Practical Aspects of Locating and Measuring Moisture in Buildings

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ABSTRACT

Bugs, mold & rot do not grow indoors until excess moisture accumulates in building materials and assemblies. Based on that fact, the advice of building scientists and biologists to designers, builders, owners and insurance companies is to “keep the building and its materials dry.” But expert advice is less common with respect to what moisture content would be considered “dry” in different materials, and about exactly how one should locate, and just where one should measure moisture content to assess the risk of microbial growth. In the three-dimensional and highly dynamic real-world environment, moisture is hard to find and materials are constantly wetting, drying, heating and cooling. Therefore, field moisture measurement and location techniques, and prudent threshold values to avoid microbial growth in actual buildings are quite different from the steady-state circumstances of laboratory studies.

This paper reviews the current state of the art for tools and techniques for locating and measuring moisture in buildings. It then proposes some threshold values of concern for moisture content and provides opinions concerning what improvements are needed in instrumentation, inspection protocols and reports to reduce the costs of quantifying risk and insuring buildings.

INTRODUCTION

Is the building still wet, or is it dry? And where is it wet? And if that masonry block is “dry enough” that you can reinstall gypsum board... how dry would that be, exactly? Sooner or later, all investigations of both chronic and catastrophic water damage need quantitative moisture measurements to provide a firm foundation for conclusions and recommendations.

The observations and opinions provided here regarding field moisture measurements fall into three categories: finding moisture, measuring moisture and improving moisture meters.

Finding Moisture

When approaching a moisture investigation in a building, it is far from obvious just where one should begin taking moisture measurements to assess the condition of materials and assemblies. Fortunately, in recent years thermal infrared cameras have become more economical, and now have the resolution needed to see subtle temperature differences in a wide field of view. These patterns can help investigators who are looking for moisture in buildings.

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Seen with thermal cameras, surface temperature patterns caused by moisture-soaked materials are often distinguishable from the patterns seen on nearby dry materials. Such patterns provide clues as to where moisture measurements should be taken, helping the investigator reduce the discouraging uncertainty of where to start. On the other hand, not all thermal patterns are caused by moisture. So some practical aspects of using these cameras will be discussed in this paper.

Measuring Moisture

Any quantitative moisture measurement is potentially useful to some extent. But it's helpful to keep in mind that with state-of-the-art, modest-cost meters, there are practical aspects of the building environment which limit the utility of moisture content readings. To increase their value, one also needs to know the precise location of the measurements; the type, brand and model number of the meter and which of several scales was used to record the measurements.

Building owners, their insurance carriers and even many investigators are not always aware of these factors. To summarize the implications briefly, the examples provided here will support the opinion that a full understanding of the context of the measurements is essential, to limit the often false impressions created by undocumented columns of moisture content values.

Suggestions for Improving Moisture Meters

In the opinion of the author, the limitations of current, low-cost, state-of-the-art moisture meters are quite severe, when considering the financial implications of the decisions supported by their moisture content readings. The multi-billion dollar annual revenue of the water damage restoration industry is ultimately driven by these measurements. One would suppose that the insurance industry and the community of building owners might be eager to have more certain, more comprehensive and more repeatable mapping and quantification of moisture than what is currently practical.

Ultimately, the most useful solution will locate, display and quantify excess moisture in three dimensions. What investigators would find very helpful is a 3-D volumetric image of excess moisture, laid over the image of all layers of the building assembly, combined with quantified moisture content vales of that excess moisture at all points within the "3-D solid" image. This would be much like what is now possible with a 3-D Functional MRI scan of the human body.

But until more portable and far lower-cost technology emerges for field use, there are a few relatively simple improvements would greatly increase the utility of portable instruments and reduce their limitations. A list of suggestions will be discussed here, for the consideration of any insurance companies, instrument manufacturers or restoration companies which might wish to gain a competitive advantage by overcoming a few of the many current limitations of low-cost, portable, handheld moisture meters.

FINDING MOISTURE

The precise location of moisture is essential to assessing the risk from accumulated moisture. But how is the investigator to determine exactly where to place the moisture meter? In recent years, thermal cameras have gained resolution and come down in cost, allowing their productive use in moisture investigations. Although the images they show cannot quantify moisture content, they are very useful in locating suspect areas.

Figure 1. Exterior investigation. A thermal camera can guide the use of moisture meters during a moisture investigation. Without seeing the thermal image, the investigator could place the moisture meter too high on the wall to detect the moisture.

Figure 1 shows an investigator who has scanned a wall in just the right spot to detect the elevated moisture immediately above a window. Excessive moisture appears as a darker pattern, indicating lower surface temperatures in areas with elevated moisture. Based on those patterns, the investigator can locate suspect areas, and then confirm and quantify a problem by using a moisture meter.

Technical Basis of Thermal Imaging

All objects in the universe radiate energy in many wavelengths to all other objects in the universe. Part of that energy can be detected by infrared sensors. Combine tens of thousands of infrared sensors into a single chip, and then recode all their signals as varying intensities of visible light. The combined and recoded signals are then assembled into a video image which shows a pattern of surface temperatures. Often, these patterns are caused by differences in moisture content.

