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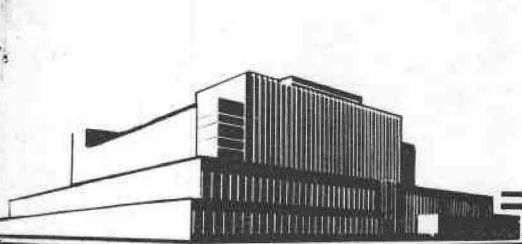

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UNITED STATES DEPARTMENT OF AGRICULTURE
FOREST SERVICE

In Cooperation with the University of Wisconsin

DEVICES THAT MEASURE AND CONTROL TEMPERATURE IN DRY KILNS

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Efficient operation of a lumber dry kiln requires good control of the drying atmosphere in the kiln. Since the control of both the dry-bulb and wet-bulb temperatures plays such a vital part in good drying, a knowledge of various ways and means of measuring and controlling these temperatures is essential.

It is important for the new kiln operator to become familiar with some of the measuring and control methods used. The experienced kiln operator will also gain by reviewing these methods, because familiarity with them will enable him to diagnose difficulties in his equipment should they arise.

Temperature-Measuring Instruments

Many types of instruments are used successfully in measuring temperatures in a lumber dry kiln. These instruments are of the filled thermal, solid-expansion, and thermal-electrical type.

In a filled thermal system, a bulb containing liquid, vapor, or gas is exposed to the temperature and connected by capillary tubing to a spring -- bourdon, spiral, or helical element in a case. As temperature at the

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bulb location changes, the pressure within the system changes. This causes the element to expand or contract and position a recording pen or indicating pointer.

Filled thermal systems are classified according to filling medium. Proper selection of the system best suited to an installation depends on such factors as range required, corrosive properties of the atmosphere to be measured, distance between bulb and instrument, bulb elevation, permissible bulb size, and range of surrounding temperatures.

The classification of the filled thermal systems is given in parenthesis in the discussion of the various systems.

Principles of Temperature-Measuring Instruments

Liquid Expansion (Class I and Class IV)

The liquid-expansion thermometer is generally filled with mercury or xylene, although other fluids, such as hydrocarbons, are not uncommon. The expansion of liquid in a pressure-spring system reflects a linear relationship between the temperature and the movement of the receiving element in accordance with the volumetric-expansion equation. Therefore, there is a uniform scale calibration. This system can be furnished with a smaller bulb than any other filled system. Range limits are from -300° to +1,000° F.

In a Class I system, only the case has been compensated for surrounding temperatures, and the instrument will be used where the case and tubing are at the same temperature. Maximum lengths of tubing for these instruments range from 15 to 25 feet.

The Class IV system incorporates a fully compensated unit where surrounding temperatures may differ along the tubing. The maximum length of tubing for this system is about 150 feet.

Vapor Pressure (Class II)

The vapor-actuated system is the most widely used of all filled thermal systems and is recommended for general use in ranges between -300° and +700° F. The range varies with the filling medium. Some of the common mediums are sulfur dioxide, methylchloride, ether, and toluene.

The vapor-pressure system requires no compensation for changes in case and tubing temperatures. A characteristic of the vapor-pressure system is an increasing scale. The vapor pressure varies with temperature in accordance with the laws of thermodynamics. The vapor pressure increases in progressively greater increments as the temperature rises.

Gas Filled (Class III)

The gas-filled, pressure-spring instruments use any relatively inert gas as a filling medium. Nitrogen is the most commonly used. Since the expansion of the gas follows Charles' law, a uniform calibration scale can be used. The bulb size, however, is larger and the response slightly slower than with the other filled thermal systems. The approximate range in the gas-filled systems is from -450° to +1,000° F.

Solid Expansion

Solid-expansion thermometers are also known as metallic, bimetallic, or mechanical thermometers. The differential expansion principle is employed, and two rods or tubes of different metals with different coefficients of expansion are used. These instruments are generally rugged, inexpensive, and easily maintained. However, the cheaper units soon lose their initial calibration, and in many instances, they become sticky and erratic.

Thermal Electrical

If a junction of two dissimilar metals or alloys in contact is heated, an electromotive force that depends only on temperature is developed. When this junction is heated and the free ends of the wire are connected to a potentiometer, the electromotive force can be measured and used as a means of measuring temperatures.

The range of temperature measurements varies greatly, depending on the combination of dissimilar wires used. In kiln-drying operations, the combination of copper and constanton has proved very satisfactory. Its effective temperature range is from -400° to +600° F. Reproducibility of the junctions is good, resistance to corrosion and oxidation is fair, and the cost is not as great as for most of the other combinations.

Resistance thermometers have also been used in measuring kiln temperature, but they generally have not proved too satisfactory. Because these instruments are so accurate, they are not too adaptable to industrial use. They are not portable in the sense that they can be used with different length lead wires, large errors result with poor contacts, and they cannot withstand rough handling. These and many other factors make them unsatisfactory for dry-kiln use.

Types of Temperature-Measuring Instruments

The temperature-measuring devices used in lumber dry kilns employ one or another of the systems discussed. The instruments may be further classified as visual or recording. A visual instrument denotes the temperature at the time of reading, but makes no record. The recording type keeps either a partial or continuous record of temperatures, often on a time-calibrated chart. Maximum and minimum types of instruments are also available, however, they do not record when the maximum or minimum temperature occurred.

Indicating Thermometers

Many kinds of indicating thermometers are available, and only reliable instruments should be used. These instruments may follow any of the systems employed in measuring temperatures, and the use requirements would govern the selection of the type to be used.

Glass-stem thermometers. --The most common indicating thermometer is the glass-stem type. In selecting a glass-stem thermometer, it is wise (1) to have the scale etched on the glass stem and (2) to specify either full or partial immersion. Thermometers mounted on separate scales, such as a metal strip, often slip in their mountings and give incorrect readings. Glass-stem thermometers are made for full or partial immersion. Thermometers used directly in the kiln should be of the full-immersion type, while those used to measure temperatures in electric ovens and similar places should be of the partial-immersion type.

Glass-stem maximum thermometers. --Maximum thermometers are useful in many phases of kiln drying. In using maximum thermometers, the mercury should be allowed sufficient time to reach a peak temperature, and the indicating mercury column should be shaken down after each reading.

The most satisfactory way to calibrate a glass-stem thermometer is to compare the readings at different temperatures within its usable range with those of a thermometer of known accuracy. For this purpose, an accurate standard 18-inch, mercury-filled thermometer with graduations from 30° to 220° F. etched on the stem is useful. This standard should be used only for calibration purposes. If a standard is not available, a number of thermometers may be calibrated at one time, using the average of the readings as the correct temperature.

The first step in the usual method of calibration is the immersion of the standard and the thermometers in constantly agitated water. The water, cold at the start, is heated, and the thermometers and standard are compared at different levels throughout the scale. Adequate time should be allowed at each level to compensate for any difference in lag of the thermometers. The difference in temperature between the standard and the thermometer being calibrated is the error, and it should be recorded. These differences, whether plus (+) or minus (-), should be applied to the tested thermometer when it is used at the various levels.

