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A Checklist for Operators of Small Dry Kilns

A companion to *A Start-up Guide for Operators of Small Dry Kilns* (FOR-132)

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Introduction

Drying air-dried hardwood lumber to the finished moisture content (MC) requires care and attention, but it's not difficult. This document describes the steps a kiln operator should follow to get the best lumber from his/her air-dried material. It will probably be most useful for operators of small kilns, but the principles are the same regardless of kiln size or type.

To get the highest quality, pay attention to the details from the moment the tree is cut. Lumber quality begins with good log handling, fast turn-around time before sawing, end coating (where appropriate), log storage, and good handling in the air-drying yard–and all that takes place before lumber gets loaded into a dry kiln. You can't take lumber that has been handled inattentively and improve upon any stain or drying defects that may have occurred.

Kiln operators must educate themselves and work carefully to dry high-quality hardwood lumber. In summary:

- Be sure that all of the kiln equipment is working properly before lumber is loaded into the kiln.
- Know how to choose and apply the correct schedule for the lumber.

Check Your Equipment and Kiln Schedule Before You Load Your Kiln

Before anything else, take a moment to ask yourself whether you and your equipment are fully prepared to do a great job drying the lumber. Here's a list of some of the things to look for:

Gaps

Does the kiln have any gaps around the door seals that need your attention? Did you bang up the kiln doors with a forklift the last time you took lumber out of the kiln?

Baffles

Are the kiln baffles operational? Are there leaks around the baffles that needs repairs?

In-kiln Moisture Sensors

Your kiln controller might be connected to moisture meter pins (called "probes" by some makers) that you screw or hammer into lumber to monitor lumber moisture content electronically during drying. These in-kiln moisture sensors are usually optional equipment, but if you use them you have to know how to use them correctly. How deep you insert the sensors and the spacing and alignment are important, and instructions vary from one manufacturer to another.

See Figure 1 for an example of an in-kiln moisture sensor from one manufacturer.

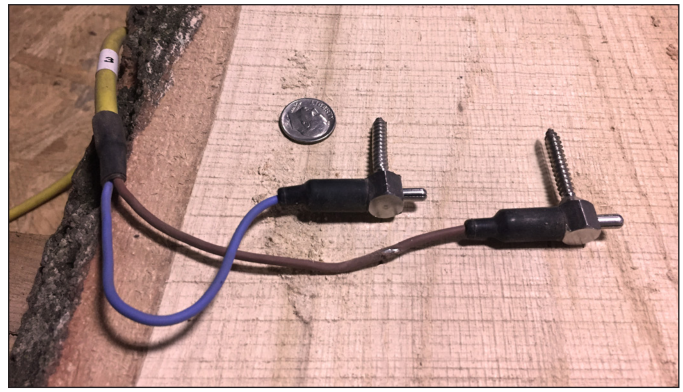

Figure 1. An example of in-kiln moisture sensors from one manufacturer, consisting of a pair of metal screw-type pins and cables that connect to the kiln controller. The sensors shown are one inch long, appropriate for 8/4 lumber; a U.S. dime is included for scale. To show the dimensions the sensors are shown on their sides in this photograph, but they go into the lumber at about the distance shown to make moisture readings. The manufacturer requires that these sensors be inserted perpendicular to the grain, but that may vary with sensors from other makers.

The type of sensors shown in Figure 1 are screwed into the wood perpendicular to the grain to about one-half the lumber thickness, at least 15 to 20 inches away from the end of the board. The figure shows a pair of probes correctly set (for this manufacturer) perpendicular to the grain and 1.25 inches apart; the pins will be inserted to a one-inch depth for 8/4 lumber.

Other makers do things differently. One kiln control company supplies different lengths of screw-type sensors to simultaneously monitor the shell and the core moisture readings, for example. (A moisture reading at the surface is known as the "shell" moisture content, whereas a reading from the board center is known as the "core" moisture content.)

If you have in-kiln moisture sensors, you have several additional things that you need to look at:

- Check to be sure all the pins at the ends of your sensors are connected and working.
- Be sure you know how to orient the sensors in the lumber. If the kiln circuitry is of European manufacture, they will probably be inserted perpendicular to the grain. U.S.-made handheld pin-type moisture meters you may be more familiar with are usually calibrated to read the moisture content when the pins are inserted parallel to the grain. Note the differences.
- The dry bulb (DB) thermometer sensing unit has to work properly because the in-kiln moisture sensor readings are affected by temperature. If the temperature sensor is not working, the kiln controller will display inaccurate moisture readings.
- With Nyle or similar kiln controllers, the Wood Group parameter must be set to match the lumber species in your kiln.

Like pin-type resistance moisture meters, in-kiln moisture sensors are affected by the placement of the sensors, the wood species, and the wood temperature. The kiln temperature, of course, is already monitored by the controller. It's up to you to tell the kiln controller which species you are drying, however.

Nyle and Wood-Mizer DH kiln manuals instruct users to set a Wood Group parameter between 1 and 4 to account for species; the species listing is usually found in an Appendix to the kiln manual. Most U.S. species are in Wood Group 3. If for some reasons you are drying a mixed load, double-check your Wood Group parameter setting. It's likely that Wood Group 3 will still be the correct setting, but Wood Group 2 is listed as an alternative for ash, cedars, and poplars.

