As Dries the Air, So Shrinks the Wood

Why woodworkers keep a weather eye on relative humidity

by R. Bruce Hoadley

Most woodworkers realize that wood moves, shrinking and swelling according to its moisture content. Accordingly, we use joints and constructions that allow for a moderate amount of wood movement, and many of us now use moisture meters to ensure that our wood has been dried to a safe level. But a one-time check of moisture content isn't enough. Here in the northeast, you can take delivery of wood kiln-dried to 7% moisture content, but if you then store it in an unheated garage, it will gradually adsorb moisture from the air and increase to a new level of up to 14%, which, if unanticipated, would come as an unpleasant surprise.

The amount of moisture in wood balances and adjusts to the relative humidity of the air around it. Assessing the humidity of the air in shop or storage areas, therefore, is as important as working with wood that has been properly dried in the first place. An extremely dry or damp period may not last long enough to cause much dimensional change in a board, but moisture exchange in the board's surface layer, which takes place immediately, can cause disheartening problems with glues and finishes.

Equilibrium moisture content—One sometimes comes across wood that has been sitting in a well-ventilated, unheated barn for thirty or forty years. It probably reached its lowest moisture content within the first two or three years, and it is not any drier or more stable today than it was then. In wood, *moisture content* (MC) is the ratio (expressed as a percent) of the weight of water in a piece of wood to the weight of the wood if it were completely dry. Green wood may start off with more than 100% moisture content (the sapwood of green sugar pine is actually more than twice as much water as wood, averaging 219% MC), but it will commonly be dried to about 7% to 9% MC for woodworking purposes. Water is held in the wood in two ways: *free water,* held in the cell

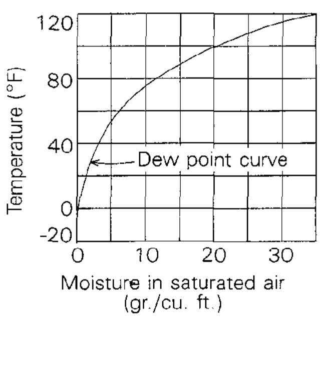
Weather, temperature and humidity

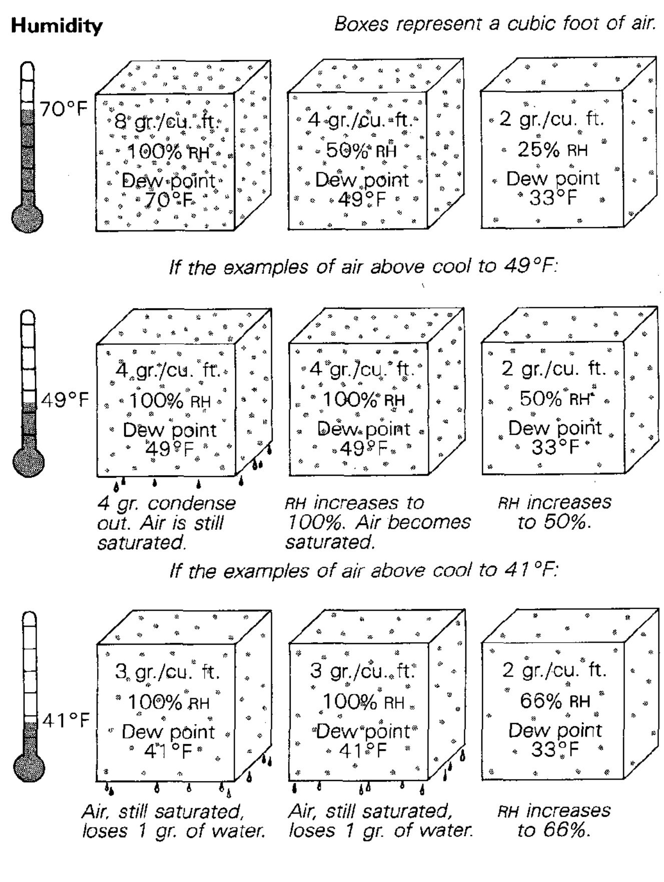
Weather systems bring air masses having a certain *absolute humidity,* the actual amount of moisture in the air at a given time, expressed in grains per cubic foot (there are 7,000 grains in a pound). Because the maximum amount of water the air can hold depends on the temperature of the air, temperature determines the upper limit of absolute humidity.