Handling of the thermometers often makes it necessary to manipulate the mercury within the capillary to reunite the main column and mercury that has become separated or to remove gas bubbles from the mercury in the bulb or stem. Manipulating the mercury is usually done by (1) warming, (2) cooling, (3) tapping on the end, and (4) tapping on the side of the thermometer. Care must be exercised in all of these operations, so that the thermometer is not broken.

Pressure-spring.--These temperature-indicating instruments are generally known as dial or index thermometers. The thermometers ordinarily embody a tube system consisting of a bulb, a flexible capillary connecting tube, and a pressure spring that moves the pointer. This same tube system is used in nonelectrical recording thermometers. The general characteristics of these pressure-spring instruments are given in table 1.

These instruments are calibrated in the same general manner as glass-stem thermometers. Recording thermometers require more attention than other types of thermometers, because they may become deranged easily. They should be calibrated in agitated water, with the bulb and a short portion of the connecting tube fully immersed. Except for gas-filled systems, all of these instruments must be calibrated in the general position in which they are used, because differences in prescribed level of the bulb and case cause errors. Because of the size of the bulb and the construction of the instrument, recording thermometers respond less quickly to temperature changes than do glass indicating thermometers.

This lag requires that the recording instrument be allowed more time to adjust itself during calibration.

Constant errors, in which the pen reading is off the same amount throughout the entire range, can be corrected by adjusting the pen arm. Usually, a small screw on the pen arm is provided for this purpose. Cumulative errors, in which the errors increase or decrease progressively, can be corrected in some instruments by changing the leverage of the pen arm. Such adjustment is delicate and should be done by an instrument service man. A correction chart can be made so that the instrument may be used until it is adjusted.

Wet-bulb recorders should be calibrated in the same manner as the dry-bulb recorders. In instruments that record both the dry-bulb and wet-bulb temperatures, both bulbs should be calibrated. Instruments with dual dry bulbs should have each bulb calibrated separately.

Thermal electrical.--These temperature-measuring instruments follow the principles previously discussed and are very satisfactory for recording temperatures under any conditions.

Temperature-Controlling Instruments

Most lumber dry kilns are equipped with instruments that automatically control temperatures. These are usually pressure-spring instruments employing a capillary tube and bulb connected to a bellows or a pressure spring. Thermal expansion and contraction with resultant pressure changes within the closed system are used either directly (self-contained type) or indirectly (auxiliary-operated type) to operate a diaphragm or electric valves in the system.

Self-contained thermostats combine in a single unit a valve and a filled system consisting of the bulb, the capillary connecting tube, and the motor head. The bulb of the tube system is placed in the kiln. Temperature variations in the kiln change the pressure inside the bulb, and this causes corresponding pressure changes in the motor head, which is usually a bellows diaphragm. This action produces movement of the valve by way of the valve stem, which is connected to the motor head. The valve itself is usually balanced to provide ease of movement. A constant counterpressure that tends to keep the valve open by opposing the varying pressure in the motor head is provided by an adjustable spring or sliding weight. The instrument is set for desired temperatures by changing the tension of the spring or the position of the weight. The setting is made by trial and error.

The principal advantages of the self-contained thermostat are that no auxiliary source of power is required for its operation and that its initial cost is comparatively small. An important disadvantage is its relatively slow response to changes in temperature, which prevents it from working well under conditions where there are wide fluctuations in the amount of steam supplied. In addition, fluctuations in the temperature of the motor head may cause changes in the setting of the instrument that will cause it to maintain the kiln at a temperature other than that desired. Further, the self-contained thermostat is not quite as sensitive as the auxiliary-operated type. In other words, the self-contained thermostat requires a greater temperature change to open and close the valve than does the auxiliary-operated type. Although manufacturers claim regulation within 2° F. of the desired temperature, this range is sometimes exceeded if the air circulation is inadequate. The self-contained thermostat is most useful in a progressive kiln, where the temperature at the control bulb is intended to be constant, rather than in a compartment kiln, where the temperature varies from time to time. On the other hand, auxiliary-operated instruments will usually control with a variation of only 1° F. in kilns with ample air circulation.

Auxiliary-operated thermostats are made in a number of different types and styles. Electricity, water or steam pressure, or compressed air is used, alone or in various combinations, to power them. Most of the auxiliary-operated thermostats in dry-kiln service, however, are air operated. The temperature-sensitive element may be bimetallic. In kiln work, however, it is usually the extension-tube type with bulb, capillary tube, and pressure-sensitive hollow spring or capsule.

A thermostat may be used to control either the dry-bulb or wet-bulb temperature. To control the wet-bulb temperature, the bulb is provided with a suitable wick and water supply. The temperature-sensitive elements for controlling either the dry bulb or wet bulb should be so located in the kiln that they are exposed to ample air circulation in the entering-air zone. A detailed discussion on the location of temperature-measuring and controlling instruments is given later in this report.

Pressure-spring recorder-controllers.--In these instruments, a mechanism controls and records the temperature. The movement of the pressure-spring regulates the power to the diaphragm valve and also moves the recording-pen arm. The discussions of the thermostats and recorders apply also to these recorder-controllers (fig. 1).

Most recorder-controllers used in lumber dry kilns are equipped with a wet bulb and one or more dry bulbs. The new instruments also have a separate power system to operate a diaphragm-motor valve that opens and closes the vents automatically. No extra capillary and bulb system is necessary, because the vent diaphragm-motor valve is connected to the wet-bulb control system.

In instruments with more than one dry bulb, the bulbs may be either separate or combined in one system. Separate dry bulbs are used to control the temperature in more than one location throughout the length of the kiln. Combined dry bulbs are actually two temperature-sensitive bulbs connected to a common capillary tube that transmits the pressure to a single pressure spring in the case. Instruments of this type are used in reversible-circulation kilns, with one dry bulb located on each side of the load. Since the bulb on the entering-air side is at the higher temperature, it will serve as the controlling bulb. When the air circulation reverses, it sometimes takes several minutes for the controlling bulb to become effective, because the pressure throughout the system must equalize. This lag of control causes a slight break in an otherwise smooth temperature record whenever the direction of air circulation is reversed.

The manufacturer's instructions should be followed with special care in the calibration and adjustment of recorder-controllers. The recording mechanism may be calibrated in the same manner as a recording thermometer. In some types, however, the thermostat mechanism interferes with the free movement of the pen arm. When the position of the setting arm or pointer fails to correspond to that of the pen arm, it is desirable that the setting arm be moved in unison with the pen arm during calibration.

The adjustment of the setting or control-indicating arm must be made with the instrument in place and the air pressure on. It is also desirable to have the temperature of the bulb within the usual operating range of the instrument. Starting with the setting arm well below the position indicated by the bulb, the arm is slowly moved until the diaphragm valve opens. The position of the arm is then noted. The setting arm is next moved in the opposite direction until the valve closes, and the position is again noted. The last movement will be small, perhaps about 2° F. on the scale. The indicating arm is adjusted until the recorder is at a temperature half-way between the "on" and "off" control points.

Both the setting and recording arms of a recorder-controller should read correctly. If they are not reading correctly, the relationship between them and the actual kiln conditions should be noted on a calibration chart.