The designation of "Wood Group" in this context overlaps with the wording used to indicate the species grouping that addresses the quantity of lumber that can be loaded into a kiln. The use of "Wood Groups" here, and either "Wood-" or "Lumber Groups" in that other usage, can be confusing. Be alert to the distinctions, and remember that the tables you need to refer to are different.

Balances and Ovendrying Equipment

Some people don't rely on in-kiln moisture sensors, particularly when they are getting used to how a new kiln performs. If you prefer a hands-on approach to monitoring how a load of wood is drying, you will need digital balances to weigh moisture wafers (sometimes called moisture sections) and sample boards to monitor the moisture content during drying.

I recommend that you have balances with both small and large capacities to measure different sizes of lumber samples. I have one balance that weighs small samples up to 1000 grams (2.2 pounds), for example, as well as a mid-range balance that weighs heavier samples up to 5000 grams (11 pounds). Those are the balances I use most often. I also have one resembling a postal scale that I use when I'm working with dense 8/4 sample boards, and I can even weigh entire boards with it (if I need to) up to 32 kg (70 pounds). I weigh samples with the smallest balance that doesn't exceed the capacity of the balance; smaller balances have finer resolution than larger capacity balances (0.1 grams versus 1 gram versus 5 grams for my equipment). I weigh samples in grams because it makes calculations easier.

None of these balances are expensive. See Figure 2 for an example of mid-range balance.

It's a good idea to purchase calibration weights that you can use now and then to be sure your balances are reading correctly. I bought three weights to use for myself: I bought a 500-gram weight to check the mid-range of my 1,000 gram balance, a 2,000 grams (2 kg) weight to check my 50,000 gram (5 kg) balance, and a 20,000 gram (20 kg) balance to check my 32 kg postal scale.[1] You could add some lower- and higher-range weights to the set if you like. You might find that your balances do not read the labelled calibration weights exactly correctly, but these weights are themselves manufactured to meet certain tolerances during manufacture. As a consequence, the actual weights may be very slightly different from their specified weights. If the weights you read are pretty close to the specified weights then you're in good shape; what you need to look out for afterwards is consistency, because if the balance readings start to drift it's time to get a new balance. Keep your calibration weights clean so that you can make reproducible measurements.

You need an oven that you can set at a minimum of 212°F to dry small lumber samples such as moisture wafers. I highly recommend an oven with a convection fan; air movement is helpful to get a more uniform temperature throughout the oven. A temperature setting of 215 to 220°F will ensure that the wood gets completely dried.

1 Troemner is a major maker of calibration weights with an online storefront. I bought Class F weights because I wanted to minimize cost yet still get accurately made weights. Weights are available with both higher and lower degrees of tolerance.

Figure 2. An example of an inexpensive intermediate-size balance. This one weighs up to 5000 grams (eleven pounds), and I use it to weigh sample boards. It's suitable for 4/4 sample boards and for many 8/4 sample boards, though that depends on the moisture content and the density. You will probably need a higher capacity balance if you dry 8/4 lumber.

I've found that small consumer-grade ovens often have inaccurate temperature settings and may have wide temperature swings. I added a digital oven thermometer to my own small convection oven and clipped the wired sensor to a shelf inside the oven so I could be sure it was hot enough; having that oven thermometer gives me confidence that the oven is actually drying my samples at a high enough temperature.

If you observe that your oven doesn't maintain an even temperature, increase the set point so it's well over 215°F most (if not all) of the time. You have to be sure that your moisture wafers dry completely to get accurate weights and moisture content readings. Drying at temperatures below 212°F will never dry your samples thoroughly, regardless of how long you leave them in the oven.

Hand-held Electronic Moisture Meters

I have both a pin-type moisture meter and a pinless meter, and I use both of them.

I use a pin-type meter to determine the surface moisture content of air-dried lumber. That information can be crucial to help determine the proper kiln setting when you are ready to load air-dried lumber into the kiln. Pin-type meters can also be used to show the moisture gradients in your lumber.

A pinless moisture meter is useful to help estimate the uniformity of air-dried. Different locations in a stack of lumber may dry differently, for example. Note any differences before putting lumber into a kiln.

Electronic moisture meters are handy tools, but they are not a substitute for properly performed ovendrying moisture content determinations. Moisture meters are very accurate with laboratory samples, but in the real world the accuracy of your meter will be affected by differences between a laboratory calibration specimen and different trees in the real world. There can be variations between heartwood and sapwood properties, for example. Even the height at which the lumber was cut might mean that pieces have different properties from the calibration specimen. If you think about it, your meter might give you slightly different readings at different locations in a single board even if the moisture content was entirely uniform throughout. Moisture meters are invaluable, but don't rely on them exclusively when you really need accurate moisture determinations.

Filling the Kiln

How much lumber you can put into your kiln? If you are operating a dehumidification (DH) kiln, this question is different from knowing your kiln capacity. The rate at which a DH kiln can remove water vapor is dependent on the equipment in the kiln. Accordingly, manuals for DH kilns recommend filling the kiln with different amounts of lumber according to the species.