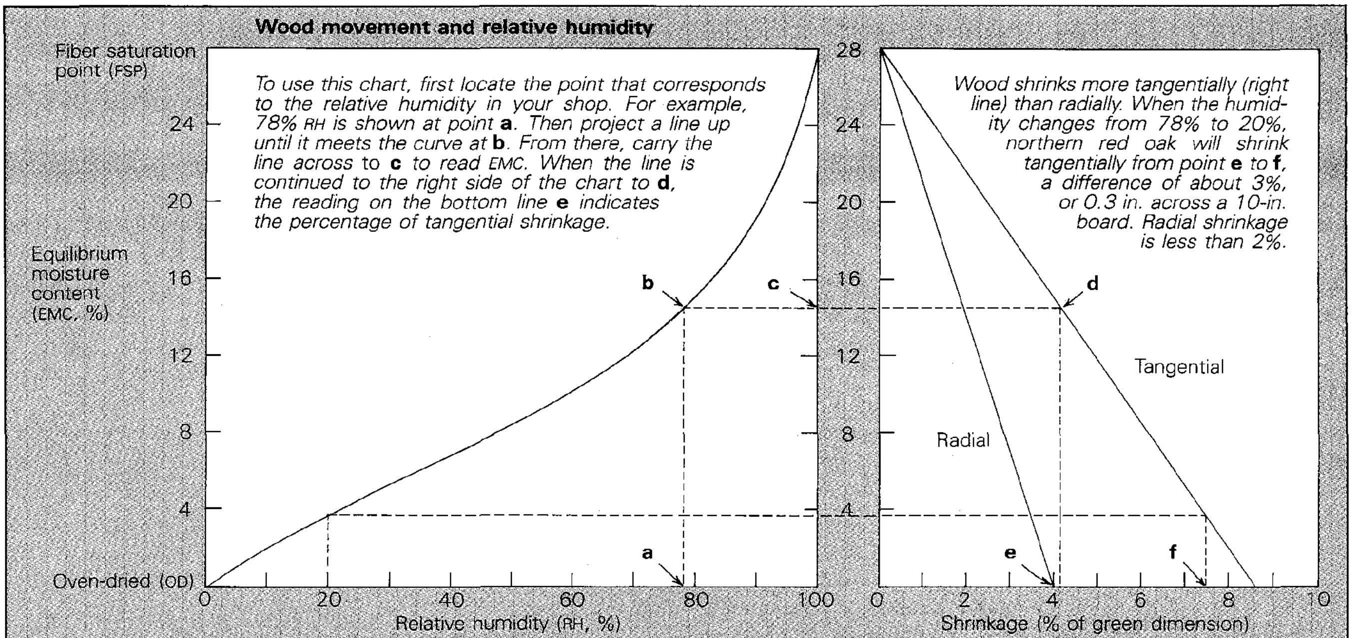
As shown at right, at 70°F the air can hold 8 gr./cu. ft., whereas at 41 °F the air can hold only 3 gr./cu. ft. We naturally associate cold weather with low absolute humidity and hot weather with high absolute humidity. It isn't absolute humidity, however, that causes the problems for woodworkers but relative humidity. And where relative humidity is concerned, the generalization does not always hold true. A hot summer day can be dry; winters can be cold and damp.

Relative humidity (RH) is the ratio (expressed as a percent) of the amount of water in the air at a given temperature to the amount it could hold at that temperature. Since air at 70°F could hold 8 gr./cu. ft., if it actually held only 4 gr./cu. ft., the RH would be 50%; if it held 2 gr./cu. ft., the RH would be 25%, and so forth.

Dew point is the temperature at which air of a given absolute humidity becomes saturated. As an example, air that contains 4 gr./cu. ft. has a dew point of 49.3°F. That is, when cooled to 49.3°F the air will be saturated and therefore will be at 100% RH. If it gets any colder, moisture will condense out. —*R.B.H.*







Moisture migrates slowly through wood as relative humidity changes. Dimensional change in thick pieces may take weeks or months, but a difference in moisture content between surface and center causes stresses that jeopardize gluing and finishing. This composite chart for northern red oak, a typical species, relates wood movement to relative humidity (RH). The left side of the chart shows how the wood's equilibrium moisture content (EMC) changes as RH changes. The right side of the chart shows the percentage of dimensional change.

cavities, and ***bound water,*** held within the cell walls themselves. When wood dries, it loses free water until the moisture content drops to about 30%; from then on it loses bound water. As the cells lose bound water they shrink, creating stresses that can lead to checking and warping.

Even after kiln-drying, wood cells continue to lose and gain moisture until there is an equilibrium between the amount of bound water and the surrounding air's ***relative humidity*** (RH, explained in the box on the facing page). When this balance with RH is reached, the MC of the wood is called the ***equilibrium moisture content*** (EMC). Note the left side of the chart above, which is based on red oak, a typical species; other species differ only slightly. Generally the EMC can vary from 0% (when oven-dried, in effect at 0% RH) to a maximum of about 30% (in an atmosphere where the air is saturated with moisture, in effect at 100% RH). A 30% moisture content is all the bound water the cells can hold, the ***fiber saturation point*** (FSP). The wood will not adsorb more moisture from the air than this, although if rained on or soaked it would absorb some free water again at the surface layers.