Thermal-electrical recorder-controllers.--These instruments control and record temperatures by means of an electronic potentiometer. The electromotive force generated by the effect of temperature on the thermocouples is automatically balanced by the electronic portion of the instrument. This balancing mechanism is continuously receptive to changes in electromotive force. When the balancing mechanism changes, the position of the recorder pen and temperature indicator changes. The control unit is coupled to the recording unit, so that it can be used to operate either electric or air-operated control valves on the steam-supply line. The choice of control, either electric or air, governs the selection of a particular instrument.

By means of a rotary type of switch and thermocouples placed in different locations in the kiln, temperatures can be easily read at any location. Control can be established in the desired zone merely by leaving the switch set at the appropriate location.

A separate instrument with a thermocouple, wick, and water-supply line is needed to control and record the wet-bulb temperature in the kiln.

The calibration of these temperature-recording and controlling instruments is the same as described for the pressure-spring type of instrument.

Location of Thermal Elements

Since thermal elements, such as dry and wet bulbs, and other means of measuring and controlling kiln temperatures are comparatively small, they actually respond only to the temperature prevailing in a small portion of the kiln. Because these thermal elements are not always located in the hot or cold zone in the kiln, excessive conditions, hot or cold, may be present. For this reason, temperature readings with thermocouples or thermometers should be taken periodically along the length of the kiln on the entering-air side to check conditions in the hot and cold zones. When the temperature in the hot zone exceeds that found at the control thermal unit, a temperature differential is determined, and the control set to compensate for this difference. Degrade caused by excessive temperatures can be reduced by following this procedure. If the temperature found at the cold zone is much below the hot-zone temperature, slower drying will prevail. In the early stages of drying, the higher relative humidity conditions in the cold zone may cause mold to form on the lumber.

Uniform longitudinal and vertical temperatures in a lumber dry kiln cannot be obtained by a recording-controlling instrument or any comparable instrument. The design, location, and condition of the heating and air-circulation systems are the governing factors in maintenance of uniform temperatures.

Even though the controlling instrument is sensitive and properly calibrated, faulty or improper mounting of the control bulbs may cause inaccurate kiln conditions. When mounting the control bulbs, the following things should be kept in mind.

1. The bulbs should be so located in the air stream on the entering-air side of the load that they will receive adequate air circulation over their surfaces (figs. 2, 3, and 4).

2. The control bulbs should be so located that they are not affected by direct radiation. A common wall between two kilns often radiates heat if the adjoining kiln is operating at a higher temperature. Insulation of the wall directly behind the control bulbs will reduce this heat-transfer effect. Locations near heating coils and spray lines can also affect the accuracy of control. If no other location can be found, the possibility of shielding the bulbs without cutting off air circulation over their surfaces should be investigated.

3. The dry bulb should never be located so that drippage or spilling from the wet-bulb water-supply box can affect its reading. Drippage on the bulb from the vents should also be avoided.

4. The water-supply box or pan for the wick of the wet bulb should not be so large that it shields the air circulation from the wick and bulb.

5. The bulbs should be so located that they are both accessible and protected so that they will not be damaged when the kiln is loaded and unloaded. Easy access to the wet bulb is mandatory, because the wicks must be changed frequently to insure good control.

Single Thermal Element

The control bulbs in many kilns are located on the walls. Many kilns have only one dry bulb. This will give satisfactory control if it has been properly mounted and the air circulation is not reversible. However, if the circulation is reversible, the temperature being controlled in one direction of air circulation is not the entering-air temperature. For example, figure 5 shows a cross section of a kiln in which transverse, reversible air-circulation temperatures are controlled by a single dry bulb located on the right wall of the kiln. In figure 5A, the air from the fans contacts the control bulb before the air passes through the lumber. The control bulb is in the entering-air stream and will control the desired temperature. As the air moves across the load, heat is used in evaporating the moisture from the wood, with a resultant drop in the dry-bulb temperature. This temperature drop across a load will vary, depending on air velocity, length of air travel, and moisture content of the lumber. The temperature drop of 5° F. assumed in figure 5 is not excessive, and an even greater drop can be expected in the early stages of drying green material.

When the direction of air travel is reversed (fig. 5B), the bulb on the right wall is in the air stream leaving the load. Unless the temperature control setting has been changed, this bulb is still controlling the air at 120° F. If the temperature drop across the load is 5° F., the entering-air temperature on the left side of the load would be 125° F. This temperature rise may be enough to cause some kiln-drying defects in the material, thereby lowering its quality and value.

When faced with such a situation, a relocation of the dry bulb is in order to insure good control and quality drying. Figures 6, 7, and 8 show several ways of making this relocation. Air ducts should be large enough to allow free flow of air in either direction of air circulation and also easy access to the bulbs. These ducts should be flared at each end, so that the velocity through the duct will be adequate to give good control. Air ducts of this type should be constructed of material that will not radiate heat to affect the temperature of the bulb. These ducts should not interfere with the loading or unloading of the kiln. These ducts must be located so that they carry heated air comparable to the air entering the load. Although the wet bulb in figures 6, 7, and 8 is located in the duct, this is not necessary. These bulbs may be placed in a more accessible location where adequate air circulation is present.

Dual Thermal Elements

Some of the difficulty arising from the use of an improperly located single-bulb control for reversible air circulation can be reduced by the installation of a dual-bulb control (fig. 9A). The two dry bulbs function as a single unit as far as kiln temperature control is concerned. Figure 9B presents a general diagrammatic sketch of the bulbs, capillary tubes, and control instrument.

Control Bulbs in "A" Flue Loads

"A" flues are generally used in external-blower kilns. In such kilns, the control bulbs are usually located on the wall and control on leaving-air temperatures. Temperatures should be taken in the "A" flue by auxiliary means, and the control unit should be underset to compensate for the difference between entering- and leaving-air temperatures.

Sensitivity and Loose Linkage in Recorder-Controllers

Most recording-controlling instruments lack the degree of sensitivity necessary for perfect control. Because of the bulb size and tube length, they do not respond instantly to temperature changes. When new, however, controlling instruments maintain conditions quite satisfactorily. If the temperatures recorded by these instruments fluctuate in cycles at least one-third as great as those obtained by the use of thermocouples or thermometers, the instrument can be considered sufficiently sensitive. Over a period of time, however, dirt gathers on the movable parts, the linkage becomes worn, and the instrument becomes less reliable. The period of reliable performance can be greatly increased by frequent maintenance and cleaning. Efficient performance is the responsibility of the kiln operator or the person detailed to do this work. Manufacturers of controlling instruments have specialists well qualified to correct trouble with these instruments, and these specialists should be consulted whenever the kiln operator or management believes it necessary.

Ways and means of controlling kiln temperatures are always being improved. Since erratic kiln conditions are costly as far as the quality of the material is concerned, the kiln operator should not only keep his operating equipment in top condition, but he should also keep up with the latest developments in temperature-measuring and controlling devices.