DH kilns are used to dry both low-density lumber (quick to dry) and higher-density species (which give up water vapor more slowly), so when a kiln manufacturer specifies a compressor size it's a bit of a balancing act. A small compressor would be sufficient if you only dry high-density, slow-drying species, but a larger compressor is needed to efficiently dry low-density species. Since compressors aren't swapped in and out of a kiln according to need, manufacturers specify a mid-size unit and vary the percentage of time that the compressor is operating. A compressor can always run at less than 100% if a slow-drying load of high-density hardwood is being dried, for example. On the other hand, it's possible that a compressor won't be able to keep up with the amount of water vapor being released by low-density hardwood species (or softwoods), even if the compressor is running 100% of the time; in that situation, the lumber volume needs to be reduced to prevent too much water vapor being released into the kiln for the compressor to control. If the compressor is too small to keep up with the amount and rate of water release, stain and mold can result.

Recognizing these issues, manufacturers of DH kilns have made recommendations about the amount of lumber to load into a DH kiln. Recommendations for species and lumber thickness are usually combined into groups to simplify running the kiln. These groups are often called "Lumber Groups", though in some manuals (even by the same manufacturer), they are called "Wood Groups". Tables of Lumber/Wood Groups, with recommended kiln loads, are found in the kiln manuals provided by manufacturers.

As an example of Lumber Groups, here's an abbreviated table from Nyle L200/Wood-Mizer KD250 dehumidification dry kiln manuals (see Figure 3). These kilns have a nominal capacity of 4,000 board feet of lumber. The reduced loading recommendations are to prevent overloading the compressor:

Figure 3. The Lumber Group information in this table is based on dehumidification kiln manuals supplied to their customers by Nyle and Wood-Mizer.

Group 1 (1500 board feet)	4/4 Softwoods, 4/4 Soft Hardwood
Group 2 (3000 board feet)	4/4 Medium Hardwoods, 8/4 Softwoods and 8/4 Soft Hardwoods
Group 3 (4000 board feet)	4/4 Dense Hardwoods and 8/4 Medium Hardwoods
Group 4 (4000 board feet)	8/4 Dense Hardwoods

With air-dried lumber, the kiln can usually be completely filled without worrying about overtaxing the kiln's compressor.

Relative Humidity

In addition to knowing the dry bulb temperature, you need to know the relative humidity in the kiln. Your kiln might have digital humidity sensors interfaced with the kiln controller to display and control the kiln humidity. If you don't have digital sensors, wet bulb (WB) thermometers can also be connected to kiln controllers.

Wet bulb thermometers, usually known simply as "wet bulbs", are ordinary thermometers with a couple of small modifications. A wet bulb has a cotton wick over the thermometer bulb, and the wick is kept wet with a connection to a water reservoir; the reservoir has to be checked frequently and refilled as needed. The wetted wick cools the thermometer in inverse proportion to the humidity in the air. Together, the difference between the wet bulb and dry bulb thermometer temperature readings is used to determine the relative humidity; you can find the relative humidity from a table like the one in Appendix A of this publication. If you are using a wet bulb, check to make sure the wick is clean before you start the kiln, because that can affect the wick's drying rate.

Some small dehumidification dry kilns, particularly older models, might not have been equipped with a relative humidity or wet bulb sensor by the manufacturer. If you install a wet bulb thermometer, one that you can read to the nearest 1°F is good enough. If you decide to add a digital humidity sensor, purchase one that is accurate and well-calibrated. You may be able to place the readout display outside the kiln chamber for convenience even if you can't connect it to your kiln controls.

Wet bulb sensors might not work well if they are placed too close to the kiln wall; if you aren't getting good air flow to the wick the wet bulb may not dry as fast as it would out in faster-moving air, and the WB temperature might be higher than it should be. This would indicate a relative humidity that's higher than the actual mid-kiln conditions.

Incorrect WB readings can create headaches for a kiln operator. I visited one DH kiln installation where the outside air temperature was at 38°F and the kiln was struggling to reach 105°F. That DB sensor reading seemed to be reasonably accurate based on a point-and-shoot infrared reading of the lumber. The wet bulb reading displayed by the kiln controller was quite low (about 73°F (a 32° depression)) considering that the lumber was over 25 percent MC; that didn't make sense. No one understood why the wet bulb temperature was so low; the lumber should have been warming up and releasing water vapor into the kiln atmosphere, increasing the WB temperature. The operator had set a 95°F WB (10°F depression) and the controller believed that the kiln was already below the set point, so the controller wasn't calling for the compressor to turn on and drying wasn't occurring.

By using a thermal imaging camera I found that the kiln needed more insulation, and that was causing several problems. The wet bulb was positioned near a wall that was reading a little higher than the ambient temperature on the outside of the kiln, but on the inside wall the temperature was at 60°F directly behind the WB. It should have been much warmer, close to the DB temperature.

The incorrect wet bulb reading made the kiln controller dysfunctional. We temporarily resolved the lack of drying by lowering the WB setting below what was indicated on the controller, thereby turning on the compressor. That improvised fix only worked because the kiln operator agreed to monitor the lumber's moisture loss much more closely while preparations were being made to upgrade the kiln insulation and to move the wet bulb to a better location.

Moisture Sampling Boards

Do you already have boards selected for moisture monitoring in your air-drying lumber? If you don't already have boards selected for moisture sampling, you should choose and prepare some to use in the kiln. Use the correct compound to prevent water end-grain water loss on your sample boards. You need selected boards to monitor moisture during drying whether you use sample boards or moisture sensors.

Sample boards are short boards, selected from typical lumber in your kiln load, that you use to monitor the moisture content as lumber dries in the kiln. The kiln drying conditions are determined by tracking the moisture contents of those boards as they dry. Every board will have a slightly different moisture content and drying rate; your goal should be to select the best boards to get a good representation of the moisture variation in your lumber.