To understand how thermal imaging relates to building inspections, it helps to understand some characteristics of infrared waves and their behavior in air.

Gamma rays and x-rays are very short. Radio and TV waves are very long. Human eyes function in a narrow slice of wave lengths near the middle of the spectrum. We only see wavelengths between about 0.4 and 0.78 microns. (400 to 780 nanometers). Infrared waves are much longer and lower in frequency than visible light—they vary from 1.0 to 24.0 microns in length.

Within the infrared band, the waves most useful for examining thermal patterns in buildings are those between 7 and 14 microns in length. These make up a large portion of the heat emissions from surfaces which have near-ambient temperatures. Also, the gasses which make up air—nitrogen, oxygen and water vapor—don't absorb too much of the energy carried by these wavelengths. So these 7 to 14 micron waves can travel from a surface through the air to the sensor without much interference. Finally, the amount of energy emitted in this particular range of wavelengths has a very strong dependence on temperature. In other words, small differences in surface temperatures generate large differences in the amount of infrared energy that the surface emits. [(1)]

So the 7 to 14 micron infrared signal is relevant and strong, and it can indicate small temperature differences clearly.

Thermal images are not X-Ray images

As one looks at the images shown here, it's important to keep in mind that thermal cameras do not see moisture, nor do they actually "see inside the wall." They only show differences in surface temperature. To make an infrared camera useful for moisture inspection, the inspector must be able to interpret the origin of the thermal differences it shows.

How Moisture Content Differences Create Surface Temperature Patterns

Excess moisture creates surface temperature differences in five ways. The first is the most common and most visually apparent in water damage situations:

1. Evaporation. Moisture cools the surface as it evaporates, so that moist areas appear cooler than dry areas. Figures 2 through 8[(2)] show this effect clearly. Water which soaked the carpet also wicked-up through the gypsum board walls. As that water evaporates, it pulls heat from the wall, creating a darker (slightly cooler) pattern in the moist areas.

2. Thermal lag. Water is dense, so it slows the thermal change of a porous material when ambient temperatures change. Moist areas appear cooler when the rest of the surface is warming up, or warmer when the rest of the surface is cooling down.

3. Differences in thermal conductivity. Moisture increases the density and therefore increases the heat flow through porous materials. Moist areas appear warmer than dry areas on the cooler side of the wall, and cooler than dry areas on the warmer side of the wall.

4. Conduction. Water cools or warms a surface by direct contact when water is flowing, dripping or moving by capillary suction away from a warm or cold source.

5. Radiation. If warm or cold water is present inside a wall, the outer surface of that wall can be changed as it absorbs heat from or releases heat to the internal water by radiation.

All of these processes are happening at the same time in any building. But evaporative cooling usually dominates thermal images of moisture after a flood, fire or other water event, especially after the building has been stabilized and the source of the water eliminated. Because evaporating moisture always makes a surface cooler, moist materials indoors (away from the exterior wall) nearly always appear darker - colder - than the surrounding dry material.

That's why, in catastrophic water damage situations, infrared cameras have become so popular. They are easy to use, and the images are easy to interpret correctly, which lets building drying contractors proceed with speed and certainty which is not possible with meters alone, which saves time and money. With the more subtle and complex paths of moisture typical of non-catastrophic investigations the cameras are still very useful, but such simple interpretation is seldom possible.

Figure 2. Moisture investigation of a single-story flood. A water heater broke, flooding the floor in this office condominium over a weekend. Water seeped up into walls through capillary action, for more than 48 hours.

Figure 3 Workstation. Water evaporating from the gypsum board slightly lowers the surface temperature, a pattern which becomes obvious when viewed through a high-resolution infrared camera.

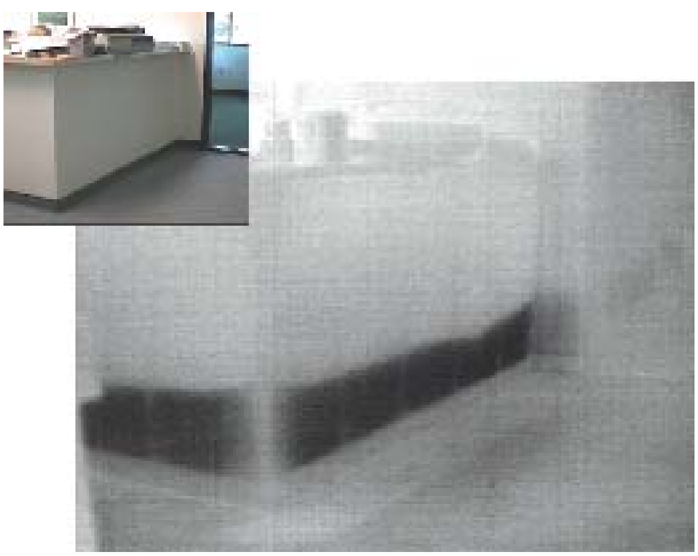


Figure 4. Chair and Carpet. The thermal pattern clearly indicates that moisture remains in part of the carpet and in the lower portion of the wall

Figure 5. **Shelf & Wall**. The visual image shows no indication of water damage. But the high-resolution infrared image allows the inspector to quickly identify suspect areas.