Left outdoors (as in a typical drying pile), the wood will arrive at an average equilibrium moisture content depending on the average relative humidity of the area. This is called its ***air-dried moisture content,*** and once the wood reaches this point it will more or less stay there, varying slightly with environmental fluctuations. Air-dried moisture content can vary widely from region to region—wood reaches a different EMC in southwestern deserts than it does in the northwest's rain forests. EMC can vary depending on local conditions within an area; the windward side of a lake, for instance, is measurably drier than the leeward. As I mentioned earlier, air-dried wood reaches an equilibrium at about 14% EMC in the northeast. This is because the relative humidity here averages about 75%. In your own part of the country, you can determine the EMC for air-dried wood if you know the average RH.

Some people define EMC as *surface moisture content,* an appropriate reminder that the wood cells at the surface attain an immediate equilibrium with the surrounding air. When we put a finish on a wooden object, it slows down moisture exchange, giving some protection from sudden changes in relative humidity. And even raw wood takes time to adjust fully—the rate of moisture migration into wood is quite slow, and one or two days of high humidity are not enough to cause much dimensional change in thick pieces. But even temporary change in a raw-wood surface layer can have critical consequences, and abrupt changes in relative humidity, particularly in the workshop, can cause serious problems: drawers that will never work right, faulty glue joints, finishes that won't shine or, at worst, won't adhere at all. These problems can come as a surprise because human beings are relatively insensitive to changes in relative humidity. While the average person can estimate indoor temperatures within a few degrees, sensitivity to relative humidity is quite another matter. We become acclimated to gradual seasonal changes, and our sense of "normal" adjusts to summer humidity and winter dryness.

I'm frequently reminded of this in my daily work. Our laboratory has an experimental room closely controlled at 72°F and 50% RH. When I enter it in winter it seems oppressively muggy and damp, while in summer it seems cool and dry. We cannot trust our senses, but must rely on instruments such as those shown on p. 95 to tell us of conditions that to us may feel only moderately uncomfortable, but to a woodworking project may spell disaster.

Effects of changes in RH—The chart above correlates dimensional change in wood to EMC and RH. My basement, surrounded by bedrock, is also my workshop, and its RH can swing from more than 90% in August (relative humidity rises when hot, muggy air is cooled by the basement) to 5% in midwinter when I have been using the woodstove. Extremes of this magnitude can cause as much as a ½-in. variation in the width of a 10-in., flatsawn red oak board. Wood exchanges moisture with the air fastest on the surface and through the end grain. Abrupt changes in RH mean that the inside of a piece of wood is at an EMC (and size) different from the surface. A sudden dry day can cause microscopic surface checking that will interfere with the quality or adhesion of finishes. Wood has a certain elasticity that allows it to absorb stresses caused by moisture changes, but this elasticity can be lost. A sudden damp day can have somewhat the same effect as a dry one—the surface, restrained from swelling by the center, becomes *compression set (FWW* #14, pp. 80-81). When the surface redries, checks result.

EMC can interfere with gluing. Silicone adhesives will not bond properly if the EMC of the wood surface is too high, and plastic resin glues (urea-formaldehyde) will not bond well if the wood is *drier* than about 7% MC. As the left side of the chart on p. 93 shows, one might encounter problems with urea-formaldehyde glues when the shop RH drops below 40%.

While thick pieces of wood may take days, weeks or even months to completely adjust to a new RH, thin veneers can reach equilibrium within an hour or less. Thus they don't surface-check, but they may quickly undergo the maximum overall change in size. I would not work veneer in my basement when its RH is approaching either extreme.

With the RH in my basement so unstable, even moderate-size pieces of wood, drawer parts for instance, can move enough from one weekend to the next to make precision cuts meaningless. Although I manage to store my wood someplace else, upstairs usually, in a closet, under the bed, in the mudroom or wherever, it still leaves me with the problem of what to do with projects that are half-done. I routinely wrap wood sculptures in plastic between work sessions to protect them, because changes in RH can cause extreme stress between the center and the surface of a thick block. Plastic film or bags have the same effect as a coat of finish—while they can't maintain the moisture content of a piece of wood indefinitely, they can isolate the wood against drastic responses to temporary swings by making changes slow and uniform.