Sample boards need to be coated on their ends. When water is prevented from evaporating from the open cells on the end grain, water is forced to evaporate from the side grain instead. This forces sample boards to dry at a rate that mimics the longer boards in the kiln. There are several commercial compounds available to kiln operators. Use one that is specifically made for sample boards, because these won't evaporate as the kiln temperature is raised (Figure 4).

If you are using moisture sensors instead of sample boards you still need to decide which boards to use for moisture monitoring, though they will be full-length instead of short sample boards. No small kiln operator likes reducing the volume of saleable lumber by cutting sample boards, and that's a good reason to use sensors. Be aware that using sensors exclusively can have drawbacks, though. According to one manufacturer, sensors can read moisture content between 8%–90% MC at 25°F, but moisture contents determined from resistance measurements are less accurate above 30% MC. If you only use moisture sensors, you may also find it difficult to accurately measure moisture contents in the range of 6–8% without sample boards.

Sample boards (and longer boards used with sensors) should not be selected because they are the easiest to get to or because they are of lower quality. The way boards gets sawn and the way the growth rings are oriented will affect the drying rate. Flatsawn and quartersawn boards will have different volumes of ray ends exposed on the surfaces, and since water leaves lumber more readily through the ray ends than from the sides of the rays, quartersawn boards will dry slower than flatsawn boards. This is why you need to select both slow-drying quartersawn boards and faster-drying flatsawn boards to monitor the lumber moisture content. You need to pay close attention to the wetter, slow-drying boards at the beginning of drying so you don't dry the lumber too quickly and you need to know how your drier boards are doing so you can slow down the kiln when they get close to your target MC. Selecting your moisture monitoring boards according to purposeful intention will help you dry your lumber more accurately and more uniformly.

The moisture variability in the lumber will likely be similar

Figure 4. This is an example of a proprietary end coating used to prevent moisture loss from the ends of sample boards. The Bright Orange Sample Sealer (B.O.S.S.) shown here is sold by Anchorseal.

Table 7.12—Kiln schedules for green, air-dried, or predried red oak—northern, Appalachian, or upland[a]

Initial MC (%)	4/4 and 5/4 (T3–D2) Dry-bulb temperature (°F)	Wet-bulb depression (°F)	Wet-bulb temperature (°F)	6/4 and 8/4 (T3–D1) Dry-bulb temperature (°F)	Wet-bulb depression (°F)	Wet-bulb temperature (°F)
>50	110	4	106	110	3	107
50	110	5	105	110	4	106
40	110	8	102	110	6	104
35	110	14	96	110	10	100
30	120	30	90	120	25	95
25	130	40	90	130	40	90
20	140	45	95	140	45	95
15	160	45	115	160	45	115
Equalize	170	43	127	170	43	127
Condition	180	10	170	180	10	170

Figure 5. Kiln schedules specify changes to the dry bulb and the wet bulb according to the moisture content of the boards you have chosen to use for moisture sampling. In this example for red oak, the kiln schedules for different thicknesses of lumber are listed in adjacent columns.

for both small and large kiln loads, but it's natural for operators of small kilns to want to minimize the number of sample boards. If that sounds like you, keep in mind that decreasing the number of sample boards increases the chance that you won't get an accurate idea of the moisture variability in your lumber. I recommend a minimum of four sample boards even if you have a very small kiln. If you are using moisture sensors, connect all the sensors available (often four sets).

Fans

Do your fans work, and are they running at the proper speed? Are the blades running at the correct pitch? Depending on how they were constructed, sometimes fan blades can shift. I have even occasionally seen fan blades installed backwards, so take a look to make sure all your fans are running in the same direction.

Any piece of equipment is liable to fail over time, and that may apply to fans more than to any other piece of equipment. "People of a certain age" will nod their heads in recognition when I say that equipment failures can occur slowly, though sometimes they fail in a dramatic fashion. Keep an eye on all of your equipment – fans, doors, moisture meters, dry bulb sensors, wet bulb sensors – everything!

Kiln Schedule

Have you selected the appropriate kiln schedule? Some species dry faster and some dry slower, and some species have to be dried more slowly than others to avoid drying defects, so choose a schedule carefully–and plan to follow it. With experience and knowledge of how your kiln performs you might decide to make slight modifications at a later date.

Many kiln operators are familiar with the kiln schedules in the Dry Kiln Operators Manual[2] but the schedules located in Drying Hardwood Lumber[3] are newer and better reflect the quality of the wood brought to sawmills in recent years. You could also contact your kiln manufacturer for help with drying schedules and operating instructions.

Kiln schedules differ according to the species and the thickness of the lumber, so be sure you are looking at the column for the thickness you are drying. It's common for schedules for different thicknesses of lumber to be listed side-by-side on the same page. Sometimes the schedule given for thinner lumber lists 4/4–5/4 lumber, and sometimes it lists 4/4–6/4 lumber. Be careful to refer to the correct column.

Your kiln schedule will probably look something like this (Figure 5 was copied from Table 7.12, *Drying Hardwood Lumber*):

This kiln schedule includes two final steps: Equalization (to help you get all of the lumber to a more uniform moisture content) and Conditioning (to help you decrease any drying stress in the lumber after drying is finished).

