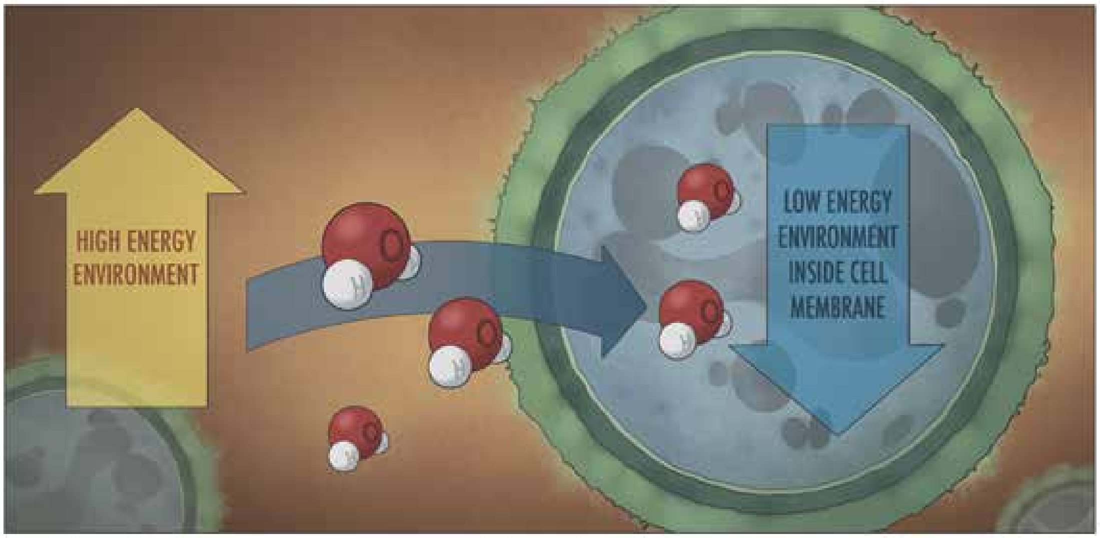
A Safe Zone for Building Materials

In fact, there is a "safe zone" which applies to all building materials. If the material's water activity stays in the safe zone, mold will not grow on it.

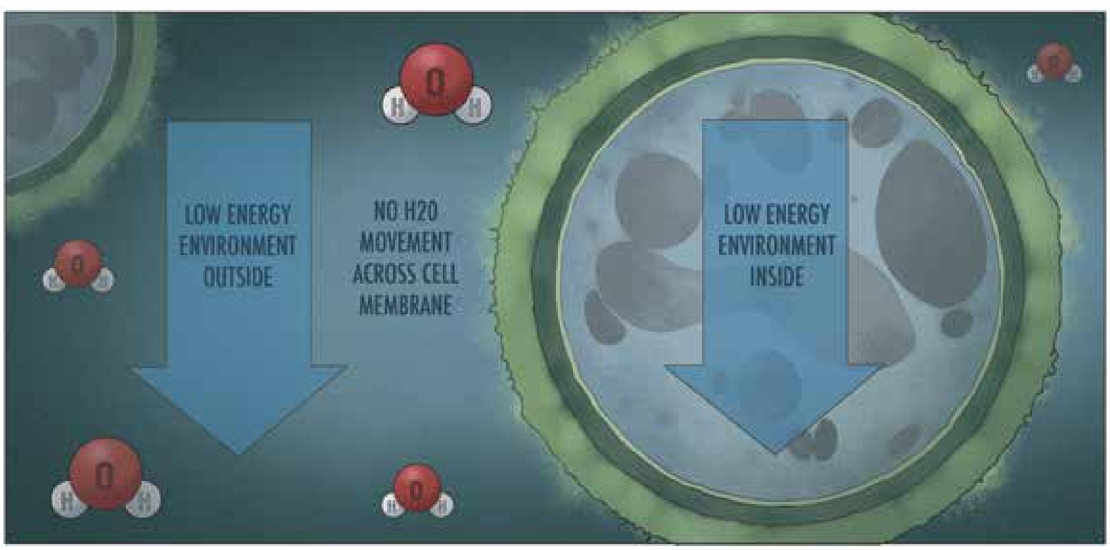
The chart on page 2 shows the water activity limits for many common microorganisms. These well-established microbial growth limits have been incorporated into FDA and other regulations and apply to all porous materials.

