ANSI/ASHRAE Standard 41.1-1986 (RA 2006)
Reaffirmation of ANSI/ASHRAE Standard 41.1-1986

ASHRAE STANDARD

Standard Method for Temperature Measurement

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ANSI

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NOTE

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FOREWORD

This is a reaffirmation of ASHRAE Standard 41.1-1986. This standard was prepared under the auspices of the American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE). It may be used, in whole or in part, by an association or government agency with due credit to ASHRAE. Adherence is strictly on a voluntary basis and merely in the interests of obtaining uniform standards throughout the industry.

This standard was written to establish methods of temperature measurement that provide consistent procedures that may be referenced in other ASHRAE standards.

There were no changes made for the 2006 reaffirmation.

1. PURPOSE

The purpose of this standard is to set forth recommended practices for temperature measurements and provide adequate and consistent measurement procedures for reference in other standards.

2. SCOPE

The procedures described herein are intended for use in testing heating, refrigerating, and air-conditioning equipment and components. The media in which temperature measurements are made include air, water, brine, and volatile or nonvolatile refrigerants, under both steady-state and transient temperature conditions between -40ºF and 400ºF (-40ºC and 204ºC).

3. DEFINITIONS

accuracy**:** the ability of an instrument to indicate or record the true value of a measured quantity. The error of indication, which is the difference between the indicated value and the true value of the measured quantity, expresses the accuracy of an instrument.

precision**:** closeness of agreement among repeated measurements of the same physical quantity by the same method under the same conditions and with the same instrument. (An instrument may be precise but not accurate.)

saturation deficiency: the amount that the humidity ratio of an air sample is below the saturated humidity ratio of air at the same temperature and pressure.

sensitivity**:** the relationship between an observed change in the position of an instrument pen, pointer, or indicator and the magnitude of change in the measured quantity required to produce that reaction of the indicator. It can be expressed as a numerical ratio if the units of measurement of the two quantities are stated. An increase in sensitivity means a corresponding increase in the ability of an instrument to react to extremely small changes in the measured quantity.

shall**:** where "shall" or "shall not" is used for a provision, that provision is mandatory if compliance with the standard is claimed.

should**:** "should" or "should not" is used to indicate provisions that are not mandatory but that are desirable as good practice.

steady-state conditions**:** an operating state of a system, including its surroundings, in which the extent of change with time of all the significant parameters is so small as to have no important effect on the performance being observed or measured.

temperature, dry-bulb**:** the temperature of a gas or mixture of gases indicated by an accurate thermometer after correction for radiation.

temperature, wet-bulb**:** the temperature at which liquid or solid water, by evaporating into air, can bring the air to saturation adiabatically at the same temperature. Wet-bulb temperature (without qualification) is the temperature indicated by a wet-bulb psychrometer constructed and used according to specifications.

transducer**:** a device that changes one form of physical quantity into another. In the measurement field, transducers are generally used to sense a variety of measurands, such as line voltage, current, power, pressure, and temperature, and to convert these to a common output signal for use with a controlling or recording instrument.

transient state**:** the state in which the system undergoes a normal change in operation, such as thermostat cycling or actuation of a defrost control.

4. INSTRUMENTS

4.1 Temperature measurements shall be made with an instrument or instrument system, including read-out devices, meeting the accuracy and precision requirements in Table 1. The following are in common use for this purpose but are not all-inclusive:

a. Liquid-in-glass thermometers
b. Thermocouples
c. Electric resistance thermometers, including thermistors

In general, the response time of liquid-in-glass thermometers is too large to be used in transient testing.

4.2 The rate of heat flow to or from a moving fluid under steady-state conditions is determined by the product of the enthalpy change and the mass flow rate for the fluid. The measurement of heat flow involves two situations that allow different levels of accuracy in temperature measurement to produce equivalent levels of accuracy in the heat flow measurement.

a. For the case of flow of air, water, or nonvolatile refrigerant, relatively small changes in enthalpy are predominantly due to sensible heat changes. These are associated with comparatively large mass flow rates. The small magnitude of the enthalpy change requires the determination of temperature and, in turn, temperature differences with considerable accuracy.

b. For the case of flow of a volatile refrigerant, a change of state is involved and relatively large changes in enthalpy are associated with comparatively small mass flow rates. Less accuracy in temperature measurement is required to obtain a desired level of accuracy in heat flow rate measurement.

Note: In two-phase measurements, temperature and mass flow rate alone are not sufficient to determine heat flow.

4.3 For transient testing, in addition to those requirements listed in Table 1, the instrumentation used shall have the following capabilities:

a. Continuously recording the data used in the calculation. For this standard, continuous recording for sampling systems used for this purpose shall have the following maximum intervals of sampling:
   - For steady-state tests—1 minute
   - For the rate of temperature change 1.0°F/s (0.5°C/s) or greater—5 seconds

     0.5°F/s to 1.0°F/s (0.25 to 0.50°C/s)—10 seconds
     less than 0.5°F/s (0.25°C/s)—20 seconds

b. Continuously recording the data used for room control. For this standard, continuous recording for sampling systems used for this purpose shall have the following maximum intervals of sampling:
   - For steady-state testing—1 minute
   - For transient testing—20 seconds

c. Achieving a total system accuracy within ±0.3ºF (±0.17°C) of individual values.

d. Achieving a total system response time of 2.5 seconds or less. The response time for this standard is defined as the time required for the system to obtain 63% of the final steady-state value when the transducer is subjected to a step change in temperature of 15°F (8°C) or more The test for system response time shall be made in the same fluid and at the same velocity as observed at the location where the temperature will be measured.

When using temperature transducers in series or parallel (such as thermocouple grids or thermopiles) to obtain the average temperature or average temperature differences in a duct with nonuniform velocities, the overall response time can be much larger than the response time measured at the average velocity. For this standard, the response time for such measurements is defined as the overall response time measured at the velocity conditions of the actual tests.

TABLE 1
Instrument and Test Tolerances for Temperature Measurement

Item Measured	Instrument Accuracy (See Section 4.6)	Instrument Precision (See Section 4.6)	Recommended Test Operating Tolerance (Total Observed Range) (Note 1)	Recommended Test Condition Tolerance (Variation of Average from Specified Test Condition) (Note 2)	Measurements are Usually within Range
Air dry-bulb temperature*	± 0.2ºF ± 0.1ºC	± 0.1ºF ±0.05ºC	1.0ºF 0.5ºC	0.5ºF 0.3ºC	–20 to 140ºF –29 to 60ºC
Air wet-bulb temperature*	± 0.2ºF ± 0.1ºC	± 0.1ºF ± 0.05ºC	0.6ºF 0.3ºC	0.3ºF 0.2ºC	0 to 90ºF –18 to 32ºC
Water or nonvolatile refrigerant temperature*	± 0.2ºF ± 0.1ºC	± 0.1ºF ± 0.05ºC	0.5ºF 0.3ºC	0.2ºF 0.1ºC	30 to 110ºF –1 to 43ºC
Water or nonvolatile refrigerant temperature**	± 0.2ºF ± 0.1ºC	± 0.1ºF ± 0.05ºC	0.3ºF 0.2ºC	—	5 to 25ºF 3 to 14ºC
Volatile refrigerant***	± 1.0ºF ± 0.6ºC	± 0.5ºF ± 0.3ºC	—	—	–30 to 250ºF –34 to 121ºC
Other temperatures required for other purposes****	—	—			0 to 300ºF –18 to 149ºC

* Items are used to determine fluid temperature change and, in conuunction with flow rate, the cooling or heating flow rates.