Make a Copy

Make a copy of your schedule and pin it to the wall. Put it someplace where you can refer to it easily–maybe close to the kiln controls or the weighing station. If you laminate a copy it will last a lot longer!

2. Simpson, William T., Editor. 1991. *Dry Kiln Operator's Manual*. USDA Agricultural Handbook Number 188. Madison, WI: U.S. Department of Agriculture, Forest Service, Forest Products Laboratory. 274 p.

3. Denig, Joseph; Wengert, Eugene M.; Simpson, William T. 2000. *Drying Hardwood Lumber*. Gen. Tech. Rep. FPL–GTR–118. Madison, WI: U.S. Department of Agriculture, Forest Service, Forest Products Laboratory. 138 p. http://www.fpl.fs.fed.us/documnts/fplgtr/fplgtr118.pdf

End Coating

If your lumber was previously air-dried you probably made a decision long ago about whether or not to spray/brush an end coat on your lumber to minimize moisture loss in the kiln. This end coating is different from the non-melting, non-evaporating type you need to use on your sample boards. This type of coating is usually made from a wax-like emulsion. Heat will affect this coating, but it works well to minimize the effect of moisture loss at the ends of boards. If you are putting green lumber into the kiln, consider whether this is something you ought to apply to stickered lumber. Denser species tend to check and split more at the ends, and more valuable lumber (even if it's less dense) is often end coated as a precaution. Examples of candidates for end coating might include white oak or 8/4 black walnut.

Appendix A: EMC Tables

These tables show values for relative humidity (RH) and equilibrium moisture content (EMC) at different kiln conditions, specified by dry-bulb temperature (DB) and wet-bulb temperature (WB). (This version has been copied from the USDA *Dry Kiln Operator's Manual,* Agriculture Handbook 188, Edited by William T. Simpson, Revised 1991.)

Table 1-6—Relative humidity and equilibrium moisture content at various dry-bulb temperatures and wet-bulb depressions below 212°F.

Dry-bulb temper-ature (°F)	Relative humidity[1] and equilibrium moisture content[2] (%) at various wet-bulb depression temperatures (°F)																	
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
30	89	78	67	57	46	36	27	17	6	—	—	—	—	—	—	—	—	—
	—	*15.9*	*12.9*	*10.8*	*9.0*	*7.4*	*5.7*	*3.9*	*1.6*	—	—	—	—	—	—	—	—	—
35	90	81	72	63	54	45	37	28	19	11	3	—	—	—	—	—	—	—
	—	*16.8*	*13.9*	*11.9*	*10.3*	*8.8*	*7.4*	*6.0*	*4.5*	*2.9*	*0.8*	—	—	—	—	—	—	—
40	92	83	75	68	60	52	45	37	29	22	15	8	—	—	—	—	—	—
	—	*17.6*	*14.8*	*12.9*	*11.2*	*9.9*	*8.6*	*7.4*	*6.2*	*5.0*	*3.5*	*1.9*	—	—	—	—	—	—
45	93	85	78	72	64	58	51	44	37	31	25	19	12	6	—	—	—	—
	—	*18.3*	*15.6*	*13.7*	*12.0*	*10.7*	*9.5*	*8.5*	*7.5*	*6.5*	*5.3*	*4.2*	*2.9*	*1.5*	—	—	—	—
50	93	86	80	74	68	62	56	50	44	38	32	27	21	16	10	5	—	—
	—	*19.0*	*16.3*	*14.4*	*12.7*	*11.5*	*10.3*	*9.4*	*8.5*	*7.6*	*6.7*	*5.7*	*4.8*	*3.9*	*2.8*	*1.5*	—	—
55	94	88	82	76	70	65	60	54	49	44	39	34	28	24	19	14	9	5
	—	*19.5*	*16.9*	*15.1*	*13.4*	*12.2*	*11.0*	*10.1*	*9.3*	*8.4*	*7.6*	*6.8*	*6.0*	*5.3*	*4.5*	*3.6*	*2.5*	*1.3*
60	94	89	83	78	73	68	63	58	53	48	43	39	34	30	26	21	17	13
	—	*19.9*	*17.4*	*15.6*	*13.9*	*12.7*	*11.6*	*10.7*	*9.9*	*9.1*	*8.3*	*7.6*	*6.9*	*6.3*	*5.6*	*4.9*	*4.1*	*3.2*
65	95	90	84	80	75	70	66	61	56	52	48	44	39	36	32	27	24	20
	—	*20.3*	*17.8*	*16.1*	*14.4*	*13.3*	*12.1*	*11.2*	*10.4*	*9.7*	*8.9*	*8.3*	*7.7*	*7.1*	*6.5*	*5.8*	*5.2*	*4.5*
70	95	90	86	81	77	72	68	64	59	55	51	48	44	40	36	33	29	25
	—	*20.6*	*18.2*	*16.5*	*14.9*	*13.7*	*12.5*	*11.6*	*10.9*	*10.1*	*9.4*	*8.8*	*8.3*	*7.7*	*7.2*	*6.6*	*6.0*	*5.5*
75	95	91	86	82	78	74	70	66	62	58	54	51	47	44	41	37	34	31
	—	*20.9*	*18.5*	*16.8*	*15.2*	*14.0*	*12.9*	*12.0*	*11.2*	*10.5*	*9.8*	*9.3*	*8.7*	*8.2*	*7.7*	*7.2*	*6.7*	*6.2*
80	96	91	87	83	79	75	72	68	64	61	57	54	50	47	44	41	38	35
	—	*21.0*	*18.7*	*17.0*	*15.5*	*14.3*	*13.2*	*12.3*	*11.5*	*10.9*	*10.1*	*9.7*	*9.1*	*8.6*	*8.1*	*7.7*	*7.2*	*6.8*
85	96	92	88	84	80	76	73	70	66	63	59	56	53	50	47	44	41	38
	—	*21.2*	*18.8*	*17.2*	*15.7*	*14.5*	*13.5*	*12.5*	*11.8*	*11.2*	*10.5*	*10.0*	*9.5*	*9.0*	*8.5*	*8.1*	*7.6*	*7.2*
90	96	92	89	85	81	78	74	71	68	65	61	58	55	52	49	47	44	41
	—	*21.3*	*18.9*	*17.3*	*15.9*	*14.7*	*13.7*	*12.8*	*12.0*	*11.4*	*10.7*	*10.2*	*9.7*	*9.3*	*8.8*	*8.4*	*8.0*	*7.6*
95	96	92	89	85	82	79	75	72	69	66	63	60	57	55	52	49	46	44
	—	*21.3*	*19.0*	*17.4*	*16.1*	*14.9*	*13.9*	*12.9*	*12.2*	*11.6*	*11.0*	*10.5*	*10.0*	*9.5*	*9.1*	*8.7*	*8.2*	*7.9*