Why Water Activity Predicts Microbial Growth

Like all organisms, microorganisms rely on water for growth. They take up water by moving it across the cell membrane. This water movement mechanism depends on a water activity gradient--on water moving from a high water activity environment outside the cell to a lower water activity environment within the cell.



When water activity outside the cell becomes low enough, it causes osmotic stress: the cell can't take up water and becomes dormant. The microorganisms are not eliminated, they just become unable to grow enough to multiply.



AQUALAB® BY DECAGON

Doing the Math

Remember the sponge and the glass? One way of measuring the change in energy from "free" water to "sponge bound" water is by comparing their vapor pressures.

Most people are already familiar with this concept: when a weather channel reports the humidity, they're reporting *relative humidity*, or the partial vapor pressure of the air, divided by the saturation vapor pressure at the same temperature. In the weather report, this number is usually multiplied by 100 and expressed as a percent.

In porous materials, the ratio of p (the partial vapor pressure of the sample) to p_0 (the saturation vapor pressure) is called water activity.

What determines water activity?

In a flooded building, water is adsorbed into building materials like carpet and drywall. This lowers its energy state. It is bound by hydrogen bonds, capillary forces, and van der Waals-London forces, so it has less energy than free water. These are called "matrix effects."

Water can also be diluted with solutes. Since work is required to restore the water to its pure, free state, this also reduces water activity. These are called "osmotic effects."

Water Activity Formulas:

$$a_w = \frac{\text{partial vapor pressure of water above sample @ }^\circ\text{C}}{\text{saturated vapor pressure @ }^\circ\text{C}}$$

$$a_w = \frac{ERH\ (\%)}{100}$$

How to Measure Water Activity

If you can enclose a sample in a sealed container and allow the air above the sample to come to equilibrium with the sample, the relative humidity of the air in the head space will equal the water activity of the sample.

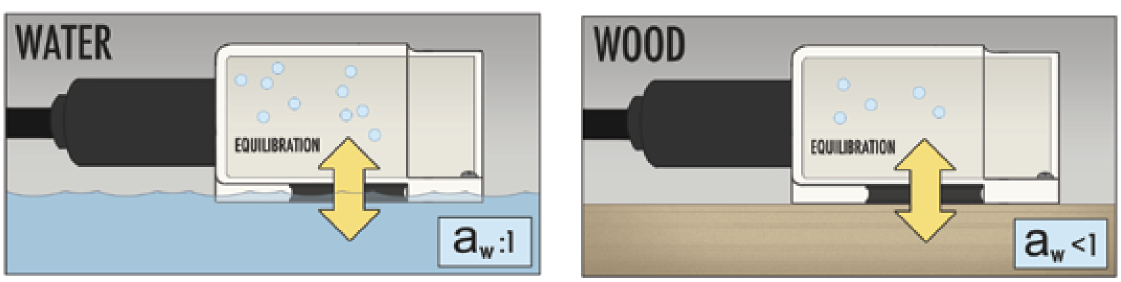
If you measure the relative humidity of the head space, you will know the water activity of the sample.

Early water activity meters actually used human or horse hair to measure water activity. Hair shrinks and expands as humidity changes, and these instruments used changes in the length of the hair to measure humidity.

More recently, electrical capacitance or resistance sensors have been sealed into the head space of the sample to measure humidity.
You can measure the water activity of a sample in a benchtop meter, but for many building applications, the sample needs to remain in place as it dries.

In this case, the best way to measure water activity is with a wall-mounted sensor. The sensor is sealed against the substrate. After the substrate and the air in the sample chamber's headspace have come to equilibrium, the sensor measures the vapor pressure in the headspace.

The vapor pressure of the air above the material divided by the vapor pressure of pure water will be the water activity of the material. ◀



Water activity sensors measure the relative humidity of the headspace when the system is at equilibrium. A close synonym for water activity is equilibrium relative humidity.