** Applicable where the temperature difference is measured with a single instrument.

*** Includes refrigerant tube temperatures where acceptable in lieu of immersion of instrument within refrigerant stream.

**** Other temperatures not required by ASHRAE standards but frequently taken for other purposes: for example, refrigerant system component temperatures, motor winding temperatures, or electrical component temperatures.

Note 1—This is the recommended tolerance to be specified on individual readings in a series of readings to be averaged over the duration of the test. Greater tolerances may be specified in specific standards for circumstances such as frosting and defrosting.

Note 2—Test conditions are recommended to average within the tolerance shown. Exceptions may be specified for special situations such as frosting and defrosting (see note1).

4.4 In no case shall the smallest scale division of the instrument exceed twice the specified precision. For example, if the specified precision is ±0.10ºF (±0.05ºC), the smallest scale division shall not exceed 0.20ºF (0.10ºC).

4.5 Where an accuracy better than ±0.50ºF (±0.30ºC) is specified, the instrument shall be calibrated by comparison with a National Institute of Standards and Technology calibrated primary or secondary standard or shall itself be similarly calibrated. The indicated corrections shall be applied to obtain the required accuracy. In this range of accuracy, mercury- in-glass or platinum resistance thermometers or individually calibrated thermocouples or thermistors are recommended.

4.6 Wherever possible, temperature-measuring instruments used to measure the change in temperature of a liquid or a gas should be arranged so that they can readily be interchanged between inlet and outlet positions after every reading. This will improve the accuracy of temperature difference measurement.

4.7 Whenever possible, temperature measurements downstream of a potential heat source or sink should be compared with upstream measurements under conditions of steady temperature with fluid flow but with no heating flow. This calibration may identify problems with the instrumentation or the test setup.

4.8 Whenever two instruments are used to measure a small temperature difference, the investigator should recognize the effect of individual instrument accuracies on the accuracy of the calculated temperature difference.

Obtaining system accuracies comparable to those in Table 1 will require careful calibration.

5. MEASUREMENT TECHNIQUES—GENERAL

5.1 The measurement of the flow of heat usually involves the measurement of flow of a fluid and determination of its entering and leaving enthalpy. The enthalpy depends on pressure and temperature. For air, the barometric pressure and dry-bulb and wet-bulb temperatures are involved. For a refrigerant, the absolute pressure and temperature are required.

5.2 For steady-state conditions, it is recommended that heat flow be measured by two independent methods. This permits establishing the acceptability of the tests by obtaining a heat balance. It is recommended that standards for steady-state testing of equipment specify that two independent methods of test give results that agree within a certain percentage in order to constitute a valid test. Equipment testing standards should specify whether the accepted heat flow rate is to be taken as the average of the two independent test results or is to be taken as the primary test result.

5.3 For transient conditions, the total energy transferred to or from a moving fluid over a given time must be considered. In general, this means that the product of the instantaneous enthalpy difference and the instantaneous mass flow rate shall be integrated over the specified time.

5.4 In general, obtaining an energy balance for transient conditions is more difficult than steady-state conditions and two or more independent methods would be preferable. At the present time, there is only one method that has been fully tested that gives sufficiently accurate results.

This method consists of measuring the instantaneous entering and leaving or the instantaneous difference between entering and leaving enthalpy of dry air and the instantaneous mass flow rate and integrating their product over a specified time. This test places four additional restrictions on the testing and measuring equipment:

1. The dry-bulb and dew-point temperature of the entering air must be low enough so that no moisture will be condensed between the measuring points.
2. If the fluid properties are weak functions of temperature and pressure, either the velocity or the temperature shall be constant across the cross-sectional area of each measurement location and a good average of the other shall be obtained. It is better to have both temperature and pressure constant at each measurement location.
3. The instrumentation must be capable of doing the integration to the desired accuracy.
4. The space providing the environmental conditioning for the equipment being tested must be capable of dealing with the time-varying load produced by the transient conditions of the equipment being tested.

5.5 No heat balance will be perfect because of one or more of the reasons listed below. In order to obtain a heat balance within a prescribed tolerance, some or all of the following causes of error shall be considered:

1. Losses or gains of heat from enclosures, pipes, wires, and connections shall be accounted for by either a calibration or calculation procedure.
2. Uniform velocity and temperature distribution at measuring location (see Section 5).
3. The effect of thermal storage in such devices as duct wall, flow mixers, and straighteners during transient conditions must be made negligibly small or accounted for by calibration procedures, calculation procedures, or by measuring their effects.
4. Simplifications introduced as prescribed calculation procedures, such as use of constant coefficients in equations and use of typical or average values of physical properties of fluids.
5. Unavoidable fluctuations, with respect to time or space, of temperatures or pressure of the fluid being measured.
6. The effects of the action and interaction of the following:

    a. Performance oscillations of instruments, especially of the self-balancing or remote reading type.
    b. Performance oscillations of the apparatus producing the test environment.
    c. Performance oscillations of the equipment being used.

7. Small deviations in the accuracy, precision, and sensitivity of the test instruments.

5.6 From the foregoing, it can be seen that some difficulties in obtaining acceptable heat balances cannot be overcome by merely specifying a high degree of instrument accuracy.

5.7 Usually it is important to measure a temperature level to establish within certain limits the specified temperature environment for operating the test. It is then, in addition, necessary to measure temperature changes. It is the latter that affect the accuracy of heat-flow determinations. Temperature differences can be obtained with improved accuracy by properly calibrating the several instruments that may be used against each other in a common environment even though this procedure does not establish absolute accuracy. This procedure is especially useful for remote reading instruments, where many factors affecting accuracy have the same numerical effect at two moderately different temperature levels, so errors due to these effects cancel out when determining the temperature difference. The following sections include suggestions for improving the accuracy of test measurements.

6. AIRSTREAM TEMPERATURE MEASUREMENTS

6.1 Determination of Average Temperatures

The determination of the average temperature of an airstream requires suitable precautions to deal with the following:

a. Nonuniformity of temperature across the airstream.
b. Nonuniformity of air velocity.
c. Thermal radiation to or from the instrument sensing elements if exposed to surrounding surfaces at temperatures other than that of the surrounding air.
d. Heat conduction through stem or lead wires to or from an instrument sensing element if the stem or lead wires are exposed to temperatures other than that of the sensing element.
e. Nonuniformity of the humidity ratio of the air in the event humidification or dehumidification is taking place.
f. The special requirements for obtaining wet-bulb temperature measurements.