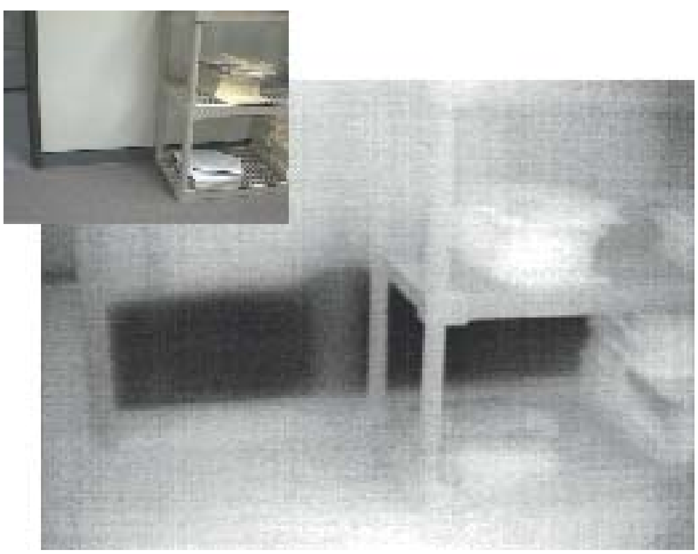


Figure 6. Water Heater. This new heater replaced the one which broke and soaked the building. This pair of images shows that layers in a wall can hide the thermal patterns which indicate moisture. Moisture does not cool the tile surface low enough to create a thermal pattern.

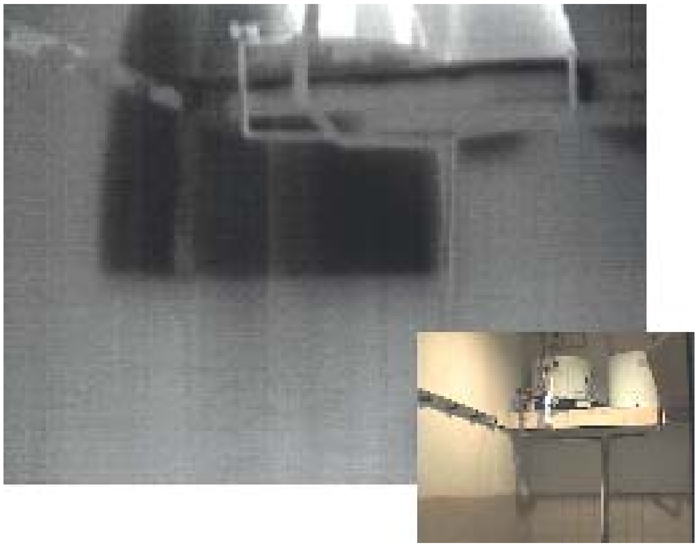


Figure 7. Incomplete Drying. Technicians pack up the drying equipment because it appears the floor is dry. But the thermal pattern suggests there is more moisture that must be removed to ensure that mold does not grow inside the wall.

False Impressions From Thermal Images

It's useful to remember that most thermal patterns on walls are not the result of moisture differences, and not all moisture differences produce thermal differences at the surface of the material. Six factors can create misimpressions:

1. Cold inside corners. Inside a room, air does not flow easily into corners. In almost all cases, this fact means that corners will appear cooler than the rest of the wall. This effect often creates a false impression of moisture problems in that part of the wall or ceiling.

2. Sunlight shadows. As the sun shines on the outside of the building, it slightly heats the inside surface. But if a tree outside blocks that sunlight, part of the wall will be cooler. This temperature difference can look like moisture when viewed from the inside of the building—where the tree itself is not visible.

3. Air conditioning. As seen in figure 13, cool air from the AC systems will create surface temperature patterns which are highly suggestive of excess moisture. Using the moisture meter in suspect areas will avoid being misled by cold air. And the more the investigator knows about HVAC systems, the easier it is to separate the temperature patterns seen through the camera into suspect and non-suspect categories.

4. Electrical heat sources. All walls hide electrical components, which generate extra heat. This can look like moisture in a situation where moisture appears warmer than the rest of the wall, as in the case of soggy insulation in an exterior wall warmed by the sun.

5. Air infiltration/exfiltration. Air constantly flows into and out of walls, changing both internal and surface temperatures. So insulation voids create thermal differences which can look like moisture differences when the inspector is not alert to that possibility.

6. Layers and gaps in the wall. Often, moisture-related temperature differences are "flattened-out" because the moisture is located inside the wall and not near its surface. Consider a brick exterior wall with an air gap for water drainage behind the brick facing. If there is excess moisture in the sheathing behind the air gap, the thermal pattern it generates is not likely to be reflected all the way through the air and through to the exterior surface of the brick.