Table 1.--Characteristics of pressure-spring instruments

Characteristics	Liquid expansion		Vapor pressure	Gas filled
	Mercury	Xylene		
Filling	Mercury under initial high pressure	Xylene under initial moderate pressure	Volatile liquid	Inert gas under moderate pressure
Scale divisions	Uniform	Uniform to 250° F.	Progressive--small spacing at low temperature, large at high	Uniform
Bulb volume	Medium	Very small	Small	Large--varies with tube length
Minimum bulb length	3 to 5 inches	1 inch	2 inches	6 inches
Maximum tube length	15 feet if not compensated--150 feet if fully compensated	75 feet	Approximately 150 feet	150 feet
Effects of temperature variation along tube	Varies with tube length and capillary bore--no variation if fully compensated	Slight with tube length	None	Varies with tube length and inversely with bulb volume
Effect of difference of bulb and instrument level on calibration	Possible	Slight	Possible	None
Lower limits of range	-36° F.	-40° F.	-300° F.	Near absolute zero
Upper limits of range	1,000° F.	750° F.	700° F.	1,000° F.

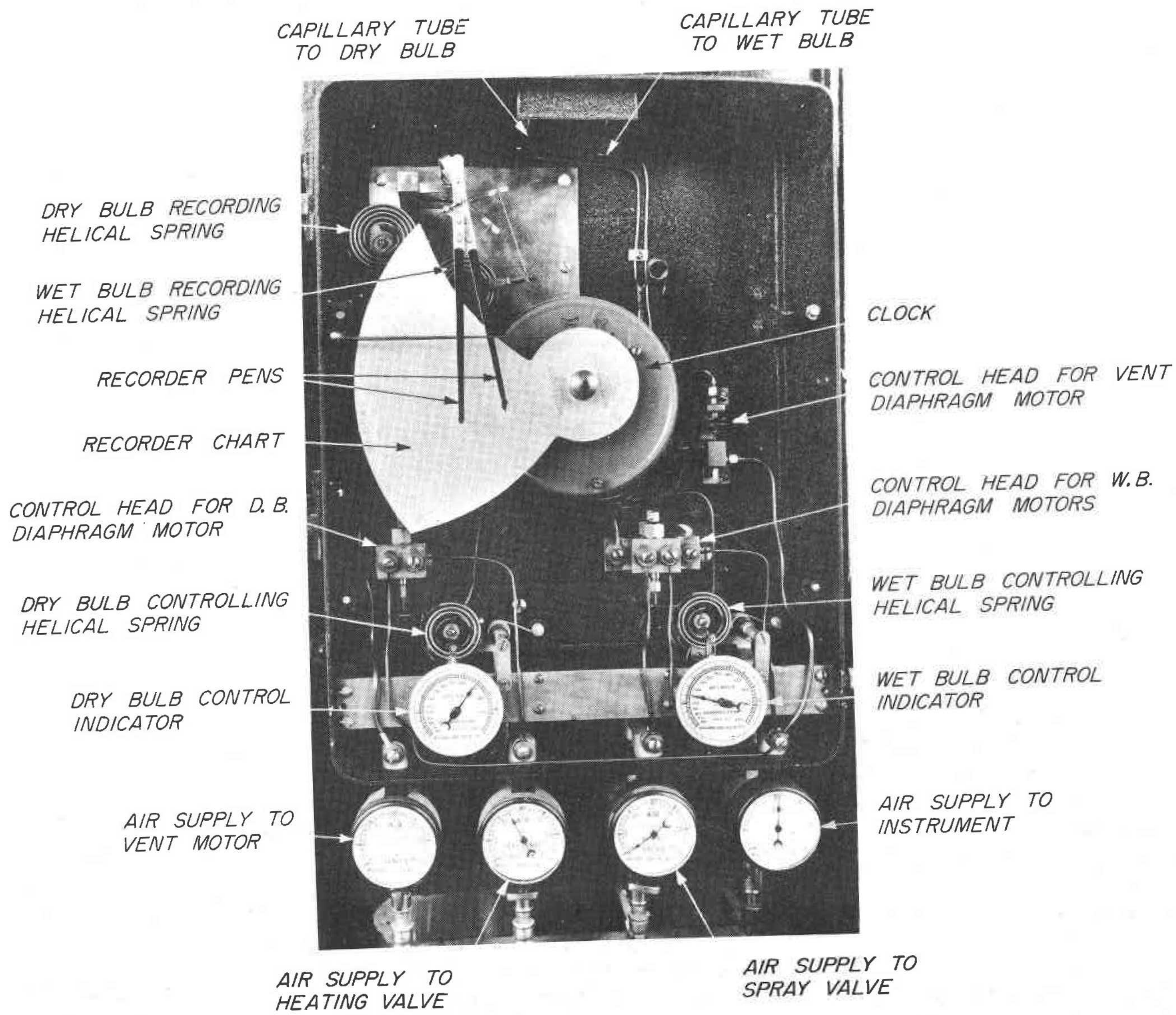

Figure 1. --Pressure-spring type of recorder-controller.

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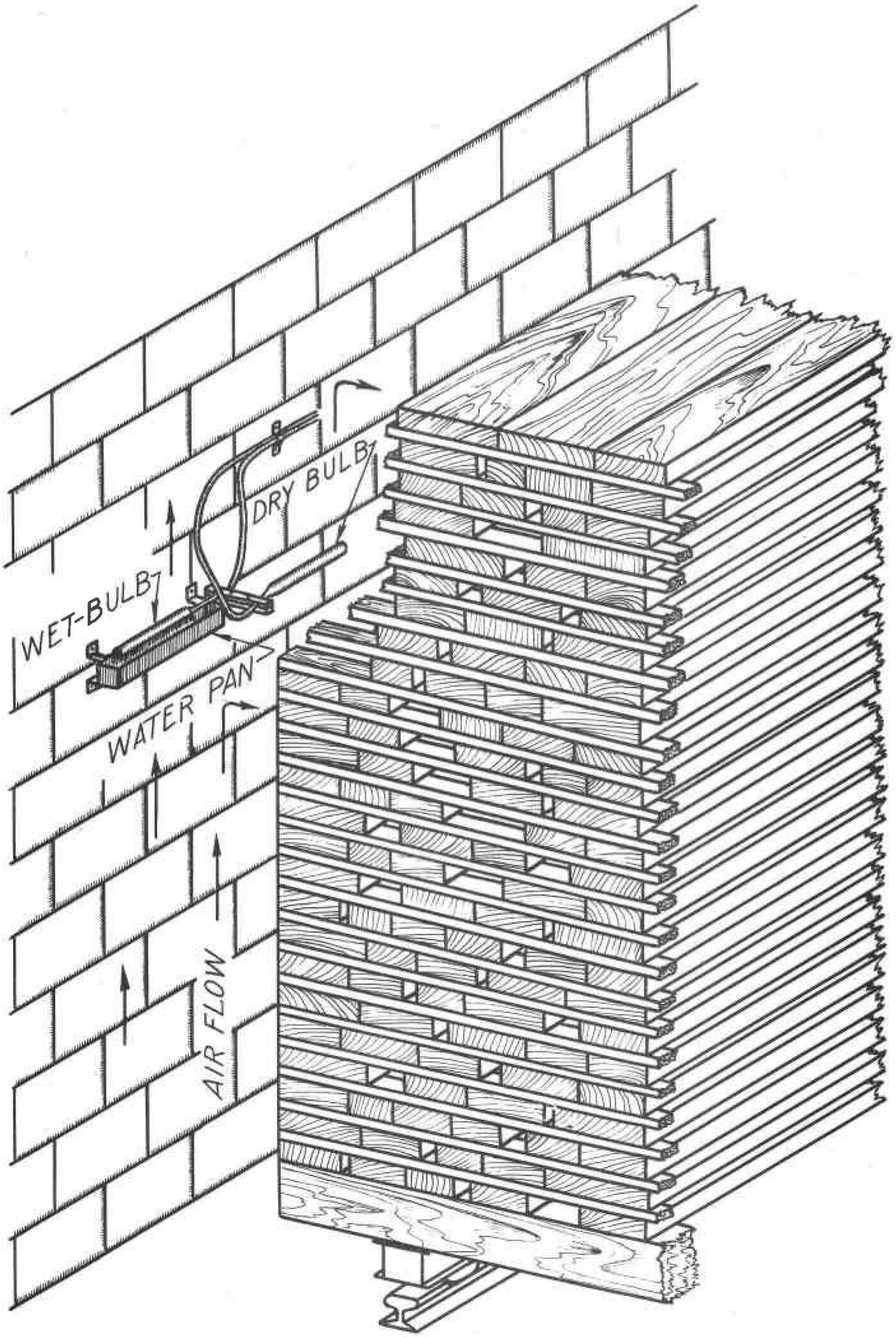