6.2 Measurements in Connection with Heat Flow Rate Determination

When temperature measurements are required in connection with the determination of heat flow rates, suitable precautions should be taken between air inlet and outlet measurement points to minimize acceptably the effect of:

a. Heat gains or losses to test apparatus ductwork, both steady state and transient.
b. Heat gains or losses due to air leakage from or into the test apparatus.
c. The creation or suppression of recirculation or other abnormal airstream patterns caused by the existence of the test apparatus that upset the normal thermal environment of the equipment being tested.
d. Oscillation of temperature with time.
e. Unsuitable instrument response time, resulting in unreliable readings, especially if the air temperature oscillations have not been adequately damped.

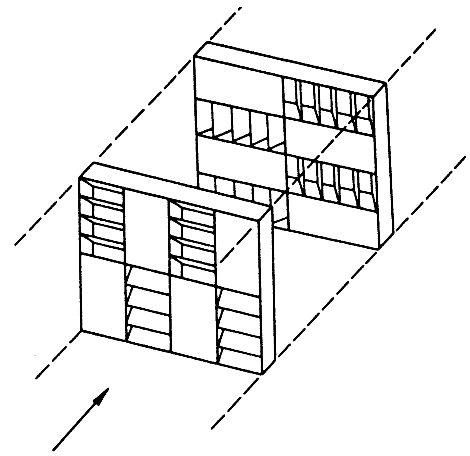

Figure 1 Mixing device.

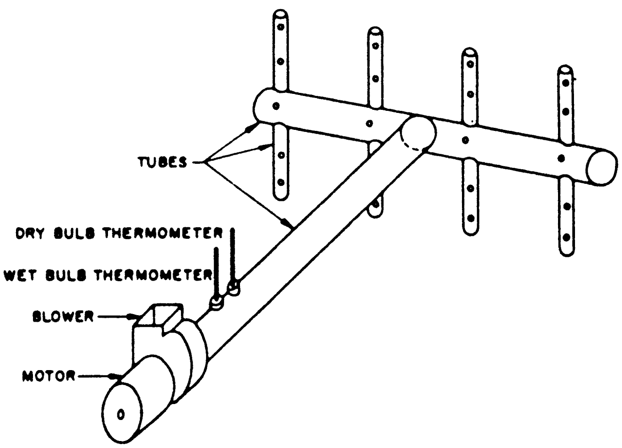

Figure 2 Sampling device.

6.3 Nonuniformity in Temperature, Humidity, and Velocity. Nonuniformity in temperature, humidity, and velocity can be dealt with by suitable mixing and sampling devices. Typical mixing and sampling devices are illustrated in Figures 1 and 2. In general, round or rectangular mixers consisting of two sets of louvers that produce a combination of shearing action and relative displacement on adjacent areas of airflow through the mixers are the most satisfactory. Sampling devices shall not be used for transient measurements.

6.4 Propeller Fan. Mixing is sometimes accomplished by an orifice or drag of a propeller fan inserted in the air duct and driven by the airstream. Such a fan should not be power operated unless suitable adjustments are made for the power input to the fan. A stationary propeller fan can also be used as an air mixer. These mixers are not as satisfactory as the shearing action-displacement type of mixers such as those shown in Figures 3 and 4.

6.5 Mixing Devices. The use of mixing devices is very desirable in principle and may be required to meet limits of nonuniformity for specified test conditions. Where temperature or velocity traverse measurements indicate nonuniformity may be the cause of failure to obtain heat balance, mixers should be used. Good mixers are bulky and must be sized for

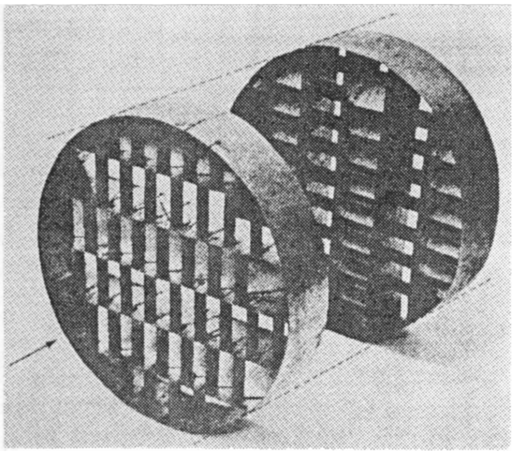

Figure 3 Mixing device.

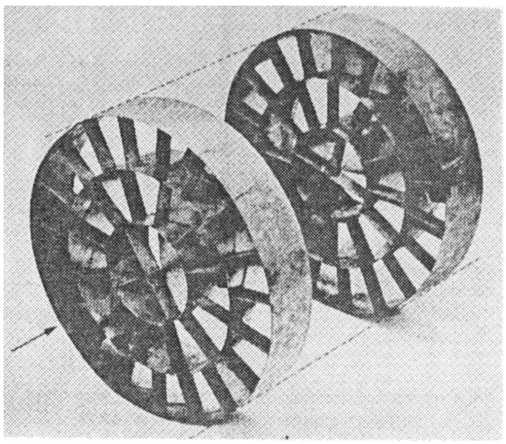

Figure 4 Mixing device.

the required range of airflow. At low airflows, their bulk introduces errors due to heat gain or loss through their enclosures and additionally can delay attainment of steady-state conditions due to heat storage effects of their materials of construction. At high airflows, the previous effects are relatively small but the fan power required may become excessive.

6.6 Sampling Devices (not to be used in transient state measurements). Sampling devices are not suitable alternatives for mixers in cases where nonuniform velocity patterns exist. Where velocities are substantially uniform, sampling devices may be used to measure an average temperature and require less space and fan power than mixers in the main airstream. A smaller blower may be used to induce airflow over the temperature instruments. This blower shall be downstream of the temperature transducer to avoid having the heat input to the blower influence the temperature reading. When the air sample is taken at a point between the equipment being tested and the airflow-measuring apparatus, it is necessary to return the air sample to the main airstream so as to avoid diverting an unknown quantity of air from the airflow-measuring device.

6.7 Centers of Segments. When the airstream has reasonably uniform temperature and velocity, temperatures may be taken within the air duct at the centers of segments of equal cross-sectional area. Not less than four such segments should be employed, and it is better practice in rectangular ducts to employ nine segments obtained by dividing the cross section in three parts horizontally and in three parts vertically. This procedure is feasible when dry-bulb temperatures alone are required and are to be obtained by thermocouples connected in parallel or in series.

6.8 Centers of Segments with Nonuniform Velocity. Averaging the temperatures as measured at the centers of equal cross-sectional areas gives the correct average air temperature only if the air velocity is the same for each area. Nonuniformity in velocity introduces errors. Both a velocity traverse and a temperature traverse should be made across the section of the air duct to establish whether a simple arithmetic average of the temperature readings is acceptable.

6.9 Heat Balance. It is the usual practice to check heat flow measurements by making heat balances wherein heat flow rates are measured by two or more completely independent sets of measurements. While this serves as a check on the measurement of temperature difference, it does not ensure that the temperature readings are correct. It is always desirable to monitor the air temperatures at one or more points by independent temperature measurements, for example, by thermocouples and by thermometer.