Table 1-6—Relative humidity and equilibrium moisture content at various dry-bulb temperatures and wet-bulb depressions below 212°F—continued

Dry-bulb temper-ature (°F)	Relative humidity[1] and equilibrium moisture content[2] (%) at various wet-bulb depression temperatures (°F)																		
	19	**20**	**21**	**22**	**23**	**24**	**25**	**26**	**27**	**28**	**29**	**30**	**32**	**34**	**36**	**38**	**40**	**45**	**50**
30	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
35	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
40	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
45	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
50	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
55	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
60	9	5	1	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
	2.3	*1.3*	*0.2*	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
65	16	13	8	6	2	—	—	—	—	—	—	—	—	—	—	—	—	—	—
	3.8	*3.0*	*2.3*	*1.4*	*0.4*	—	—	—	—	—	—	—	—	—	—	—	—	—	—
70	22	19	15	12	9	6	3	—	—	—	—	—	—	—	—	—	—	—	—
	4.9	*4.3*	*3.7*	*2.9*	*2.3*	*1.5*	*0.7*	—	—	—	—	—	—	—	—	—	—	—	—
75	28	24	21	18	15	12	10	7	4	1	—	—	—	—	—	—	—	—	—
	5.6	*5.1*	*4.7*	*4.1*	*3.5*	*2.9*	*2.3*	*1.7*	*0.9*	*0.2*	—	—	—	—	—	—	—	—	—
80	32	29	26	23	20	18	15	12	10	7	5	3	—	—	—	—	—	—	—
	6.3	*5.8*	*5.4*	*5.0*	*4.5*	*4.0*	*3.5*	*3.0*	*2.4*	*1.8*	*1.1*	*0.3*	—	—	—	—	—	—	—
85	36	33	30	28	25	23	20	18	15	13	11	9	4	—	—	—	—	—	—
	6.7	*6.3*	*6.0*	*5.6*	*5.2*	*4.8*	*4.3*	*3.9*	*3.4*	*3.0*	*2.4*	*1.7*	*0.9*	—	—	—	—	—	—
90	39	36	34	31	29	26	24	22	19	17	15	13	9	5	1	—	—	—	—
	7.2	*6.8*	*6.5*	*6.1*	*5.7*	*5.3*	*4.9*	*4.6*	*4.2*	*3.8*	*3.3*	*2.8*	*2.1*	*1.3*	*0.4*	—	—	—	—
95	42	39	37	34	32	30	28	26	23	22	20	17	14	10	6	2	—	—	—
	7.5	*7.1*	*6.8*	*6.4*	*6.1*	*5.7*	*5.3*	*5.1*	*4.8*	*4.4*	*4.0*	*3.6*	*3.0*	*2.3*	*1.5*	*0.6*	—	—	—

Table 1-6—Relative humidity and equilibrium moisture content at various dry-bulb temperatures and wet-bulb depressions below 212°F—continued