Figure 8. Excess Moisture?... Perhaps Just Cold Air. It's essential to confirm the presence of moisture with moisture meter readings. Not all thermal patterns indicate a moisture problem. Cold air from the air conditioning system creates thermal patterns which can look like excess moisture.

Best Practices For Using Thermal cameras

To avoid misunderstandings, three basic practices are useful:

1. Confirm findings with moisture meters. Most inspectors use moisture meters to confirm any differences in moisture content suggested by an infrared image. The best inspectors also record the moisture content readings for both "dry" and "wet" portions of material in the infrared image.

2. Document the location of infrared images using visual images. One of the major benefits of using infrared cameras is graphic documentation. So it's very useful to record visual images of the affected areas, with moisture content readings shown in the photo, to validate the suspicion of moisture provided by the thermal camera.

3. Record locations of images on building floor plan. A simple sketch of the building's floor plan is also helpful to indicate where each image was taken. And when as-built, dimensioned floor plans are available, marking the image locations and angles on a copy of the plans provides an even clearer picture of the extent of the problem and completeness of the solution.

Infrared Camera Characteristics

As of June 2008, costs for cameras which have enough pixels to be useful in building investigations cost between $5,000 and $18,000. The most useful features include more pixels, greater thermal sensitivity and visual video capability.

More pixels. In current infrared cameras, there are three two choices of optical resolution: 14,400 or 76,800 or 19,200 pixels. In manufacturer's specification sheets, these totals are usually expressed as the number of vertical and horizontal pixels. 14,400 is described as 120 x 120. 76,800 is described as 320 x 240 and 19,200 is described as 160 x 120. But it's more useful to keep in mind the total number of pixels. The 76.8k image provides four times more visual data than the 19.2k image and five times more visual data than the 14,400.

Figure 9. More pixels are better. In many situations, the thermal patterns generated by moisture are not very obvious. Generally, the higher the resolution of the camera, the easier it is to locate moisture. [3]

Water sprayed onto the back of a sheet of gypsum board evaporates...

.... removing enough heat from the back of the gypsum to slightly reduce the temperature on the front side. Five minutes after the spray, a high-res camera (76.8k pixels) can see this moisture-generated thermal pattern

The low-res camera, which has only 25% as many pixels, has more difficulty showing the same pattern

For moisture inspections, more pixels are better, because the investigator is looking for very subtle patterns of small temperature differences. With many pixels, one can see patterns that are nearly invisible to cameras with fewer pixels.

Thermal sensitivity. The more sensitive the sensor, the finer-grained an image is possible, and the easier it will be to detect subtle patterns which suggest elevated moisture. The thermal sensitivity of a camera is usually expressed as the “Noise equivalent temperature difference.” This value is abbreviated as either NEDT (delta T) or NETD. The value, expressed in thousandths of a degree Kelvin (milliKelvin), quantifies the temperature difference which is the same as the “noise” of the signals from that sensor. Smaller numbers are better, and small differences can make a very useful improvement in the quality of the image for the purposes of forensic investigation.

As of June 2008, most forensic investigators would strongly prefer an image from a camera with a thermal sensitivity of 70 mK over one from a camera with a sensitivity of 100 mK. On the other hand, much less sensitive cameras (over 100 mK) are widely used, and are very successful in finding the less subtle patterns of catastrophic water damage or for finding voids in exterior wall insulation.

Visual image along with infrared. Visual video allows the inspector to locate the area of concern because the inspector can see familiar visual clues. Also, for reporting the results to others, a visual reference to document the location of the infrared image is nearly essential.

Camera Features Less Useful For Moisture Investigations

Based on this author's experience, there are many camera features which can add confusion and misdirect the investigators efforts when looking for moisture:

Radiometric accuracy is usually misleading. For moisture investigations, there is seldom any use in knowing the exact surface temperatures in the image. It doesn't help to know that one part of the wall is at 76.25°F while another part of that same wall is at 75.96°F. By avoiding the natural inclination to assign meaning to such seductively precise temperatures, the investigator can focus on understanding the patterns, and on and the productive use of the moisture meter to confirm or eliminate the presence of moisture problems.

Adjustable emissivity correction adds confusion. For the same reason one probably won't need radiometric capability, there is usually no need to make corrections for differences in emissivity between different surfaces. Those corrections are very important for measuring temperature accurately, because different surfaces emit (and reflect) ambient infrared at different rates. But adjusting camera emissivity settings for more accurate temperature measurement does not improve the investigator's ability to perceive patterns related to moisture content.

Industrial temperature range can be counterproductive. Many fine and very costly cameras are optimized for industrial uses, where the inspector needs to measure surfaces with a broad range of temperatures—perhaps -40°f to 2000°F. But in moisture inspection, the inspector is much more concerned with very small differences in temperature in the range between 0 and 200°F—very narrow by the standards of industrial and scientific infrared imaging. For building moisture inspections, that narrower range of thermal sensitivity is much more useful, because it typically produces the most informative images.