Figure 2. --Control bulb mounted on kiln wall. These bulbs may be too close to the wall to permit circulating air to contact them properly.

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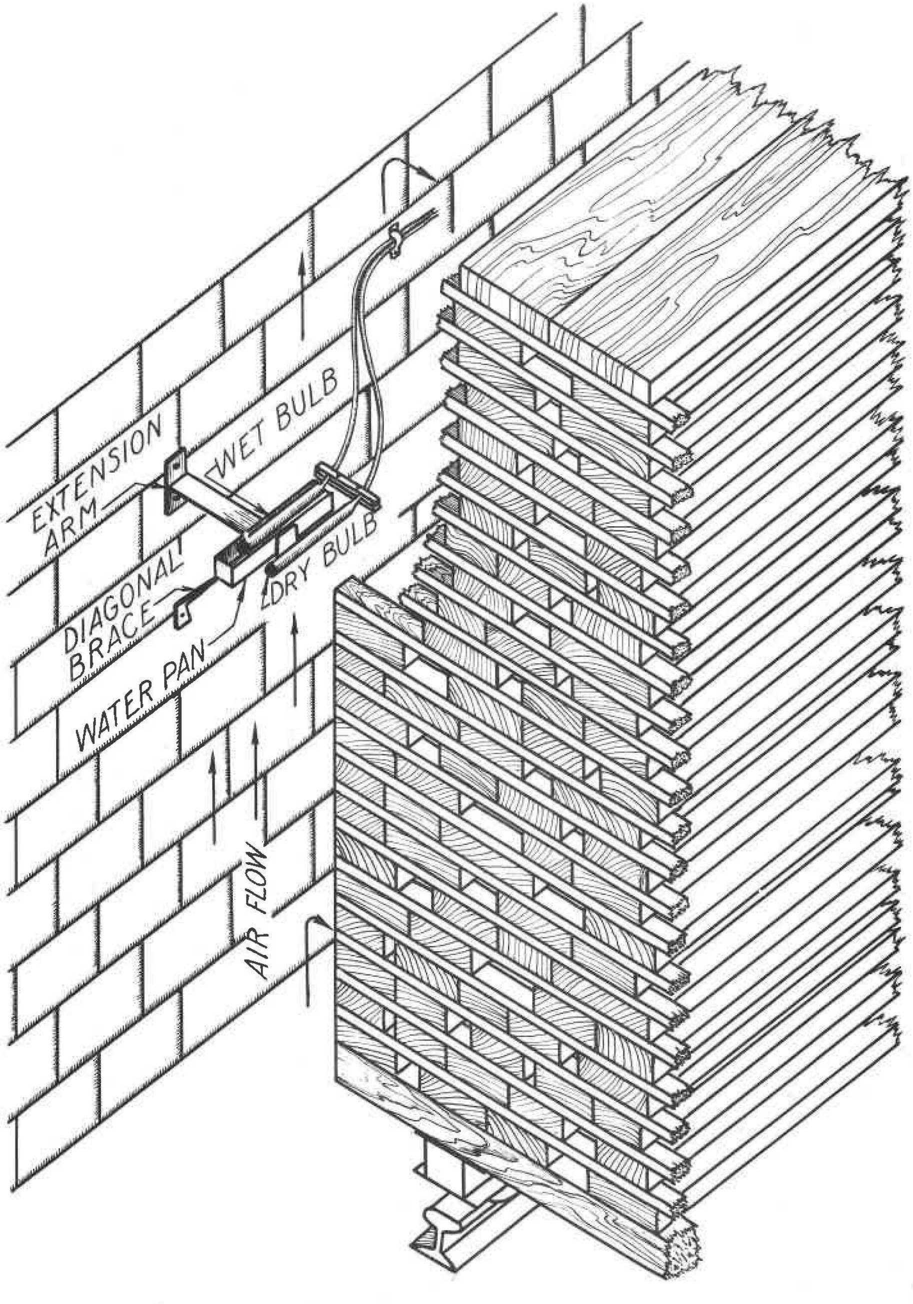

Figure 3. --Control bulbs mounted on kiln wall so that the bulbs are far enough from the wall to be in the entering-air stream.

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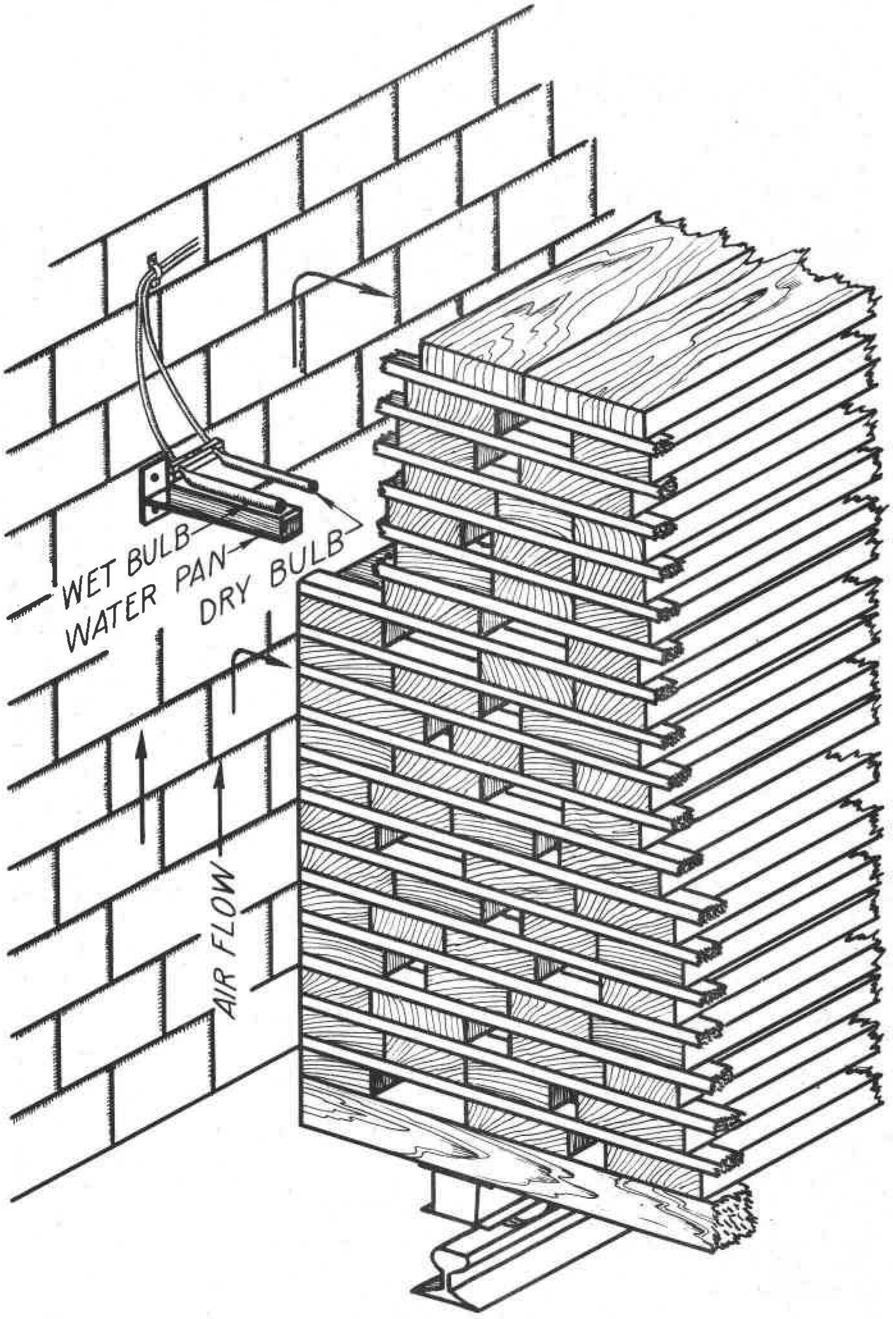