6.10 Radiation Errors. Temperature measurements in the airstream are subject to error due to thermal radiation when the sensing elements are exposed in direct line of sight to surfaces appreciably different in temperature from the airstream. In such cases, the sensing elements can be shielded from direct exposure in any suitable manner. A shield made with a tube-shaped piece of polished aluminum foil with a dull black inside surface is effective and convenient. Two concentric tube-type shields are more effective than one. The shield length should be at least two tube-diameters beyond the sensing element. For temperature measurements within the scope of this standard, radiation effects may be negligible They may be important, for example, when the sensing elements are exposed to large surfaces of a hot refrigerant condenser. It is good practice to check temperatures with both shielded and unshielded sensing elements to establish the necessity for shielding in case of doubt as to whether the sensing element should be shielded. Improving the sensing element's response to convective heat transfer by using the smallest possible sensing element minimizes radiation errors.

In addition to radiation errors, errors due to thermal conduction to and from the sensing element may exist.

Both radiation and thermal conduction errors tend to become more significant as air velocity decreases (see Section 10).

6.11 Matched Dry-Bulb and Wet-Bulb Instruments. When air humidity is to be established by means of wet- and dry-bulb temperature measurements, it is important that the instruments be matched. That is, they should indicate the same temperature when both are dry and in the same ambient, or a correction should be applied. This ensures more accurate determination of the wet-bulb depression. The two sensing elements should be close together in the airstream so as to measure the same sample of air, but the dry-bulb element should always be upstream or to one side of the wet-bulb element so that the dry-bulb measurement will not be influenced by evaporation of moisture from the wet-bulb. Inadvertent accumulation of moisture from any source on the dry-bulb temperature-sensing element will cause an error. This is more likely to occur during tests at high humidity, both below and above freezing temperatures, especially when fog conditions exist.

6.12 Wet-Bulb Velocity. Wet-bulb temperature measurement must be made under conditions that provide proper air velocity over the wet-bulb and then only after sufficient time has been allowed for evaporative equilibrium to be attained. The air velocity must be within the range for which the instrument is calibrated. For mercury-in-glass thermometers and other sensing devices of similar diameter, an air velocity of 700 to 2000 ft/min (3.5 to 10 m/s), preferably near 1,000 ft/min (5 m/s), is required to ensure accurate results. Instruments of smaller diameter, such as thermistor or thermocouple psychrometers, require proportionately lower air velocities and require suitable calibration. (See Section 6.14 as an example.) Wet-bulb measurements require additional techniques and precautions as indicated below.

6.13 Wet-Bulb Wick. A suitable material for the wick is cotton tubing of a fairly soft, fine mesh weave. Before use, the wick should be thoroughly cleaned by washing or boiling in distilled water. A snug fit on the sensing element is necessary. In order to prevent excessive conduction of heat from the stem of a mercury-in-glass thermometer, the wicks should cover approximately one inch (25 mm) of the stem as well as the bulb (see Figure 5). With continued use, wicks become encrusted with impurities that interfere with the proper action. It is, therefore, highly important that wicks be frequently cleaned or replaced.

Only distilled water should be used on the wick. When the water is continuously supplied by a reservoir of water, it is important to have that portion of the wick exposed to air movement extend from the thermometer bulb a distance of approximately one-half inch (13 mm) to the water container. This distance is sufficient to let the water attain wet-bulb temperature before reaching the bulb and is not great enough to permit the wick to dry out before adequately wetting the bulb. The use of the continuously wetted wick technique should be discouraged since physical relationships between bulb immersion length, wick length, water level from airstream, velocity, etc., affect the performance of this measurement. If this technique is used, provisions must be made so that the reservoir can be removed or emptied and a check made on the measurement with a shorter wick and conventional "hand wetting."

Another technique that can be used to eliminate the removal of the temperature sensor from the psychrometric device each time it requires wetting is a special psychrometric box (see Figure 5-A) that allows wetting by hand and/or continuous wetting. Plastic tubing fitted to the box and strung to a convenient area for the test operator carries water for the psychrometer.

6.14 Thermocouple Psychrometers. Temperature of the water in the reservoir is more important for glass thermometers with a larger wick than for thermocouples that employ a smaller diameter wick. In the case of the glass thermometer, more warm water (compared with the temperature of water at the wick) is drawn to the mercury bulb per unit time than in the case of the thermocouple with a thin wick. There is evidence to show that, provided there is sufficient lead immersion in the airstream and sufficient radiation shielding is provided, an air velocity of 350 fpm (1.8 m/s) is sufficient for properly designed thermocouple psychrometers. Figure 5 shows a thermocouple psychrometer that has given good performance.

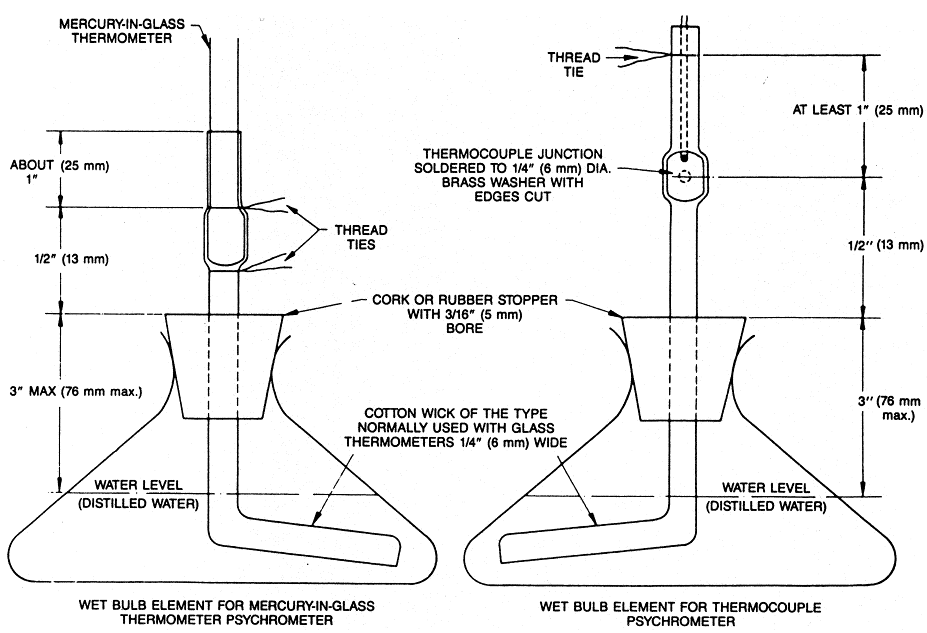

Figure 5 Wet-bulb elements.