MEASURING MOISTURE

After the suspect areas have been identified by using some combination of the investigator's experience, thermal cameras or other means, the next step is measuring moisture content, using portable meters.

In most cases, the low-cost meters in use for building inspections report values for softwood lumber (Douglas fir or northern pine), rather than the moisture content of the wide range of composite material actually being measured in a building. Much more will be said about this later in the paper. For now, the reader is encouraged to recognize that field moisture readings are usually "wood moisture equivalent" (WME) readings rather than the actual material-specific moisture content.

The first point to keep in mind is that moisture content varies widely over short distances. If one knows the moisture content in one location, it is not appropriate to assume that the moisture content of that same material, even two inches away, is the same.

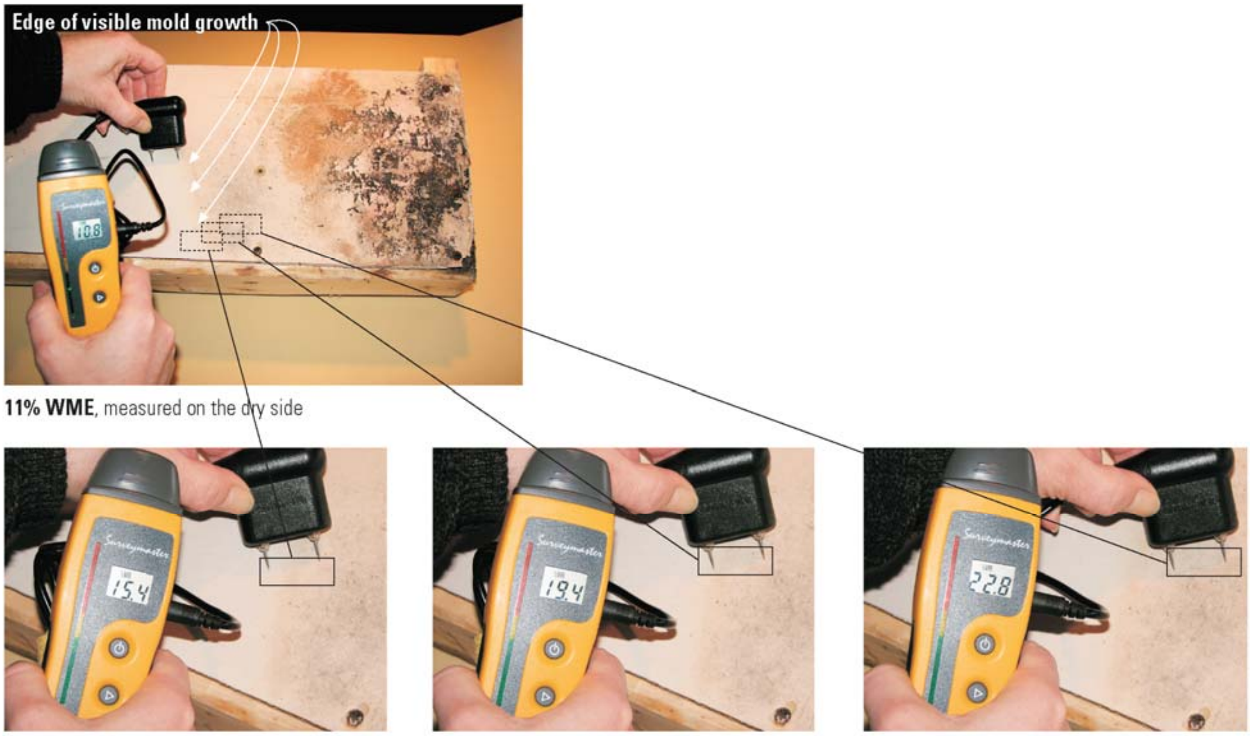
The Precise Location of Measurements Is Meaningful

Figure 10 shows an informal mold-growth test conducted in the unconditioned basement of the author's 230-year-old, post-colonial home in Portsmouth, NH. [3] A short test wall section, consisting of fir 2" x 4" studs covered by paper-faced gypsum board, was stored standing on its end.

The upper end leaned against the dry basement wall, and the lower end rested on the hard-packed earthen floor. Over several months, moisture from the earth slowly wicked upwards through the gypsum board, eventually providing enough moisture for mold to grow on the untreated paper face of the gypsum board, at the lower end of the test wall section.

Many months later, mold also succeeded in growing on the surface of a fir stud, where it was in direct contact with the earth floor.

Figure 10. Exact measurement location is important. Moisture content and therefore mold growth can vary significantly over short distances.



11% WME, measured on the dry side

15% WME, measured across the visible edge

19% WME, measured on the moldy side

23% WME, measured in the moldy area

There are two useful points illustrated by figure 10. First, note the significant difference between moisture measurements taken in the gypsum board surface, less than 1/2 an inch apart. On the left, or "dry side" of the visible mold growth line, the moisture meter reads 11% (WME). Then, just 1/2 an inch to the right and straddling the visible mold growth line, the meter reads 15%. Move another 1/2 inch to the right and the meter reads 19%. Another movement of 1/2 inch to the right provides a moisture reading of 23%.

