3.3 Air temperature

Air temperature is measured with a thermometer. Thermometers are substantially affected by radiation. For accurate measurement they should be installed within a shelter to avoid radiation. Because temperature can fluctuate widely with time and location, a proper thermometer and proper measuring procedures must be chosen to satisfy the observation objectives. In selecting a thermometer, factors including the following should be fully examined: time constant of the temperature sensing unit, durability, required calibration frequency, installation location, number of installation locations, and measured range.

In the International System of Units, [K] is the designated measurement unit of temperature. [°C] is used in usual temperature measurement (Appendix 3.3-1).

Types of instruments

There are various types of thermometers, as Table 3.3-1 indicates. For long-term meteorological observation, platinum resistance thermometers and thermocouple thermometers are most commonly used. These are equipped with a sheath in which a temperature sensing unit is loaded and sealed with insulation. The characteristics of thermometers that are generally used for continuous measurement are discussed in this section.

Table 3.3-1 Thermometers.

Name	Principle	Characteristics
Electrical resistance thermometer	Temperature change in electrical resistance	Easy to handle. The temperature sensing unit is larger than that of a thermocouple.
Thermocouple thermometer	Thermo-electromotive force	The size of temperature sensing unit can be minimized. Each junction needs to be maintained carefully for accurate measurement.
Radiation thermometer	Thermal radiation	Wide-range remote measurement is possible, although it is difficult to maintain the measurement accuracy.
Self-registering metallic thermometer	Metallic expansion	Self-registering, driven by a spring. The measurement accuracy is low.
Fluid-filled thermometer	Fluid expansion	Low-priced instrument. It is high in accuracy, but it needs a reader.
Ultrasonic anemometer thermometer	Ultrasonic Doppler effect	Appropriate for measuring sensible heat flux, the instrument is expensive and requires calibration.

Thermistor thermometers

This thermometer contains a metallic resistor whose resistance decreases as the temperature rises. Because the rate of change in resistance in response to temperature variation is pronounced, this thermometer is well suited to measuring very subtle temperature changes. A thermistor element can be made smaller than a platinum thermo resistor, which is advantageous for the production of size-reduced temperature sensing units. Error and noise caused by resistance of the lead wires can be mitigated by increasing the signal output and electric resistance of the element. Accordingly, remote measurement away from a data logger through extended lead wire becomes possible. The instrument requires regular inspections, as it may be susceptible to self-heating and the age-related changes in the element are relatively great. Because the instrument has strong nonlinearity and its elements are not standardized, it is usually used with a linearizer-integrated special converter. Various handy, low-priced thermometers with a power source and a data logger in, such as the HOBO series produced by Onset Computer Corporation, US (Photo 3.3-1) and the Ondotori series by T&D Corporation, Japan (Photo 3.3-2), are commercially available. Most are used for low-cost automatic continuous measurement and multi-point observation of the thermal environment.

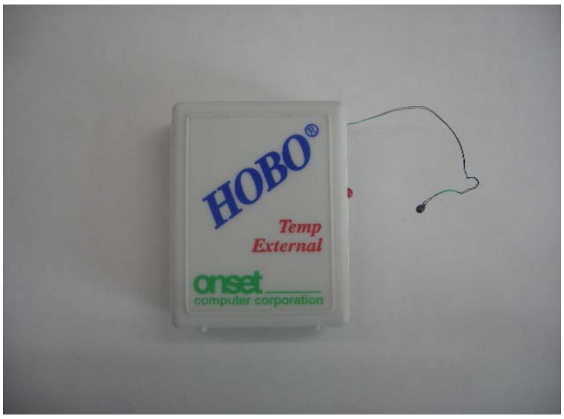

Photo 3.3-1 HOBO by Onset (thermistor thermometer).

Photo 3.3-2 Ondotori by T&D (thermistor thermometer).

Tips!

When no linearizer is available, temperature can be converted after the relationship between temperature and resistance of the element (possibly provided by the thermistor manufacturer) is determined and the voltage supplied from the constant voltage source is measured.