Controlling RH—The ideal moisture content for wood is not necessarily the numerical mean between the highest and lowest extremes, but depends on the yearlong seasonal variation. Indoors, the average RH in the northeast averages close to 40%, mostly due to heating in winter, which commonly lowers levels to 20% for weeks at a time. Red oak furniture, therefore, will eventually reach an average EMC indoors of about 7% to 8%. This is the reason woodworkers in the northeast start out with wood dried to this level. Our workshops, then, should be maintained at a humidity level of about 35% to 40% in order to keep our stock at a 7% to 8% EMC. One would do well to think: "My lumber should be at an equilibrium with 40% relative humidity," rather than thinking only about the wood's 7.5% moisture content. This approach has the advantage of automatically accommodating the different EMCS of various wood species and of wood products such as particleboard, fiberboard and hardboard.

Without its being our intent, many of our daily activities affect indoor RH. In our homes and workshops, we routinely modify temperature by heating and cooling the air. If we increase the temperature while the absolute humidity remains unchanged, the relative humidity will be lowered. If we cool the air, such as happens when I ventilate my cool basement with warmer air from outside, the relative humidity will rise. Routine activities such as cooking and washing may release surprising amounts of water. Mopping a kitchen floor and allowing it to dry, for instance, may add several *pounds* of water to the indoor air. So will moving a quantity of green wood into a storage area filled with wood that has been carefully dried. On the other hand, air conditioners and dehumidifiers cool the air below its dew point. The water condenses out and drips away. Muggy summer air can lose so much moisture as it passes through an air conditioner that it will be comfortably dry when it mingles with the warmer air inside the room. The principles involved above are the basic ways we can control humidity. Some of the methods are expensive, and corrective methods are, in the end, based on economics.

One key factor in deliberately controlling humidity is the size of the area—the smaller and better insulated, the more isolated from volumes of outdoor air, the easier (and cheaper) the job. It is probably futile to try to control RH in a drafty area with leaky doors and windows. Where an entire workshop is too large to be brought under control at a reasonable cost, part of it can be sealed with polyethylene sheet, and small heaters or dehumidifiers can be used to lower RH. If RH must be raised, a humidifier such as the vaporizers sold in drugstores for respiratory relief (about $15 and up) will suffice. In a tight shop, even a pan of water placed on a heater outlet may be enough.

The individual woodworker must decide how much variation he can stand. Rough drawshaving of green-wood chair parts can be done at just about any RH. A marquetarian, however, should monitor humidity very carefully, in both workshop and storage area.

One way to keep an eye on RH is to listen to weather reports, and perhaps to arrange a visit with a local meteorologist (television, radio or university) to get information about local high and low periods and the times of year when drastic change is most likely. This, combined with good instruments, will give you a jump on the most dangerous periods.

In winter, with my woodstove drawing in and heating large amounts of already dry winter air, there is a practical limit to the RH that I can maintain in my basement shop. As it gets to a reasonable level, water condenses on cold walls and windows. In summer the outdoor temperature may reach into the 90s, with RH levels above 85% for days at a time. Letting this air into my basement is disastrous. It is frustrating to get ready to spend a weekend on a project, only to discover that low or high humidity makes it unwise to work. For many of us, woodworking is a periodic or a sporadic activity. We can, perhaps, choose our work times to coincide with suitable shop conditions. Someday, when I get to it, I'll partition and insulate part of my basement, at least enough for storage, and I'll use a small heater, dehumidifier and humidifier to get me through the extremes. In the meantime, I'll watch my instruments, exercise restraint, and keep exhorting woodworkers to pay attention to humidity. □

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Measuring relative humidity

Perhaps the most familiar instrument for measuring relative humidity is the dial-type hygrometer commonly found in home weather stations. This type uses a hygroscopic material, such as animal skin or hair, connected to the pointer on the dial. It has the distinct advantage of providing continuous readings at a glance. But it is subject to inaccuracy for several reasons: the sensing element may react differently to rising humidity than it does to falling, it may lose accuracy after being exposed to extremes, and it can be quickly contaminated by sawdust. These dial instruments are cheap ($15 and up) and convenient, but most of them come with inadequate directions. If you use one, keep it clean, mount it where there will be good air circulation around it, and check its calibration regularly.