Such large differences over very short distances illustrate why knowing the exact location of the measurement is important for understanding its true importance. For example, if a report stated that "the exterior wall moisture content was found to be 16%", a prudent decision-maker would want to know exactly where the measurement, or measurements, were taken. Was the moisture content consistently 16% both up and down and across that entire wall? How many readings were taken to reach the conclusion that the moisture content was 16%? Was the 16% number a maximum?.. or an average? If the 16% was an average, what was the maximum and where was that maximum reading taken?

A second point illustrated by figure 10 is that mold growth rates can also be highly variable over short distances. In this test, there is no visible growth at 11% but prolific growth at 19%, less than two inches away. And this variation happened in gypsum board, which is a uniform material that transports any internal moisture rather quickly.

With rapid moisture transport in the material, this sharp edge of mold growth might not be the usual expectation. One could expect that over several months, the moisture content of the gypsum board (and therefore the potential for mold growth) would be more uniform along the length of the board. But that's not always the case, as shown here. The sharp differences in mold growth come from those sharp differences in moisture content. So again, in reaching conclusions about the potential for mold growth, the exact location of the moisture measurement can be important when making decisions about mold-sensitive material.

Figure 11. Photo-based documentation of moisture readings. The exact location and full physical context of moisture values is very helpful in judging their numerical significance.

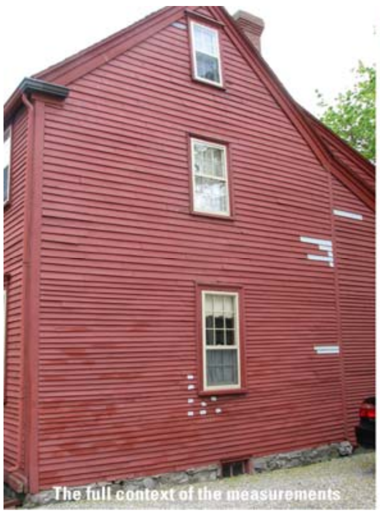


Figure 11 shows one way to comprehensively record the entire "moisture geography", at a reasonable cost of time and effort. The first photo shows the overall context of the measurements. We can see the area of concern along with it's position with respect to the building as a whole. The second photo is taken close enough to read the moisture content values written on the strips of masking tape, but still far enough away to show the increase in moisture content as the readings approach the window frame.

Influence of the Operator's Skill and Experience

Figure 12 shows an example of the importance of the operator's understanding of the instrument. The meter shown is a "non-penetrating" type. It does not use pins to penetrate the material. Instead, it measures moisture by the change in an electrical field projected immediately behind the meter.

Figure 12. Pressure and angle affect the reading. A technician's skill and consistency can significantly influence a meter reading.

Reads 12% when flat

Reads 10% if tilted slightly left

Reads 8% if tilted slightly upwards

Inside that electrical field is both the moist material and the thin air gap between the back of the meter and the moist material. The electrical properties of that thin air layer are very different than the properties of the moist material.

So as shown in figure 12, if the operator does not press the meter down evenly to ensure the air gap is of uniform thickness, the reading shown on the meter will be higher or lower the next time the technician makes a measurement, even though the true moisture content of the material may not have changed.

A similar issue applies to resistance-based, or “pin-type” meters. Two pins are pressed into the wet material and the resistance between those pins is converted to a moisture content reading. But the electrical resistance of air is much higher than the resistance of solid materials. So when there is any tiny air gap between a pin and the material—if the operator does not seat the pins firmly, or if the pins wobble in the material while the reading is being taken—two meter readings taken in the exact same location can be different, even when there is no actual change in moisture content.

Any error introduced by these particular meter characteristics will always understate the moisture content. With both pin-type and “non-penetrating” meters, any small air gap will produce readings below (drier) than the true moisture content of the material.

Given the limitations of current state of the art, moderate-cost meters, these are problems which can only be minimized by the skill of the operator and the consistency of his or her work habits. There is no simple way to cross-check the operator’s technique from written reports after the fact. To reduce the uncertainty caused by these issues, it can be useful to know (and to document) exactly who took the readings.

Importance of the Meter Type, Its Manufacturer, and Measurement Scale

In the moderate-cost range ($100 to $500), there are two principal types of moisture meters in common use: resistance, or “pin-type” meters, and capacitance/impedance, or “non-penetrating” meters. (There are several other types of meters beyond that price range which are not in common use, but those will be discussed in some other article)

When analyzing moisture measurements in a written report, it’s useful to keep in mind that meters from different manufacturers usually show different values for the same moisture content, even if they use the same measurement principle and are taken in precisely the same location.

Figure 13. Meters from different manufacturers show different values for “saturated” moisture content.