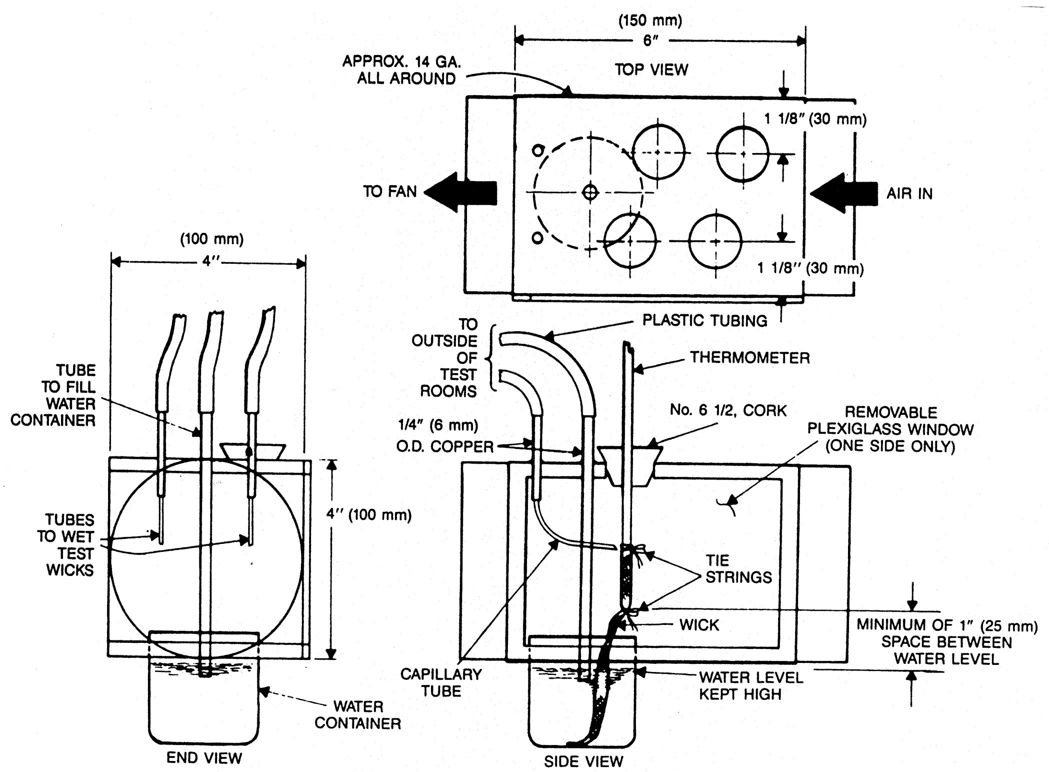

Figure 5A Psychrometer box.

6.15 Thermodynamic Wet-Bulb. In practice, the wet-bulb thermometer does not always read the true thermodynamic wet-bulb temperature and under certain conditions may deviate considerably from it. The relative rates of diffusion of moisture from the wetted surface, as compared to the diffusion of heat from the surrounding air to the wetted surface, tend to make the measured wet-bulb temperature lower than the thermodynamic wet-bulb temperature Heat received by conduction and by radiation from surrounding objects at dry-bulb temperature tends to make the wet-bulb thermometer read high. Fortunately, these two effects tend to balance each other, with the result that the wet-bulb thermometer may correspond to the thermodynamic wet-bulb temperature at certain air velocities and will generally deviate from the theoretical values less than if either one of these effects were present without the other.

6.16 Wet-Bulb Depression Errors for Conventional Size Thermometer Bulbs. Figure 6 shows the error in the wet-bulb depression for various air velocities. It should be noted that for temperatures in the comfort air-conditioning range, a velocity of approximately 1,000 ft/min (5 m/s) is desirable for minimum error. At lower temperatures, a considerably lower velocity is indicated. This curve shall be used to correct the reading of wet-bulb thermometers where it is impractical to maintain a suitably high velocity.

6.17 Stem Diameter. Note that the curves in Figure 6 apply to a thermometer bulb of conventional size (slightly under 1/4 in. [6 mm] diameter). The air velocity for zero correction decreases with smaller sensor sizes. Instruments such as thermocouples and thermistors typically have comparatively

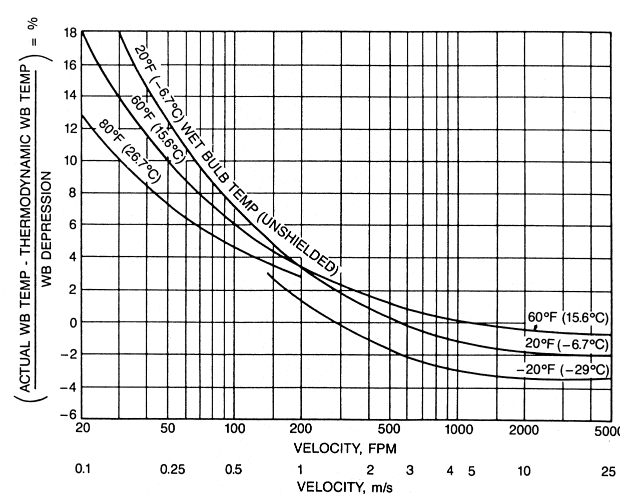

Figure 6 The effect of airstream velocity on the wet-bulb psychrometer.

small sizes of temperature-sensing elements. In such cases, the correct velocity should be established by calibrating the equipment so as to match data obtained by simultaneous use of liquid-in-glass wet-bulb thermometers.

6.18 Wet-Bulb Radiation Errors. If the wet-bulb thermometer is located close to cooling or heating surfaces, an error may result due to radiation from such surfaces. In order to avoid this error, a shield constructed from polished metal should be placed between the thermometer and the radiating surface. (See Section 6.10 for methods of correction.)

6.19 Wet-Bulb Radiation Shields. Wet-bulb thermometers located in air ducts should not be shielded from the duct wall if the wall is at or near dry-bulb temperature If necessary, the outside of the duct should be insulated to avoid a large difference between the duct wall and the inside dry-bulb temperatures.

6.20 Use of Thermocouples for Psychrometric Readings. Thermocouples are entirely satisfactory for taking psychrometric readings if suitable equipment is available and proper precautions are taken in its use. The wet- and dry-bulb thermocouples may be connected in series to give a direct reading of the depression, and, when measured on a potentiometer of suitable precision, such a series couple forms one of the most reliable methods of obtaining psychrometric data.

6.21 Wet-Bulb Readings at Near Freezing Temperatures. The remarks of Sections 6.12 through 6.20 apply to wet-bulb measurements at temperatures above freezing. At temperatures at or below freezing, errors in measurement can arise, as true wet-bulb temperature exists only when the thermometer is coated with ice or, if a wick is in place, when the external surface of the wick is coated with ice. Water covering the thermometer may not be frozen but instead may be supercooled. The equilibrium temperature between moist air and supercooled water is different from that between moist air and ice. To avoid having to establish what type of equilibrium exists, it is recommended that a sample of air be heated above freezing before measuring its moisture content.

6.22 Wet-Bulb Readings at Near Freezing Temperatures in a Moving Airstream. When it is necessary to measure wet-bulb temperature at or near freezing in a moving airstream, the problem of ice can be avoided by continuously withdrawing a sample of air. The dry-bulb temperature of this air is first determined. Then this air sample is heated electrically to a convenient temperature above freezing. The dry-bulb and wet-bulb temperatures of the heated sample are then measured. From these data, the humidity ratio, i.e., the mass of water vapor per unit mass of dry air, is established. This humidity ratio, together with the lower dry-bulb temperature and the psychrometric properties of moist air, is then used to determine the wet-bulb temperature prevailing at the lower dry-bulb temperature.