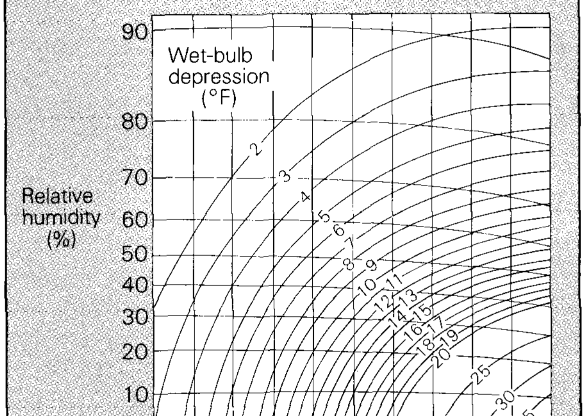
The instrument most frequently used to calibrate other hygrometers is the sling psychrometer (about $35). It consists of two thermometers mounted side by side. One thermometer bulb is covered with a dampened wick. As water evaporates from the wick, it lowers the temperature of the wet-bulb thermometer. The difference is called the *wet-bulb depression.* On dry days, the water evaporates more rapidly than it does on damp days, so the drier the day, the greater the wet-bulb depression. Wet-bulb depression can be converted (by consulting a chart such as the one below) to relative humidity. To ensure that the air around the wet bulb does not become saturated with evaporating moisture, the instrument is swung in vertical circles (by means of its swiveled handle) until the wet-bulb temperature no longer drops.

A variation of the sling psychrometer is the stationary dual-bulb hygrometer ($10 and up). You can easily make one from a pair of matched thermometers. Wicks can be made from stretchy cotton slipped tightly over one bulb with the free end dangling in a small reservoir. It's best to use distilled water so that mineral deposits don't accumulate in the wick. Keep a good airflow (fan it until the wet-bulb temperature no longer drops), avoid mounting the instrument where conditions such as direct sunlight would affect the dry-bulb reading, and keep the wick clean.—*R.B.H.*

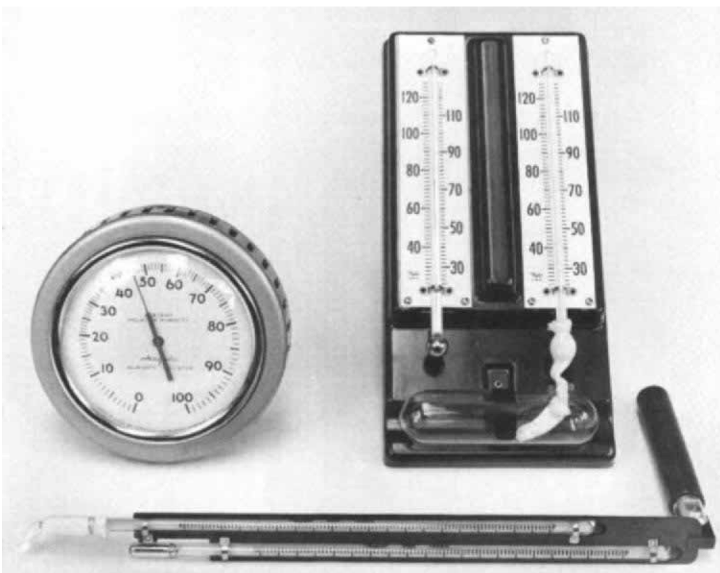
Sources—Here are some suppliers who carry instruments for monitoring RH:
Abbeon Cal. Inc., 123-78A Gray St., Santa Barbara, Calif. 93101 (805) 966-0810
The Ben Meadows Co., PO Box 80549, Atlanta, Ga. 30366 (800) 241-6401
Edmund Scientific Co., 5975 Edscorp Bldg., Barrington, N.J. 08007 (609) 547-3488
Fisher Scientific Co., 711 Forbes Ave., Pittsburgh, Pa. 15219 (412) 562-8300
Fine Tool & Wood Store, 724 West Britton Rd., Oklahoma City, Okla. 73114, Tel: (800) 255-9800
TSI Company, PO Box 151, Flanders, N.J. 07836, Tel: (201) 584-3417
Sporty's Tool Shop, Clermont County Airport, Batavia, Ohio 45103 (513)732-2411

Part of a dry-kiln control system, this cellulose wafer (left) reacts almost instantly to changing RH levels to yield EMC readings directly, without reference to conversion charts. Available from Lignomat USA (14345 NE Morris Court, Portland, Ore. 97230), the device currently costs $80 without the meter, mostly due to the cost of the kiln-proof holder—the wafers themselves, which are replaced every three weeks, are only about 35¢.

Reading a psychrometer



Find the dry-bulb temperature (the room temperature) on the bottom line; read up to meet the curved line that indicates wet-bulb depression (the difference between wet-bulb and dry-bulb readings), and then read the RH, as indicated by the lines numbered at the left.



Instruments to help you avoid the frustrating woodworking problems caused by uncontrolled relative humidity in work and storage areas. Clockwise from upper left: dial hygrometer, dual-bulb hygrometer, sling psychrometer.