Figure 4. --Control bulbs mounted perpendicular to kiln wall.

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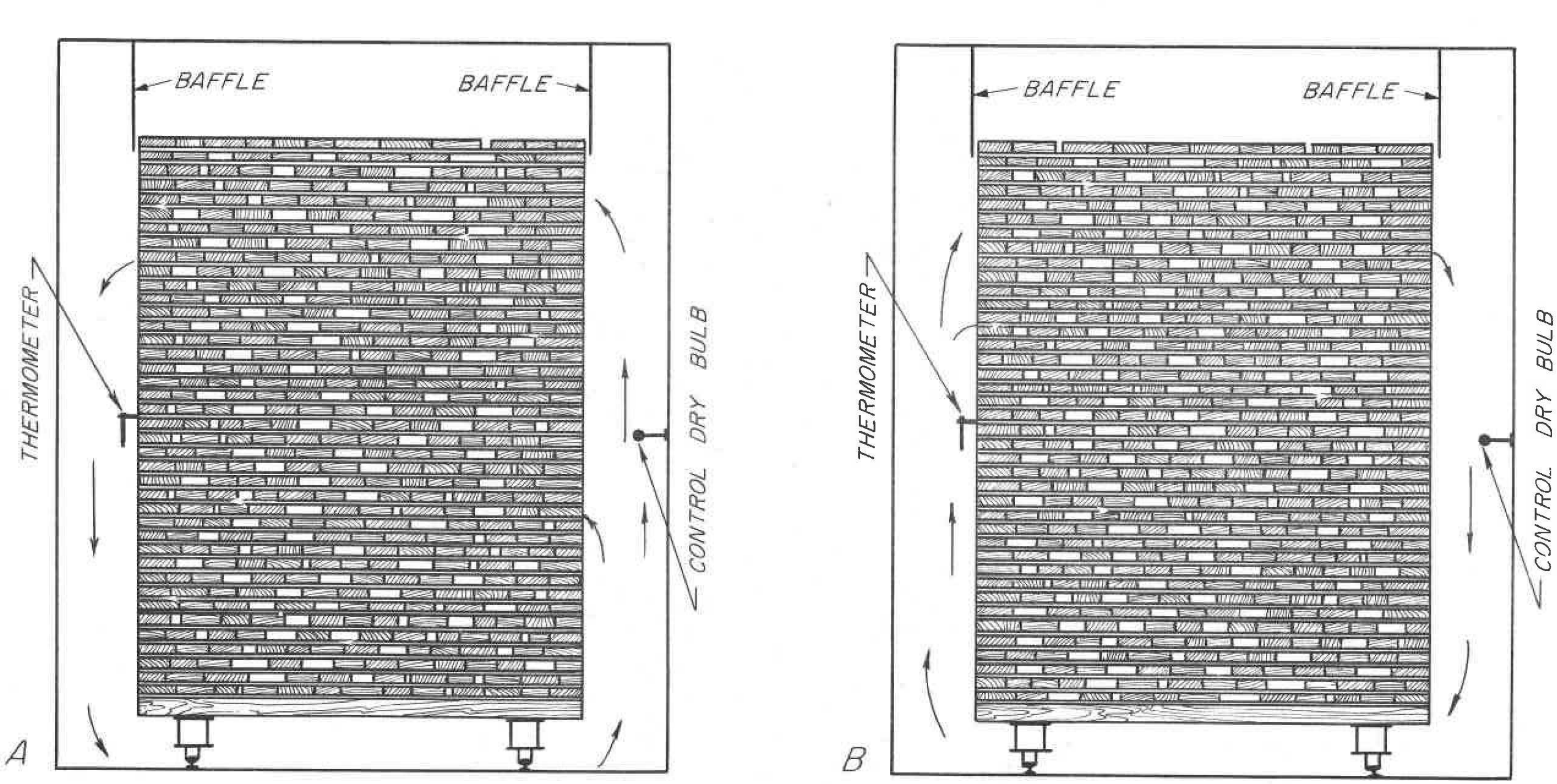

Figure 5. --Air movement in a kiln with transverse, reversible circulation controlled by a single bulb. (The desired entering-air temperature is assumed to be 120° F. and the temperature drop across load 5° F.) In cross section (A), as the air moves from right to left, the leaving-air temperature becomes 115° F. When the circulation is reversed (B), the entering-air temperature becomes 125° F. unless the controlling instrument setting is lowered.