Tips 3.3-1

Platinum resistance thermometer

The instruments are standardized, with Pt100 indicating the resistance of 100 Ω at 0 °C. The three- and four-wire types (Photo 3.3-3) that are often used for meteorological observation have high measurement accuracy, as they are capable of offsetting the resistance value of the lead wire by measuring the output voltage of the bridged circuit. Thus they are well suited for stable, long-term observation. To make wiring resistance uniform, lead wires of the same diameter, material, and length should be used, and corrosion prevention must be given to all the connections. If wire is extended excessively, resistance may increase too much for the data logger to register. Because the heat capacity of a resistance element is greater than that of a thermocouple, the response speed is accordingly slower. The sheathed platinum resistance thermometer is highly resistant to age-related changes, which makes it well suited to long-term observation, but it should be handled carefully as it is susceptible to vibration and shock.

Photo 3.3-3 HMP45D of Vaisala (platinum thermometer, discontinued model, replaced by HMP155).

Tips!

In case of Pt100, between resistances of R_{100} [Ω] at 100 °C and R_0 [Ω] at 0 °C, the ratio R_{100}/R_0 is 1.3850, which conforms to the standard of the International Electrotechnical Commission (IEC). Because the standard (R_{100}/R_0=1.3916) specified in the Japanese Industrial Standards (JIS) before 1989 was different from the IEC's, the standard before 1989 is distinguished as JPt100.

Tips 3.3-2

Thermocouple thermometers

When metal gains a thermal gradient, thermo-electromotive force is generated within the metal as a result of a difference in density of free electrons. If two different kinds of metal wires that generate different electromotive forces at the same temperature are joined at their ends to form a circuit (thermocouple), a current flows in a certain direction as long as a disparity of temperature is maintained between the two points of contact. This is called the Seebeck effect, and it is used by the thermocouple thermometer for temperature measurement (Fig. 3.3-1). The instruments are relatively simple in structure, moderate in price, standardized and therefore compatible with each other. The point that is connected to a data logger is called a reference junction or a cold junction, and its temperature is referred to by the sensor as a base value of temperature. The data logger determines the temperature of the measuring point by sensing the terminal temperature with a thermistor. To avoid the occurrence of temperature difference between terminals, the terminal may be covered to reduce the effects of radiation. For the thermocouple thermometer, the difference in shape and size between metal components of two different materials little affects on the thermo-electromotive force. But the thermocouple thermometer is characteristically susceptible to noises because of high wire resistance to electromotive force. For wire extension, a compensation lead wire appropriate for each type of thermocouple should be used to compensate for the thermo-electromotive force between thermocouple terminal and logger terminal.

For observations from a tower, the copper-constantan thermocouple (T-type), which has high thermo-electromotive force and low resistance, is often used. Because copper readily oxidizes, care should be exercised against corrosion around the junctions. In tower observations, a device with two sheathed thermocouples in a shelter, one as a dry-bulb thermometer and the other as a wet-bulb thermometer, is often used for observing vertical distribution of temperature and humidity.

If high responsiveness is required of temperature measurement, the following method can be used: the ends of copper wire and constantan wire with a diameter of 0.1 mm or so are polished and applied with electric welding or silver soldering, and then the junction is trimmed and covered with thin film insulator. Although the device can be made by hand, a super-fine thermocouple for which the end of the thermocouple wire is welded and processed to 13 μm is supplied by manufacturers such as OMEGA Engineering, INC., US. Although finer thermocouples have higher responsiveness, they are more susceptible to vibration and therefore need to be carefully handled.

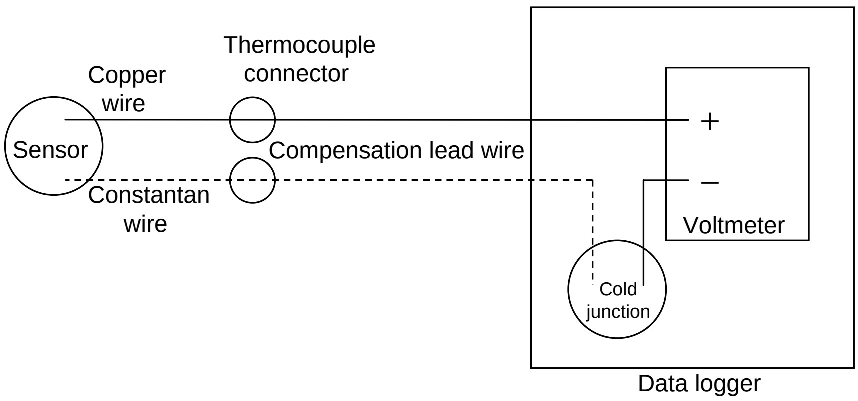

Fig. 3.3-1 Thermocouple circuit.