6.23 Wet-Bulb Readings at Temperatures Below Freezing. Where it is feasible and preferable to directly measure wet-bulb temperatures at temperatures below freezing, a thermometer with an ice-coated bulb, without a wick, is preferable. The wick covering for the wet-bulb thermometer at temperatures below freezing no longer serves the usual purpose, for ice, unlike water, does not respond to capillary forces. True wet-bulb readings are obtained only when the surface of the wick is completely covered with a layer of ice. The ice held within the wick is useless.

6.24 Ensuring Equilibrium at Temperatures Below Freezing. As a result of the reduced vapor pressure at low temperatures, a longer time is necessary to reach equilibrium than at higher temperatures. This condition is offset, however, by the ice remaining on the bulb for a much longer period of time. Readings of the wet-bulb thermometer must be continued over a sufficiently longer period to ensure that equilibrium has been reached.

6.25 Freezing Water Directly on Bulb. Careful tests indicate that reliable results are obtained by discarding the wick and freezing a layer of ice directly on the thermometer bulb. An ice film 0.02 in. (0.5 mm) thick has been found to have a life of roughly one hour when exposed to an air velocity of 900 fpm (4.6 m/s) with a saturation deficiency of about 0.0002 pounds (1.4 grains) of moisture per pound (0.0002 kg/kg) of dry air The ice film is best formed by dipping the chilled thermometer into distilled water at approximately 32ºF (0ºC). The thermometer is then removed from the water and the film allowed to freeze. The process may be repeated several times if necessary to build up a suitable film thickness.

6.26 Ice Stress. There is evidence that the mechanical expansion of the ice in freezing might set up stresses in certain types of thermometers to cause an error. One method of overcoming this condition is to build a tube the same size as the thermometer bulb, freeze a coating of ice over it, thaw it with warm water inside the tube, and place the cup of ice over the thermometer.

6.27 Control of Conduction. In order to prevent excessive conduction of heat along the glass stem of the thermometer to the bulb, it is important that the ice film cover about one inch (25 mm) of the stem as well as the bulb.

6.28 Use of Supercooled Water. The tendency of water to resist freezing at temperatures below freezing is well known. This condition of supercooled water can and does exist on the wick of the wet-bulb thermometer and may give rise to considerable error. While it is possible by the aid of a special psychrometric chart to obtain correct readings of psychrometric properties with the wick wetted with supercooled water, it is generally more desirable to coat the bulb with ice.

6.29 Alternate Methods of Measurement of Wet-Bulb Temperature. Other methods for measuring wet-bulb temperature may be found in *ASHRAE Standard 41.6-1982, Standard Method for Measurement of Moist Air Properties.*

7. WATER, BRINE, AND NONVOLATILE REFRIGERANT TEMPERATURE MEASUREMENTS

7.1 Water, brine, and nonvolatile (under conditions of use) refrigerant temperature measurements require a minimum of precautions inasmuch as measurements may be conveniently made by insertion of the sensing element within the fluid stream, preferably downstream of an elbow or tee connection or other mixer (see Figure 7). The temperature-sensing element should be inserted directly within the fluid or within a well inserted into the conduit. The depth of immersion should be not less than 10 diameters of the well or bulb. Glass thermometers must not be inserted directly into the fluid unless calibration corrections to compensate for pressure effects are made. When a sensing element is inserted into a well, good thermal contact should be obtained by filling the well with a light oil, unless it is feasible to ensure better contact as, for example, by the attachment of a thermocouple with solder to the inside of the well. To ensure rapid temperature response, the well should not be larger than necessary to accept the sensing element. Some thermometers are intended for use with a specific depth of immersion. This should be considered when establishing the depth of the well. Suitable stem corrections are required when used other than as recommended.

7.2 Whenever possible, small temperature difference measurements should be made with instruments of sufficiently high precision that read temperature difference directly, such as calibrated thermocouples.

8. VOLATILE REFRIGERANT TEMPERATURE MEASUREMENTS

8.1 The determination of temperature of vapors should be made by inserting the temperature-sensing element directly within the refrigerant or in a well inserted within the stream. When a sensing element is inserted into a well, good thermal contact should be obtained by filling the well with a light oil, unless it is feasible to ensure better contact as, for example, by the attachment of a thermocouple with solder to the inside of a well. The well should be as small in diameter as feasible It is good practice to insert the well in a tee in the conduit with the refrigerant making a 90° turn in the tee. The depth of the well should take into consideration the proper depth of immersion of sensing elements.

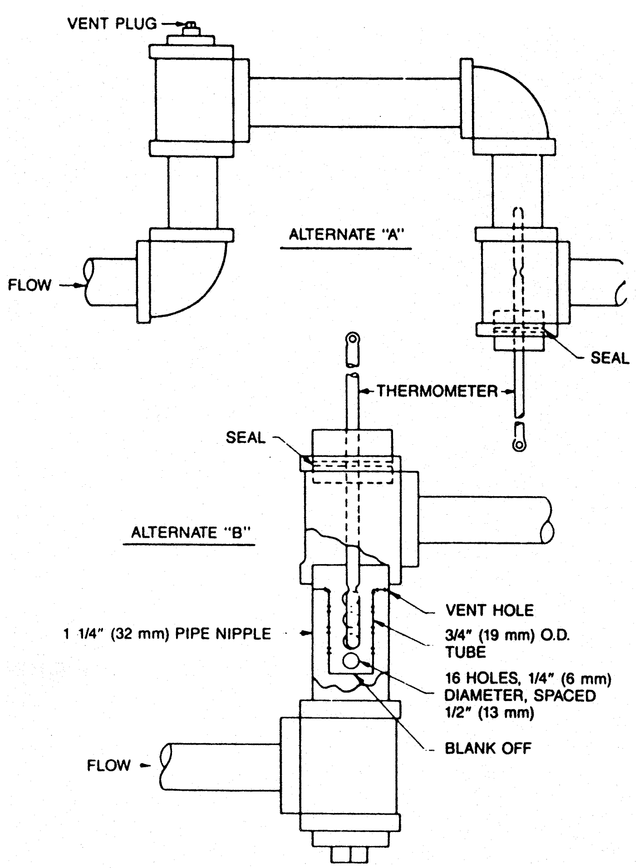

Figure 7 Suggested methods for ensuring thorough mixing.

8.2 The determination of vapor temperature by measuring the temperature of the conduit surface rather than by insertion within the conduit is in general not recommended but is sometimes desirable for noncritical measurements where it is not feasible to disturb factory-assembled components. Precautions given under measurement techniques should be observed (see Section 10.11). Tube surface temperature measurement for the purpose of reestablishing a temperature condition to be duplicated in a succeeding test is an example of an acceptable use of surface temperature. It is essential to apply a layer of insulating material extending to at least 6 in. (150 mm) on each side of a surface temperature-measuring element.