Available Instrumentation for Measuring Water Activity

Benchtop Water Activity Meters-
Decagon Devices has provided AquaLab Water Activity Meters for 30 years. These are benchtop laboratory instruments that are used in laboratories and food companies all over the world. Although Decagon's AquaLab is the most accurate instrument for measuring water activity, it is difficult to get a measurement that is relevant to the indoor environment.

AquaLab Cellular Data Logger and VP-3 Sensor-
The VP-3 Sensor used in conjunction with the Cellular Data Logger is currently the best way to measure water activity in buildings. Five sensors can be connected to the logger and the data can be accessed by multiple researchers remotely.

AquaLab ProCheck Hand-held Reader and VP-3 Sensor-
The VP-3 Sensor used with the ProCheck is a great way to measure the water activity of building materials. The sensors can be installed and then monitored by the hand-held ProCheck.

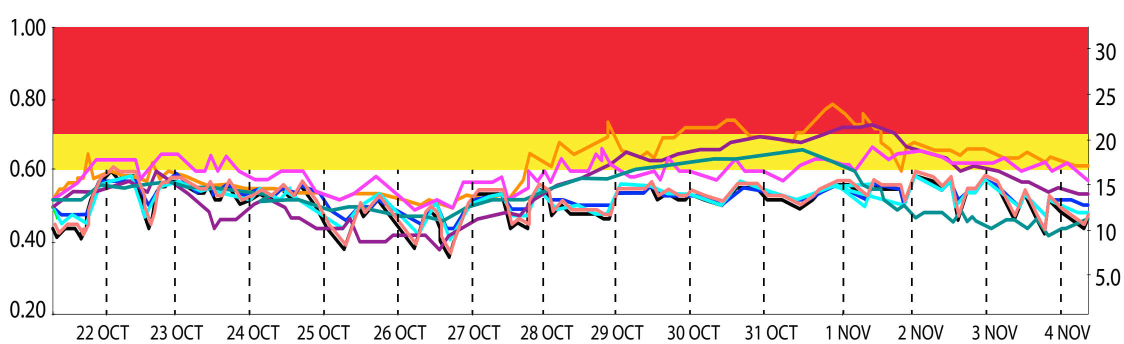
Applications: Water Activity and a Shoe Warehouse

Ian Cull of Indoor Sciences, Inc. had a client with a shoe warehouse and a mold problem. In order to prevent the shoes from molding the relative humidity of the warehouse was being controlled. The client was spending several thousand dollars a day to keep generators running to keep the space air conditioned.

Cull realized that the relative humidity of the space was being controlled well below the water activity safe zone to prevent mold. Cull installed several water activity sensors in the facility and attached them to shoes. Cull monitored the water activity of the shoes while recommending a decrease in the use of the temporary air conditioning.

By monitoring the water activity of the shoes over time with data loggers, the client could lower energy costs to air condition the building by staying just below a water activity of 0.700. Using this target water activity, Cull's client is able to lower air conditioning costs while at the same time ensuring that materials in the warehouse will not mold.

Range of a_w	Molds Generally Inhibited by lowest a_w in this Range
1.00-0.80	Most Molds
0.80-0.70	Xerophilic Molds (dry loving)
0.70-0.60	Few Extreme Xerophilic Molds
0.60-0.00	No possibility of Mold Growth