Photo 3.3-4 Sheathed thermocouple.

Tips!

For silver brazing (soldering), a copper crucible or a copper plate is heated with a burner at a high temperature, and borax and silver solder are put into the crucible to melt. After trimming, the junction sections of the thermocouple are put in the crucible and soldered. The wire diameter is reduced if necessary, and the junction is coated with insulation. For electric welding, a spot welder and optional welding tweezers for thermocouples are appropriate. Although welding kits can be handmade easily (Ohtani, 1999a), due caution has to be taken, as the resistor generates very high heat. The production of a thin thermocouple requires a welder whose voltage and pulse width can be adjusted.

Tips 3.3-3

Measuring method

In measuring temperature, the thermometer should be placed in a shelter to prevent influences of radiation, rainfall and snowfall. In Japan, shelters equipped with a fan that blows at a speed of 3 ms^{-1} or over (Photo 3.3-5) are used in most places. A horizontal shelter needs to be installed, and its installation must be such that solar radiation will not enter. In addition, caution has to be taken so that air can blow in the direction where the fan heat does not affect the observation.

In general meteorological observation, temperature is measured in an open observation field without obstacles. The standard measuring height specified by the Japan Meteorological Agency is 1.5m above ground (snow surface) and that of the World Meteorological Organization (WMO) is between 1.25 and 5 m above ground.

To continuously observe the vertical distribution of temperature, particularly high measurement accuracy is required. In evaluating the static stability of atmosphere, the potential temperature (the temperature which an air parcel would acquire when brought adiabatically to a standard atmospheric pressure) is a key factor of the vertical distribution. However, because the difference in potential temperature is approximately equal to the difference in atmospheric temperature within the surface layer, the atmospheric temperature is often employed. As for the measuring height in a forest, the upper limit is set at a point more than twice the tree height, where the vertical gradient of temperature becomes smaller. Other measuring points may be two elevation points above the vegetation community, one at the tree crown, one under the canopy and one near the ground surface. It is desirable to have as many measuring points as possible.

The radiation thermometer is suitable for measuring a wide range of vegetation surface temperature. For its use, caution has to be exercised regarding the influences observation angle, radiation and shade made by the thermometer itself, quantity and rate of radiation released by substances other than vegetation, and the like.

Photo 3.3-5 Shelter.

Tips!

A shelter fan is prone to breakdown by the entry of foreign matter. Whether the fan is revolving should always be checked, and preparations for replacement in the event of trouble need to be made. Particularly during the summer, when small bugs are occasionally pulled into a shelter in large quantities, a fan and a temperature sensing unit need frequent cleaning. The frequency of cleaning can be reduced by installing a net (that for a drain or a corner strainer in the kitchen sink) over the shelter intake mouth.

Tips 3.3-4

Calibration

Instrument error is simply calibrated with a reference instrument that is placed regularly at the same elevation as the one to be tested. The reference instrument should be inspected by the manufacturer, and age-related changes should also be checked for.

It is desirable to exercise calibration with a commercially available thermometer test bath. A waterproof thermometer is usually tested in a constant-temperature water bath equipped with a water circulator and a temperature control unit.

Tips!

For a test in a constant-temperature water bath, anti-freezing solution is added to keep the water from freezing at low temperature.

Tips 3.3-5

Appendix 3.3-1: Unit conversion

Conversion between Celsius C [°C] and absolute temperature T [K]

$$C = T - 237.15$$

$$T = C + 273.15$$

Conversion between Celsius C [°C] and Fahrenheit X [°F]

$$C = \frac{5}{9}\left(X - 32\right)$$

$$X = \frac{9}{5}C + 32$$