Dry-bulb temper-ature (°F)	Relative humidity[1] and equilibrium moisture content[2] (%) at various wet-bulb depression temperature (°F)																	
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
100	96	93	89	86	83	80	77	73	70	68	65	62	59	56	54	51	49	46
	—	*21.3*	*19.0*	*17.5*	*16.1*	*15.0*	*13.9*	*13.1*	*12.4*	*11.8*	*11.2*	*10.6*	*10.1*	*9.6*	*9.2*	*8.9*	*8.5*	*8.1*
105	96	93	90	87	83	80	77	74	71	69	66	63	60	58	55	53	50	48
	—	*21.4*	*19.0*	*17.5*	*16.2*	*15.1*	*14.0*	*13.3*	*12.6*	*11.9*	*11.3*	*10.8*	*10.3*	*9.8*	*9.4*	*9.0*	*8.7*	8.3
110	97	93	90	87	84	81	78	75	73	70	67	65	62	60	57	55	52	50
	—	*21.4*	*19.0*	*17.5*	*16.2*	*15.1*	*14.1*	*13.3*	*12.6*	*12.0*	*11.4*	*10.8*	*10.4*	*9.9*	*9.5*	*9.2*	*8.8*	8.4
115	97	93	90	88	85	82	79	76	74	71	68	66	63	61	58	56	54	52
	—	*21.4*	*19.0*	*17.5*	*16.2*	*15.1*	*14.1*	*13.4*	*12.7*	*12.1*	*11.5*	*10.9*	*10.4*	*10.0*	*9.6*	*9.3*	*8.9*	8.6
120	97	94	91	88	85	82	80	77	74	72	69	67	65	62	60	58	55	53
	—	*21.3*	*19.0*	*17.4*	*16.2*	*15.1*	*14.1*	*13.4*	*12.7*	*12.1*	*11.5*	*11.0*	*10.5*	*10.0*	*9.7*	*9.4*	*9.0*	*8.7*
125	97	94	91	88	86	83	80	77	75	73	70	68	65	63	61	59	57	55
	—	*21.2*	*18.9*	*17.3*	*16.1*	*15.0*	*14.0*	*13.4*	*12.7*	*12.1*	*11.5*	*11.0*	*10.5*	*10.0*	*9.7*	*9.4*	*9.0*	*8.7*
130	97	94	91	89	86	83	81	78	76	73	71	69	67	64	62	60	58	56
	—	*21.0*	*18.8*	*17.2*	*16.0*	*14.9*	*14.0*	*13.4*	*12.7*	*12.1*	*11.5*	*11.0*	*10.5*	*10.0*	*9.7*	*9.4*	*9.0*	*8.7*
140	97	95	92	89	87	84	82	79	77	75	73	70	68	66	64	62	60	58
	—	*20.7*	*18.6*	*16.9*	*15.8*	*14.8*	*13.8*	*13.2*	*12.5*	*11.9*	*11.4*	*10.9*	*10.4*	*10.0*	*9.6*	*9.4*	*9.0*	*8.7*
150	98	95	92	90	87	85	82	80	78	76	74	72	70	68	66	64	62	60
	—	*20.2*	*18.4*	*16.6*	*15.4*	*14.8*	*13.7*	*13.0*	*12.4*	*11.8*	*10.2*	*10.8*	*10.3*	*9.9*	*9.5*	*9.2*	*8.9*	*8.6*
160	98	95	93	90	88	86	83	81	79	77	75	73	71	69	67	65	64	62
	—	*19.8*	*18.1*	*16.2*	*15.2*	*14.2*	*13.4*	*12.7*	*12.1*	*11.5*	*11.0*	*10.6*	*10.1*	*9.7*	*9.4*	*9.1*	*8.8*	*8.5*
170	98	95	93	91	89	86	84	82	80	78	76	74	72	70	69	67	65	63
	—	*19.4*	*17.7*	*15.8*	*14.8*	*13.9*	*13.2*	*12.4*	*11.8*	*11.3*	*10.8*	*10.4*	*9.9*	*9.6*	*9.2*	*9.0*	*8.6*	*8.4*
180	98	96	94	91	89	87	85	83	81	79	77	75	73	72	70	68	67	65
	—	*18.9*	*17.3*	*15.5*	*14.5*	*13.7*	*12.9*	*12.2*	*11.6*	*11.1*	*10.6*	*10.1*	*9.7*	*9.4*	*9.0*	*8.8*	*8.4*	*8.1*
190	98	96	94	92	90	88	85	84	82	80	78	76	75	73	71	69	68	66
	—	*18.5*	*16.9*	*15.2*	*14.2*	*13.4*	*12.7*	*12.0*	*11.4*	*10.9*	*10.5*	*10.0*	*9.6*	*9.2*	*8.9*	*8.6*	*8.2*	*7.9*
200	98	96	94	92	90	88	86	84	82	80	79	77	75	74	72	70	69	67
	—	*18.1*	*16.4*	*14.9*	*14.0*	*13.2*	*12.4*	*11.8*	*11.2*	*10.8*	*10.3*	*9.8*	*9.4*	*9.1*	*8.8*	*8.4*	*8.1*	*7.7*
210	98	96	94	92	90	88	86	85	83	81	79	78	76	75	73	71	70	68
	—	*17.7*	*16.0*	*14.6*	*13.8*	*13.0*	*12.2*	*11.7*	*11.1*	*10.6*	*10.0*	*9.7*	*9.2*	*9.0*	*8.7*	*8.3*	*8.0*	*7.6*

Table 1-6—Relative humidity and equilibrium moisture content at various dry-bulb temperatures and wet-bulb depressions below 212°F—concluded