Figure 13 shows an example of this fact. The gypsum board being measured by these resistance meters is essentially saturated. So the reading will be simply “maxed-out”—the true moisture content is going to be out of scale for all of the meters. Meter one indicates that fact by showing an upwards-facing arrow at the 44% maximum value on its pre-printed scale (WME). Meter two maxes-out at 37%. Meter three pegs its scale at “40%”, while meter four suggests the moisture content is “over 100%.” In fact, most resistance-based meters are not very accurate when wood moisture content is more than about 35%. So in this situation the true moisture content is not reliably reported by any of these instruments. Correctly reported, the moisture content is simply “more than 35% on a softwood lumber scale”.

Figure 14. Different meters also show different values in the range of mold-risky moisture contents.

Figure 14 shows a similar example. In this case the meters are used to read a much lower moisture content in gypsum board—a moisture content which is in the usual range of interest for making decisions about whether gypsum board is “dry enough” for further work. The meters show values from a low of 13% (WME) to a high of 19%, in exactly the same location (The pin positions do not vary by more than 1/8th of an inch).

There are two obvious implications of these meter characteristics. First, the prudent investigator keeps in mind that any reading above 30% really only indicates that the material is “pretty darn wet”. Distinctions such as 34% vs. 46% moisture content read from meters made by different manufacturers do not reliably indicate a meaningful difference in moisture content. Secondly, if the type, manufacturer and model number are not recorded along with the moisture readings it will be difficult to compare readings taken on different days to each other, even if the readings are taken in precisely the same location.

Wood moisture equivalent vs. material-specific moisture content

Next it is useful to keep in mind that none of the above readings could be even remotely close to correct percentages of gypsum board moisture content. These numbers in the 11 to 35% range are far too high.

As it leaves the factory, dry gypsum board has a moisture content of about 0.4% by weight. Later, if gypsum board becomes soaking wet and is crumbling apart, it’s moisture content is still not likely to be more than 2%. Most gypsum board simply cannot hold more than about 2% of its weight in water without significant structural deterioration. Around that level, the paper face debonds from the gypsum core and the gypsum begins to fracture. So the percent moisture content readings on the meters in figures 1 through 4 cannot be correct for gypsum board, even though the readings can still very useful for comparison purposes.

The experienced investigator recognizes that the scale shown on most pin-type meters is calibrated for softwood lumber; usually Douglas fir. So in the case of the readings above, one should record the fact that the readings taken in the gypsum board are based on the Wood Moisture Equivalent, or the “WME” scale.

It’s also useful to keep in mind that the electrical characteristics of lumber are different than the electrical properties of the same wood when it’s chopped up, compressed and baked into engineered wood products. For example, the softwood lumber calibration does not apply directly to OSB (Oriented Strand Board), even though the OSB is made of softwood. A correction must be made to account for the increased electrical resistance of glue, and of the air spaces between the wood chips at low moisture contents. In addition, higher temperatures will reduce the electrical resistance of both lumber and OSB (the opposite of what happens in metals, in which warmer temperatures raise electrical resistance).

Table 1. Corrections for Aspen-based oriented strand board (OSB). [5]

	Softwood Moisture Meter Readings (Moisture as a percent of dry weight)					Surface Temperature (°F)
	8%	12%	16%	20%	24%	
Corrected Values for % Moisture in Aspen OSB						
	10	14	18	22	26	14°
	8	13	17	21	25	32°
	8	12	15	19	23	50°
	7	11	14	18	22	68°
	6	10	13	17	20	86°

Combined correction factors for Aspen OSB were developed by the Canadian Wood Council and the Canadian Mortgage and Housing Corporation in 2001. Those correction factors are shown in table 1. They show that in general terms, unadjusted softwood-scale measurements overestimate the true moisture content of Aspen OSB at ambient and higher temperatures, while they underestimate its true moisture content as the temperature goes below freezing.

There’s another complication when reporting the moisture content of gypsum board, masonry block, brick and concrete. Capacitance or impedance-based meters are often used for these materials, and many such meters have only “relative” scales, rather than percent moisture content by weight. In other words, the meters may display values from

0 to 100 or perhaps 0 to 200. But these do not refer to percent moisture content by weight. Instead, they are simply non-absolute indicators of “higher or “lower” moisture content. Also, different manufacturers use different non-penetrating measurement technologies. And each manufacturer uses different “relative scale” values for the same moisture content. As a result, it’s simply impossible to know whether there is any truly higher or lower moisture content indicated by a relative reading of 73 from one manufacturer compared to a relative reading of 122 from a different manufacturer.

To summarize, when reporting moisture measurements in buildings the most useful documentation will show the exact location of the measurement, in it’s fullest “geographic” context. It’s also important to record the manufacturer and model name of the instrument, along with which of it’s possible scales are being used, as well as the date, time and the name of the person who took the measurements.

This information—admittedly not always included in most reports today—will enhance the value of any investigator’s conclusions and recommendations, and will provide a firmer foundation for decisions made by owners and insurance companies with respect to moisture problems in buildings.