AQUA LAB BY DECAGON

Moisture Content, Relative Humidity and Water Activity

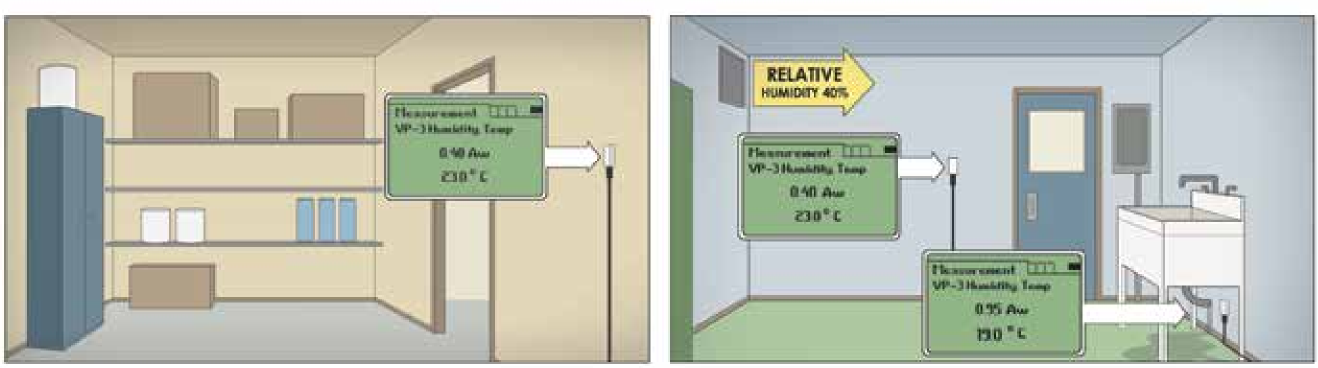
Moisture Content is relative. Moisture content is simply a quantitative measurement of the amount of water contained in a material. Many people use moisture content. But even though every moisture meter has some kind of calibration mechanism, scientifically speaking, moisture content is a relative measurement. For this reason "dry" and "damp" are relative terms.

There's no independently verifiable zero to the moisture content scale, so there's no independent standard to calibrate moisture content meters or methods to each other. The properties of every material bind water differently. An optimal moisture content to inhibit mold growth in wood is different than the optimal moisture content to inhibit mold growth in drywall.

Relative Humidity

Relative humidity is the partial vapor pressure of the air in a space divided by saturation vapor pressure at the same temperature. When we talk about the relative humidity of the air, this number is usually multiplied by 100 and expressed as a percent.

A relative humidity above 70% supports mold growth, but lowering the ambient humidity in a room



"It is essential to understand that local differences in ventilation and surface temperature can generate micro-climates with very high a_w in a room with an otherwise low relative humidity. For this reason, a measurement of indoor RH is a very poor predictor of mold problems." (Mycotoxin Production By Indoor Molds, Kristian Fog Nielsen).

is not enough, in and of itself, to inhibit mold growth. Materials inside the room may still be damp enough for mold to grow.

Water Activity is Absolute

By contrast, water activity is an absolute measurement. Saturated salt solutions have known water activity values. Any chemist can mix one up; any scientist will agree on what its water activity is. You can use these saturated salt standards to verify the accuracy of your water activity sensor. That makes water activity a universal metric.

It is defined as the vapor pressure of water in a substance divided by that of pure water at the same temperature; therefore, pure distilled water has a water activity of exactly one.

Higher water activity substrates support more microorganisms. Bacteria usually require at least 0.91 a_w, and fungi at least 0.60. Water migrates from areas of high a_w to areas of low a_w. For example, if honey ($a_w \approx 0.6$) is exposed to humid air ($a_w \approx 0.7$) the honey will absorb water from the air. Water activity is a concept of thermodynamics which states that high energy is always transferred to low energy or high a_w to low a_w. Since water activity is based on scientific standards, it's an absolute, defined, reliable, and universal way to communicate about dampness and dryness. ◀

For more information contact:
Decagon Devices
AquaLab Division
2365 NE Hopkins CT
Pullman, WA 99163
www.aqualab.com
sales@aqualab.com
509-332-5601

AQUA LAB® BY DECAGON

Water Activity:
A Scientific Metric for Structural Drying

Government Compliance Regulations for Microbiological Control

FOOD STANDARDS

2009 Food Code definition of Potentially Hazardous Foods

21CFR 110
Current food manufacturing practice in manufacturing, packing, or holding human food

21CFR 113
Thermally processed low-acid foods packaged in hermetically sealed containers

21CFR 114 Acidified foods

HACCP
Critical control point

ANSI/NSF Standard 75 Shelf-Stable Baked Goods

PHARMACEUTICAL STANDARDS

21CFR 211.113
Control of microbiological contamination

USP <1112> Microbiological attributes of non-sterile pharmaceutical products

ICH Guidelines

Decagon Devices
AquaLab Division
2365 NE Hopkins CT
Pullman, WA 99163
www.aqualab.com
sales@aqualab.com
509-332-5601