8.3 The determination of temperature in a liquid may be made the same as for vapors except that the measurement of conduit surface temperature may be an acceptable measure of the liquid temperature.

8.4 It is good practice to check refrigerant temperature measurements against the saturation temperature corresponding to the measured refrigerant pressure at locations where the refrigerant can be expected to be in a saturated condition.

8.5 Simultaneous pressure and temperature readings are also frequently taken to establish whether the refrigerant is in a saturated condition or is superheated or subcooled.

8.6 To ensure accurate use of thermodynamic properties of the refrigerant, it is appropriate to assume that the refrigerant is not wholly a vapor unless a prescribed minimum amount of superheat is indicated by temperature and pressure measurements. Likewise, it is appropriate to assume that the refrigerant is not wholly liquid unless a prescribed minimum amount of subcooling is shown by temperature and pressure measurements. It is not within the scope of this standard to specify such minimum values of superheat and subcooling, but the necessity for prescribing such values in connection with the establishment of test procedures should be recognized.

8.7 Temperature and other measurements shall be taken downstream of volatile refrigerant flowmeters to determine whether adequate subcooling exists.

9. MEASUREMENT TECHNIQUES—MERCURY-IN-GLASS THERMOMETERS

9.1 The mercury-in-glass thermometer is direct reading and can be obtained with adequate calibration accuracy, 0.05°F (0.03°C) for total immersion, 0.5°F (0.3°C) for partial immersion. It holds its calibration well. It must be so placed that its indication measures the temperature at the location intended, while at the same time it must be accessible for reading.

9.2 Precautions are necessary to ensure that heat from the body of the reader, an electric lamp, or from other extraneous sources does not affect the reading.

9.3 Glass thermometers must not be inserted directly into a conduit conveying fluid unless calibration corrections are applied to compensate for pressure effects. For such measurements, the thermometer should preferably be inserted into a thermometer well built into the circuit.

9.4 Glass thermometers may require correction for depth of immersion and for the temperature of the ambient around the stem. This is the emergent stem correction.

9.5 Glass thermometers may require correction for orientation. For example, a glass thermometer inserted upside down in an air duct may read high by as much as 0.10ºF (0.05ºC).

9.6 Glass thermometers are comparatively easy to interchange between two positions for alternate readings in order to obtain an average temperature difference reading that is unaffected by the calibration of the thermometers, which difference is small.

10. MEASUREMENT TECHNIQUES—THERMOCOUPLES

10.1 Thermocouples offer great flexibility in application, are remote reading, and with suitable instruments are readily adapted to the measurement of temperatures at several points in rapid succession.

10.2 Thermocouples must be properly made and correctly connected to measuring instruments directly or by use of thermocouple extension wires. A suitable voltage-measuring device, such as a potentiometer or digital voltmeter, must be used to measure the voltage generated by the thermocouple, which includes a reference junction (sometimes called the cold junction). The accuracy of temperature measurement is subject to errors in each of the components of the thermocouple circuit, including thermocouple junctions, switches, and extension wire. Commercial thermocouples and extension wires are subject to tolerances that, under conditions of use, may or may not fall within the desired tolerance range (see Table 2). Individual thermocouple calibrations may be needed to provide the required accuracy. Use of dissimilar metals in switching circuits must be avoided unless means are taken to eliminate extraneous thermocouple effects. Isothermal conversion junctions can be used to eliminate thermocouple junctions in switch wiring. Temperature measurement is additionally subject to errors in measurement of electrical potential by the voltage-measuring device. For maximum accuracy, there should be no splices in the thermocouple wires between the measuring and reference junctions. Substantial errors can be introduced at such splices because of manufacturing tolerances between wires of the same nominal compositions.

TABLE 2 *

Limits of Error of Thermocouples, Extension Wires, and Alternate Extension Wires for Standard Wire Sizes†

Thermocouples, Typical Material**	Temp. Range,		Limits of Error††		Ext. Wire Types	Temp. Range,		Limits of Error		Ext. Wire Types	Temp. Range,		Limits of Error***
	ºF	ºC	Std.	Special		ºF	ºC	Std.	Special		ºF	ºC	
E NICKEL–10% CHROMIUM Constantan	32 to 600	0 to 315	± 3ºF (± 2ºC)	± 2 1/4ºF (1.25ºC)	EX	0 to 400	–18 to 204	± 3ºF (2ºC)	—	—	—		
J IRON Constantan	32 to 530	0 to 275	± 4ºF (± 2ºC)	± 2ºF (± 1ºC)	JX	0 to 400	–18 to 204	± 2ºF (± 0.1ºC)	± 2ºF (± 1ºC)	—	—		
K NICKEL–10% CHROMIUM Nickel–5% (Aluminum, silicon)	32 to 530	0 to 275	± 4ºF (± 2ºC)	± 2ºF (± 1ºC)	KX	0 to 400	–18 to 204	—	—	WX	75 to 400	24 to 204	± 6ºF (±3ºC)
S PLATINUM–10% (RHODIUM platinum)	32 to 1000	0 to 538	± 2 1/2ºF (1.5ºC)	—	—	—	—	—	—	SX	75 to 400	24 to 204	± 12ºF (±6.7ºC)
R PLATINUM–10% (RHODIUM platinum)													
T COPPER Constantan	–75 to +200	–60 93	± 1 1/2ºF (0.8ºC)	±3/4ºF (0.4ºC)									
	200 to 700	93 to 370	± 3/4%	± 3/8%	TX	–75 to 200	–60 to 93	± 1 1/2ºF (0.8ºC)	± 3/4ºF (0.4ºC)	—	—		

* Derived from Bibliography 4.
† Does not include use or installation errors.
** The positive material is shown in capitals.
†† The limits of error of thermocouples are based on a Reference Junction temperature of 32ºF (0ºC). For the conversion of an error in degrees Fahrenheit to degrees Celcius (centigrade), the ratio 5/9 should be used.
*** The limits of error for alternate types of extension wires listed are applicable for a temperature of 75ºF (29ºC) only at the point where the thermocouples and extension wires are joined.

10.3 In an individual test situation using one or more thermocouples, it is necessary to establish the accuracy of measurement by checking one or more representative thermocouples against a known reference temperature, independently measured. For example, a thermocouple may be placed in a water bath in a thermos bottle whose temperature is established at a representative level and checked with a mercury-in-glass thermometer having the accuracy and precision listed in Table 1. Thermocouples must be individually calibrated for use where 0.2ºF (0.1ºC) or better accuracy is specified. In addition, a check at 32 F (0ºC) using a bath composed of distilled water and distilled water ice is recommended. An abundance of ice should be kept properly stirred to guard against stratification of water at temperatures above 32ºF (0ºC) at the bottom of the bath**.**

10.4 To obtain an accuracy of 0.5ºF (0.3ºC) or better, thermocouple wires must be calibrated individually against an accurate instrument such as a resistance thermometer in a liquid bath or a secondary instrument such as a glass thermometer with telescope and a fine scale division. In the case of copper-constantan, it is usually sufficient to calibrate the constantan wire at a few points on a spool, but both wires should be homogeneous throughout the length of the lead used. Homogeneity can be determined by running a source of low heat[1] along the length of the leads to be used, one at a time, both ends connected to a galvanometer. A deflection on the galvanometer indicates inhomogeneous wire, and it should be discarded.