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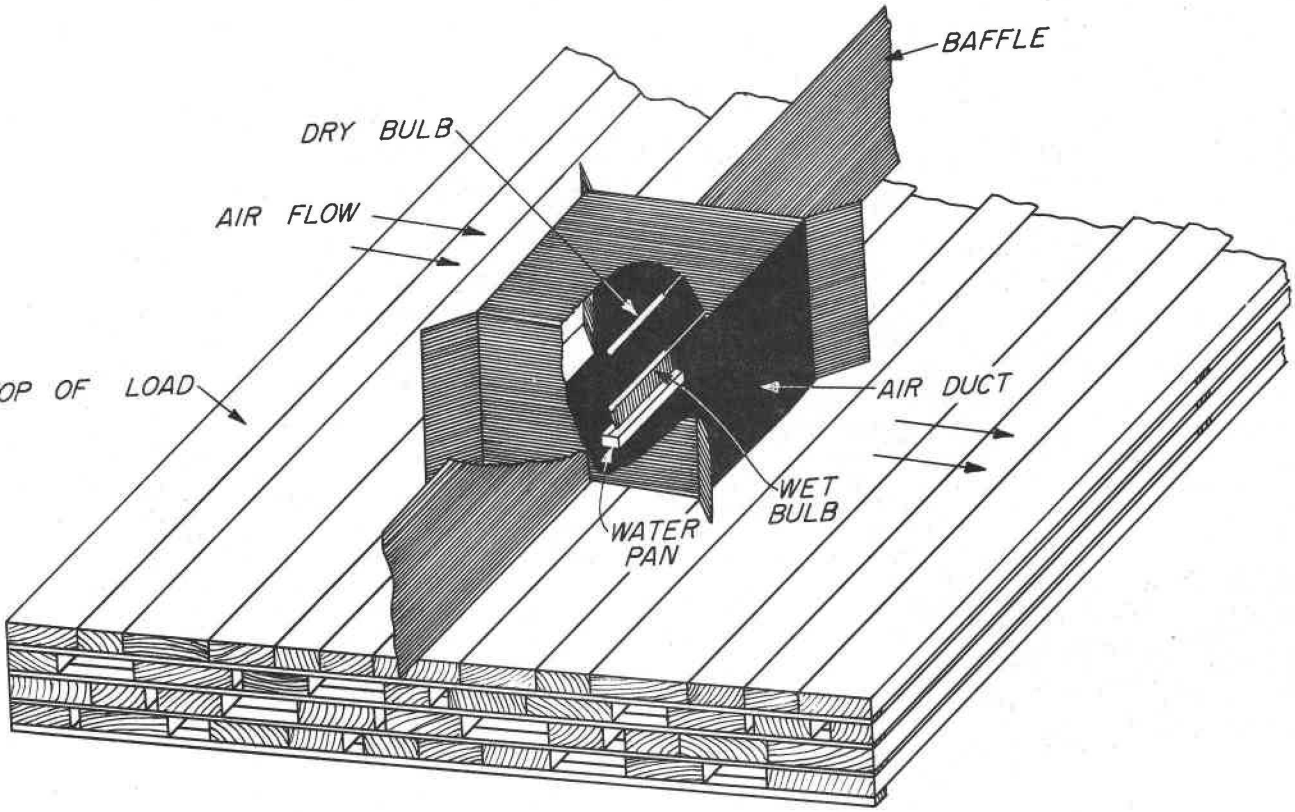

Figure 6. --Single dry bulb mounted above the load in a single-track kiln, so that it will control the entering-air temperature regardless of the direction of air circulation. The wet bulb may be located in a more accessible location.

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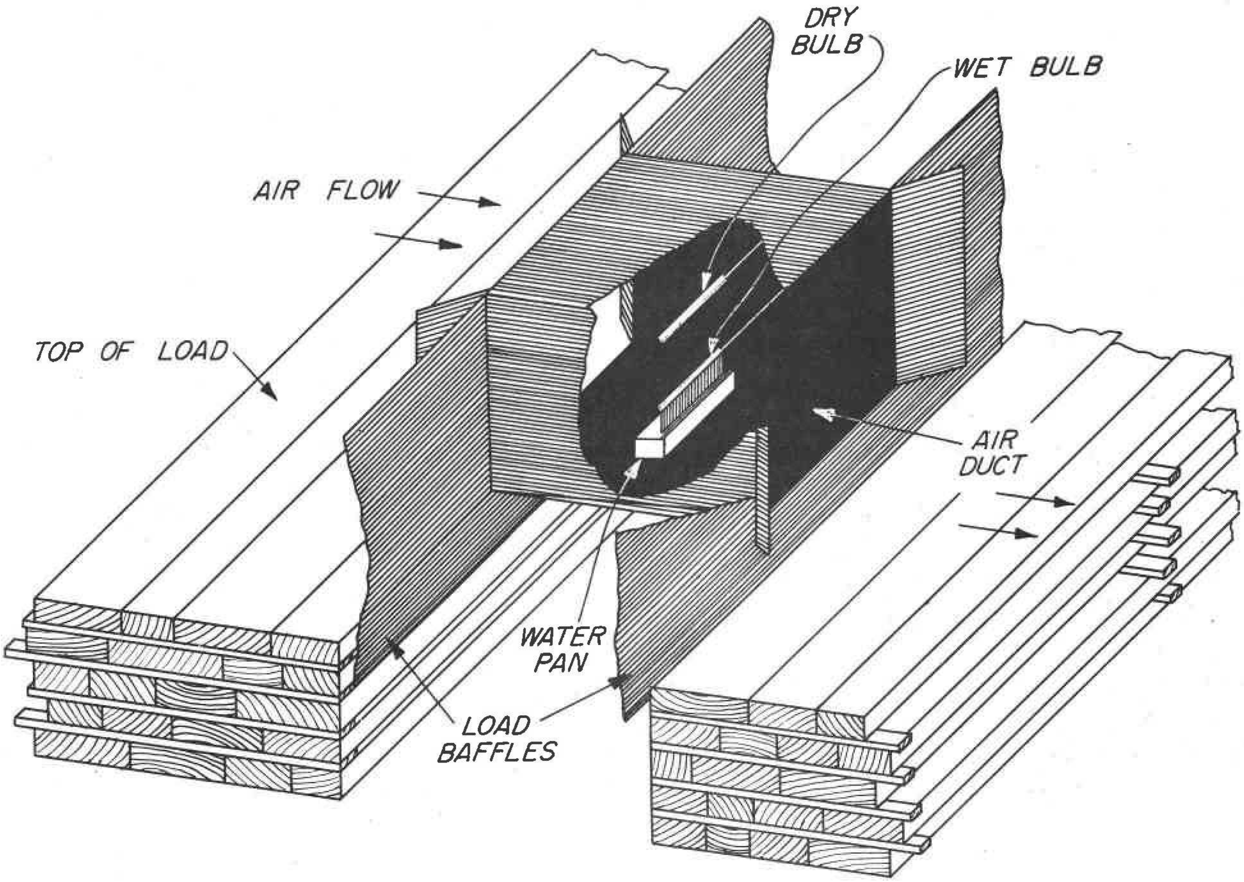

Figure 7. --Single dry bulb located above the loads in a double-track kiln, so that it will control the entering-air temperature regardless of the direction of air circulation. The wet bulb may be located in a more accessible location.