SUGGESTIONS FOR IMPROVING MOISTURE METERS

In order of increasing cost and complexity, a list of highly useful but missing features of current instruments includes:

Backlit display

It is astonishing to this author that based on currently-available commercial products, apparently no moisture meter manufacturer understands that in most building investigations, the measurements will be taken in locations with little or no light, and in locations above or below the investigator’s eye level. It is nearly impossible to read the display of current moisture meters when the instrument is extended above one’s head or below ones knees, because there is so little visual contrast between the numbers displayed and screen which surrounds them. A backlight would go a long way to reducing this problem, and make it a great deal easier to simply photograph the instrument reading as documentation.

Figure 15. The utility of a backlit display. Even at eye level in good light, meter displays are difficult to read. This meter—which measures air properties rather than the moisture content of materials—shows the benefit of a backlit display.

An example of such an instrument display is shown in figure 15. Unfortunately, that particular instrument measures air temperature, humidity and velocity rather than material moisture content. But it shows what can be added easily and economically, increasing the practical utility of an important instrument.

Remote probe with local display. Beyond the backlit display, the ability to probe remotely and read locally is another clearly useful feature. Most investigations require taking readings in remote or confined spaces such as high ceilings, attic eaves, shallow crawl spaces, behind baseboards, on the surface of floors and above dropped ceilings. A remote probe, mounted on a gimbal at the end of an extendable pole, with its display held near the investigators hand, would be a major improvement over most currently available devices.

Date, time and geocoordinates on the display. The bulk of the time of a moisture investigation is not field work. The really time-consuming and soul-deadening part of the work is compiling the report, in a way that is credible and understandable to others, and to oneself many months after the investigation has faded from memory.

Given that thousands of moisture readings are probably required for reliable results (but seldom taken currently), it will be very useful for the instrument to display the current date, time, latitude and longitude of the reading. In it's simplest form, such a display would allow photo documentation. In a more complex datalogging implementation, the instrument would allow downloading a file containing each measurement with its date, time, latitude and longitude. Such a file could then be synchronized with a mapping program, and with digital photographs, which in modern cameras always record the date and time of each image.

Integral wide-angle camera recording the location of measurement and it's surrounding environment. A further improvement would be the addition of a wide-angle low-light camera with flash to record the measurement, its exact location, it's full context along with its date and time.

Technology which measures moisture directly. Moisture meters do not measure moisture. They only measure a change in the electrical properties of dry material. The variation in the electrical properties of the dry materials is so great that absolute measurements are simply not possible outside of the laboratory. All we have now are relative measurements.

If measurement technology could quantify water molecules exclusively, it could be a great improvement over current instruments. As an example from a related field, there are instruments which measure the attenuation of specific infrared wavelengths by the different gaseous components of air. This technology has led to low-cost, high-accuracy absolute measurements of water vapor. A similar effort to isolate the signals of water molecules in solids, as distinct from signals of the surrounding solids, would be very helpful.

Relevant Moisture Inspection Protocol

Beyond better moisture meters, the building industry needs more conclusive and repeatable moisture inspection protocols. Currently, no protocol with which the author is familiar answers the relevant questions reliably. Among these questions are:

1. How many moisture measurements does it take to be certain the building does not currently "have a moisture problem"?

2. What moisture reading is a prudent threshold of short term or long term concern in each material and in each building subassembly?

3. Where (exactly, within a few centimeters) should these measurements be taken?

4. When should they be taken, and how often?

5. How should the measurements be recorded, and in what form should they be displayed to form a meaningful report.

6. And what *is* a "moisture problem," exactly?

The underlying question is; what sort of moisture problem constitutes a risk? One answer could be the definition developed in 2003 by the ASHRAE Presidential Ad-Hoc Committee on Indoor Mold (The American Society of Heating, Refrigerating and Air Conditioning Engineers). According to that definition:

“A moisture problem is one which interferes with the use or enjoyment of the building, or which shortens its intended useful life.”

Meaningful Reports

Beyond improving the inspection protocol, the measurement technology and agreeing on a common definition of what constitutes a moisture problem, there is the issue of the report. There’s not much point in better measurements and better-defined procedures if the report is not actionable. The author suggests that a truly meaningful report should serve at least two functions. Its contents and its graphic presentation would allow:

1. an insurance company to insure the property based on a defined level of risk

2. the owner to see what steps are needed to reduce the current risk, if any.

CONCLUSIONS

Locating moisture quickly and certainly, and measuring it repeatably and meaningfully are not easy tasks at present. Further, there are few if any practical protocols to guide this essential component of reducing the risk of mold and other moisture-related problems in buildings. As discussed in this paper, the current techniques and tools for this purpose are neither reliable, nor low in cost, nor certain.

The author looks forward with great anticipation to more practical moisture meters, and to development of an investigation protocol which would produce actuarily-useful reports, to allow the building and insurance industries to reliably, quickly and economically assess and insure the risk of moisture accumulation.

These are matters of some concern to insurance companies. Therefore they should be of concern to the entire community of building owners, designers, material suppliers and builders. Insurance governs mortgage financing. Mortgage financing in turn governs all building construction and all transfers of real property.

The author submits that moisture measurements, moisture inspection protocols and reporting requirements for buildings need improvement. Perhaps the observations contained in this paper can be useful points of departure for these efforts.

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