10.5 Thermocouples may be used for air wet-bulb temperature measurements. A suggested arrangement is shown in Figure 5.

10.6 Individual thermocouples may have errors introduced by cold working of the metal after forming the junction. For precise work, calibration after forming may be indicated.

10.7 Temperature differences may be measured by means of thermocouples arranged in multiple-junction thermopile fashion. Other series, parallel, or series-parallel arrangements of thermocouples can be utilized for various measuring problems.

10.8 When fabricating the thermocouple, the two elements must be permanently joined at one end to form the measuring junction. For the temperature range of concern in this standard, the junction may be welded or soldered. For Type T (copper-constantan) thermocouples, the junction may be made with soft solder. For Type K (chromel-alumel) or Type J (iron-constantan), the joint may be made with silver solder. When the junction is to be attached to a metallic surface, the same joint alloy should be used as was used to form the junction.

10.9 There are three methods of welding in common use, namely: (1) gas welding, (2) electric arc welding, and (3) resistance welding. Detailed information on welding procedures is given in Bibliography 1.

10.10 Thermocouples may be attached to metallic surfaces by soldering. It is important to be sure that the junction is actually at the surface and not inadvertently formed by a drop of solder connecting the wires at a point not actually at the surface. It is necessary to be sure that the thermocouple wires are not in contact with each other so as to cause a short circuit, especially where insulation is burned off the wire during soldering.

10.11 It is additionally necessary to ensure that the indicated temperature is not biased unduly by heat transfer to or from the thermocouple wires, particularly if the wires are exposed to a moving airstream. Errors on the order of 10% or more of the temperature difference between surface and ambient are possible due to this cause. To minimize such errors, the thermocouple wire should be taped to the metal surface for 1 in. (25 mm) or 2 in. (50 mm) so that the portion of the wire in the vicinity of the junction is kept at surface temperature. There should be a minimum of thermal insulation between the wires and surface, although it is necessary to maintain the electrical insulation of the wires. If thermocouples are electrically grounded at the point of measurement, precautions must be taken to eliminate voltage differences between the point of measurement and the measuring instrument. Vapor-sealed thermal insulation may then be placed over the junction and adjacent wires, if necessary, where temperature differences are great and/or ambient velocities are high. To establish the necessity for these extra precautions, it is advisable to attach two thermocouples, one with minimum attention to this effect and one adequately insulated. Comparison of temperature readings will indicate whether more elaborate precautions are necessary.

10.12 Bare thermocouple leads in an airstream with proper immerse give best results in a duct because the lead conductors "see" approximately the temperature of the gas.

11. MEASUREMENT TECHNIQUES—RESISTANCE THERMOMETERS

11.1 A resistance thermometer measures temperature as a function of electrical resistance of a wire as it is subjected to various temperatures The resistance thermometer offers advantages of high accuracy, high speed of response, and nearly linear response to temperature change. There is virtually no limit to the distance between the measurement and the recording or indicating point. Measurement accuracy is affected very little by ambient temperature changes. Special lead wires are not required as for thermocouples. The resistance element is relatively expensive compared to a thermocouple. A complex, expensive instrument is required to determine the resistance. Resistance thermometers require, calibration before they can be used.

11.2 Precision resistance thermometers are used as temperature standards for calibrating other instruments for use within the temperature range of interest in this standard.

[1] Temperature not to exceed 200ºF (93º) and not high enough to damage any insulation of wire coating. Too much heat will cause an inhomogeneity.

11.3 Thermistors are a special type of resistance thermometer. They are made of semiconductor materials that can be made to provide high accuracy, sensitivity, and fast response coupled with small size. Thermistors measure temperature as a function of electrical resistance but have a much higher temperature coefficient of resistivity than resistance thermometers made of wires or metals. They are, therefore, particularly useful for measurements within a small range of temperatures. Each thermistor must be calibrated individually in a liquid bath if an accuracy of 0.2ºF (0.1ºC) or better is required. Because of the relatively high resistance of thermistors, care must be taken to maintain the electrical insulation of resistance of the thermistor element. Thermistors have a tendency to drift unless they have been properly "cured" by the manufacturer before use. But if this has been properly done and if they arc not subjected to shock and are treated with care, they will hold their calibration for long periods to within 0.05ºF (0.03ºC) and better. Thermistor time constants are on the order of one to two seconds; consequently, thermal damp-ing of the airstream is recommended.

11.4 In general, resistance thermometers (including thermistors) arc used where high accuracy is required. Their installation and usage more nearly follow practices employed for mercury-in-glass thermometers than for thermocouples; however, resistance thermometers retain the advantage of the remote reading instrumentation of thermocouples.

11.5 The techniques suggested in connection with mercury-in-glass thermometers and thermocouples are equally applicable for use with resistance thermometers except as obviously inappropriate due to the mechanical construction of the instrument. Under controlled conditions and with suitable calibration, resistance thermometers can be used to provide electrical averaging of many points of temperature measurement.

(This appendix is not part of this standard. It is merely informative and does not contain requirements necessary for conformance to the standard. It has not bee processed according to the ANSI requirements for a standard and may contain material that has not been subject to public review or a consensus process. Unresolved objectors on informative material are not offered the right to appeal at ASHRAE or ANSI.)

APPENDIX A
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POLICY STATEMENT DEFINING ASHRAE'S CONCERN FOR THE ENVIRONMENTAL IMPACT OF ITS ACTIVITIES

ASHRAE is concerned with the impact of its members' activities on both the indoor and outdoor environment. ASHRAE's members will strive to minimize any possible deleterious effect on the indoor and outdoor environment of the systems and components in their responsibility while maximizing the beneficial effects these systems provide, consistent with accepted standards and the practical state of the art.

ASHRAE's short-range goal is to ensure that the systems and components within its scope do not impact the indoor and outdoor environment to a greater extent than specified by the standards and guidelines as established by itself and other responsible bodies.

As an ongoing goal, ASHRAE will, through its Standards Committee and extensive technical committee structure, continue to generate up-to-date standards and guidelines where appropriate and adopt, recommend, and promote those new and revised standards developed by other responsible organizations.

Through its *Handbook*, appropriate chapters will contain up-to-date standards and design considerations as the material is systematically revised.

ASHRAE will take the lead with respect to dissemination of environmental information of its primary interest and will seek out and disseminate information from other responsible organizations that is pertinent, as guides to updating standards and guidelines.

The effects of the design and selection of equipment and systems will be considered within the scope of the system's intended use and expected misuse. The disposal of hazardous materials, if any, will also be considered.

ASHRAE's primary concern for environmental impact will be at the site where equipment within ASHRAE's scope operates. However, energy source selection and the possible environmental impact due to the energy source and energy transportation will be considered where possible. Recommendations concerning energy source selection should be made by its members.

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