Dry-bulb temper-ature (°F)	Relative humidity[1] and equilibrium moisture content [2] (%) at various wet-bulb depression temperatures (°F)																		
	19	20	21	22	23	24	25	26	27	28	29	30	32	34	36	38	40	45	50
100	44	41	39	37	35	33	30	28	26	24	22	21	17	13	10	7	4	—	—
	7.8	*7.4*	*7.0*	*6.7*	*6.4*	*6.1*	*5.7*	*5.4*	*5.2*	*4.9*	*4.6*	*4.2*	*3.6*	*3.1*	*2.4*	*1.6*	*0.7*	—	—
105	46	44	42	40	37	35	34	31	29	28	26	24	20	17	14	11	8	—	—
	7.9	*7.6*	*7.3*	*6.9*	*6.7*	*6.4*	*6.1*	*5.7*	*5.4*	*5.2*	*4.8*	*4.6*	*4.2*	*3.6*	*3.1*	*2.4*	*1.8*	—	—
110	48	46	44	42	40	38	36	34	32	30	28	26	23	20	17	14	11	4	—
	8.1	*7.7*	*7.5*	*7.2*	*6.8*	*6.6*	*6.3*	*6.0*	*5.7*	*5.4*	*5.2*	*4.8*	*4.5*	*4.0*	*3.5*	*3.0*	*2.5*	*1.1*	—
115	50	48	45	43	41	40	38	36	34	32	31	29	26	23	20	17	14	8	2
	8.2	*7.8*	*7.6*	*7.3*	*7.0*	*6.7*	*6.5*	*6.2*	*5.9*	*5.6*	*5.4*	*5.2*	*4.7*	*4.3*	*3.9*	*3.4*	*2.9*	*1.7*	*0.4*
120	51	49	47	45	43	41	40	38	36	34	33	31	28	25	22	19	17	10	5
	8.3	*7.9*	*7.7*	*7.4*	*7.2*	*6.8*	*6.6*	*6.3*	*6.1*	*5.8*	*5.6*	*5.4*	*5.0*	*4.6*	*4.2*	*3.7*	*3.3*	*2.3*	*1.1*
125	53	51	48	47	45	43	41	39	38	36	35	33	30	27	24	22	19	13	8
	8.3	*8.0*	*7.7*	*7.5*	*7.2*	*7.0*	*6.7*	*6.5*	*6.2*	*6.0*	*5.8*	*5.5*	*5.2*	*4.8*	*4.4*	*4.0*	*3.6*	*2.7*	*1.6*
130	54	52	50	48	47	45	43	41	40	38	37	35	32	29	26	24	21	15	10
	8.3	*8.0*	*7.8*	*7.6*	*7.3*	*7.0*	*6.8*	*6.6*	*6.4*	*6.1*	*5.9*	*5.6*	*5.3*	*4.9*	*4.6*	*4.2*	*3.8*	*3.0*	*2.0*
140	56	54	53	51	49	47	46	44	43	41	40	38	35	32	30	27	25	19	14
	8.4	*8.0*	*7.8*	*7.6*	*7.3*	*7.1*	*6.9*	*6.6*	*6.4*	*6.2*	*6.0*	*5.8*	*5.4*	*5.1*	*4.8*	*4.4*	*4.1*	*3.4*	*2.6*
150	58	57	55	53	51	49	48	46	45	43	42	41	38	36	33	30	28	23	8
	8.3	*8.0*	*7.8*	*7.5*	*7.3*	*7.1*	*6.9*	*6.7*	*6.4*	*6.2*	*6.0*	*5.8*	*5.4*	*5.2*	*4.9*	*4.5*	*4.2*	*3.6*	*2.9*
160	60	58	57	55	53	52	50	49	47	46	44	43	41	38	35	33	31	25	21
	8.2	*7.9*	*7.7*	*7.4*	*7.2*	*7.0*	*6.8*	*6.7*	*6.4*	*6.2*	*6.0*	*5.8*	*5.5*	*5.2*	*4.9*	*4.6*	*4.3*	*3.7*	*3.2*
170	62	60	59	57	55	53	52	51	49	48	47	45	43	40	38	35	33	28	24
	8.0	*7.8*	*7.6*	*7.3*	*7.2*	*6.9*	*6.7*	*6.6*	*6.4*	*6.2*	*6.0*	*5.7*	*5.5*	*5.2*	*4.9*	*4.6*	*4.4*	*3.7*	*3.2*
180	63	62	60	58	57	55	54	52	51	50	48	47	45	42	40	38	35	30	26
	7.8	*7.6*	*7.4*	*7.2*	*7.0*	*6.8*	*6.5*	*6.4*	*6.2*	*6.0*	*5.8*	*5.7*	*5.4*	*5.2*	*4.8*	*4.6*	*4.4*	*3.8*	*3.3*
190	65	63	62	60	58	57	56	54	53	51	50	49	46	44	42	39	37	32	28
	7.7	*7.4*	*7.2*	*7.0*	*6.8*	*6.6*	*6.4*	*6.2*	*6.0*	*5.9*	*5.7*	*5.5*	*5.3*	*5.0*	*4.8*	*4.5*	*4.4*	*3.8*	*3.3*
200	66	64	63	61	60	58	57	55	54	53	52	51	48	46	43	51	39	34	30
	7.5	*7.2*	*7.0*	*6.9*	*6.6*	*6.4*	*6.2*	*6.0*	*5.9*	*5.7*	*5.6*	*5.4*	*5.2*	*4.9*	*4.7*	*4.5*	*4.3*	*3.8*	*3.3*
210	67	65	64	63	61	60	59	57	56	54	53	52	50	47	45	43	41	36	32
	7.4	*7.1*	*6.9*	*6.8*	*6.5*	*6.3*	*6.1*	*5.9*	*5.8*	*5.5*	*5.4*	*5.3*	*5.1*	*4.8*	*4.6*	*4.4*	*4.2*	*3.7*	*3.8*

[1]Relative humidity values not italic.
[2]Equilibrium moisture content values italic.

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