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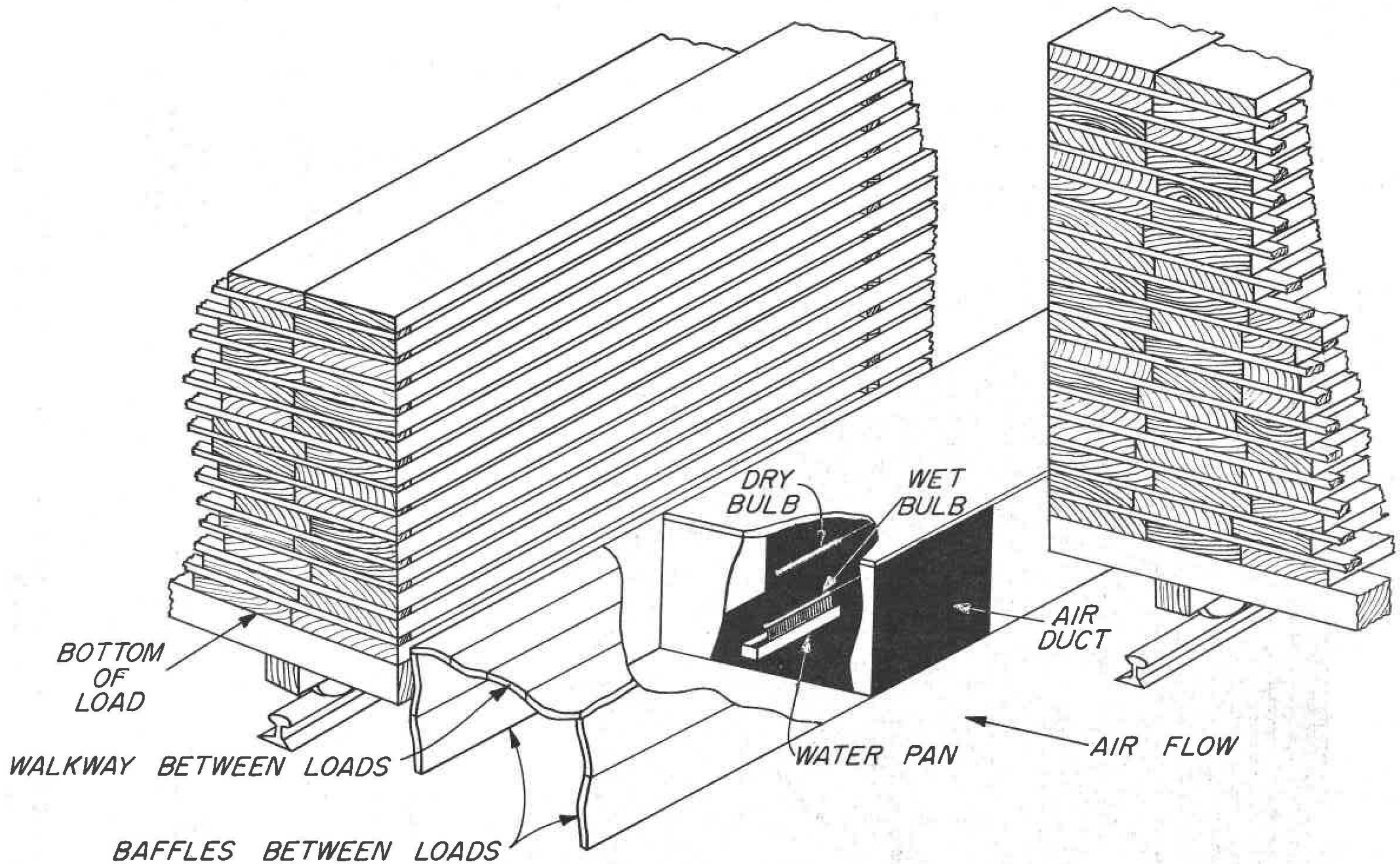

Figure 8. --Single dry bulb located below the loads in a double-track kiln, so that it will control the entering-air temperatures regardless of the direction of air circulation. The wet bulb may be located in a more accessible place.

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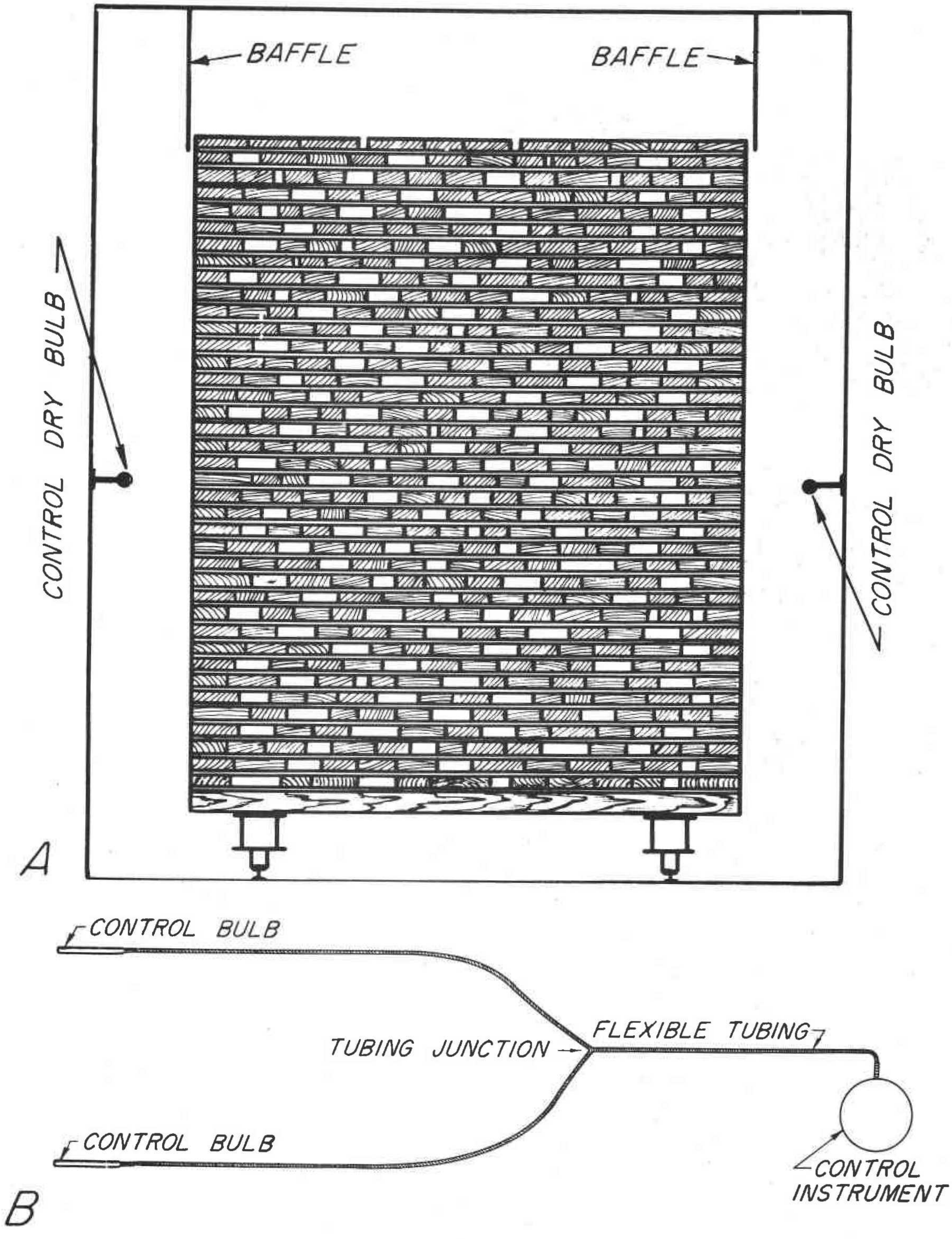

Figure 9. --Dual dry-bulb control system. In A, dry bulbs are located on opposite kiln walls. B presents schematic arrangement of dual dry bulbs, capillary tubing, and control instrument.

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