warm air or forced hot water systems the fan or circulator usually is controlled by a thermostat in the furnace or boiler and runs whenever the air or water temperature is above a minimum value, as discussed in Chapter 26. If straight two-position control is used for this application, the *on* and *off* periods are relatively long and there is a tendency towards cold drafts on the floor during off periods. If timed two-position control is used, the burner may be cycled (started and stopped) often enough to provide results very comparable to proportional control. The heat input to the home is proportioned continuously to the heat loss from the home. The fan of a forced warm air system or the circulator of a forced hot water system may be run almost continuously, thus minimizing the possibility of cold drafts.

Proportional control is used on residential applications when provisions are made for it in the design of the system. Face and bypass dampers on warm air systems, throttling valves on steam systems and three-way mixing valves on hot water systems are typical examples of controlled devices which permit proportional control. With these arrangements the burner usually is controlled by a thermostat in the furnace or boiler. Proportional control will permit nearly continuous circulation of warm air or hot water, thus reducing cold drafts.

Automatic night set-back through the use of a day-night type room thermostat is a refinement frequently added to residential control systems. Though opinions vary regarding the amount of fuel that can be saved by automatic night set-back, tests made both in the warm air heating research residence and the I = B = R research home at the University of Illinois indicate that, on thermostatically controlled systems, a possible fuel saving of from 7 to 10 percent may be obtained by reducing the house temperature 6 to 10 F from about 10:00 p.m. to 5:30 a.m.

It is often desirable to divide the house into two or more zones for greater accuracy of control and comfort. Each zone may then be maintained individually at the desired temperature level. The division into zones should be based upon exposure or occupancy; the most common division is usually found to be (1) the living section such as living room, dining room, den; (2) the sleeping section; (3) the service section such as kitchen, pantry, servants' quarters; and (4) recreational areas.

Further discussion of zone control principles has been given in Part II of this chapter.

Year-round residential air-conditioning systems which provide for heating in winter and cooling in summer should be given the same consideration in selecting the control system as required for commercial air-conditioning systems. See Chapter 19. The basic principles are the same and the final results must provide for the comfort of the occupants. A reduction in investment for automatic controls may result in wasteful operation of the system and discomfort for the occupants.

Special thermostats have been designed to take care of the year-round residential air-conditioning systems. The changeover from heating to cooling is usually accomplished by a selector switch which is part of the thermostat. In some systems the changeover is completely automatic by the action of the thermostat. Generally, both the heating and cooling functions are controlled by timed two-position action. Some form of humidity control may be added. If so, normally, reheat would be required.

When an *add-on* unit is installed to obtain a year-round air-conditioning system by change of a straight heating system, it may be controlled separately or integrated with the heating control system. However it is accomplished, the control system should be simple enough for the user to understand how to operate it effectively.

REFERENCE

[1] E. J. Brown and J. R. Fellows: Pressure losses and flow characteristics of multiple-leaf dampers (ASHAE JOURNAL SECTION, *Heating, Piping and Air Conditioning*, August 1957, p. 119).

BIBLIOGRAPHY

Automatic Control Terminology (American Society of Mechanical Engineers, 1954).

R. H. MacMillan: *An Introduction to the Theory of Control in Mechanical Engineering* (Cambridge University Press, New York, 1951).

E. W. F. Feller: *Instrument and Control Manual for Operating Engineers* (McGraw-Hill Book Co., New York, 1947).

J. E. Haines: *Automatic Control of Heating and Air Conditioning* (McGraw-Hill Book Co., New York, 1953, 1st ed.).

Save Fuel for Victory (University of Illinois, *Engineering Experiment Station Circular Series* No. 47, p. 31).

CHAPTER 44

INSTRUMENTS AND MEASUREMENTS

Temperature Measurement, Pressure Measurement, Air-Flow Measurement, Air Change Measurement, Measurement of Air Currents, Humidity Measurement, Measurement of Mean Radiant Temperature, Heat Transfer Through Building Materials, Combustion Analysis, Smoke Density Measurements, Sound and Vibration Measurements, Determination of Air Contaminants

HEATING and air-conditioning engineers and technicians require instruments for both laboratory and field use. Somewhat more precision is attainable and essential in the laboratory, where research and development are undertaken, than in the field, where acceptance and adjustment tests are conducted. The purpose of this chapter is to describe briefly some of the more important instruments, and to outline their uses and characteristics.

TEMPERATURE MEASUREMENT[1, 2]

Thermometers

Any device capable of indicating temperature is a thermometer, but in common usage the term *thermometer* without qualification has come to signify the ordinary liquid-in-glass temperature indicating device. Mercury-filled thermometers have a useful range from −40 F, the freezing point of mercury, to about 1000 F, at or near which the glass usually softens. Lower temperatures can be measured with alcohol-filled thermometers for which the range is about −94 F to +248 F. The better thermometers have their scales, either Fahrenheit or Centigrade, etched with acid into the glass which forms their stems.

Thermometers are calibrated during manufacture for at least two temperatures, frequently the freezing and boiling points of water, and the space between the calibration points is then divided into the desired scale divisions. The probable error for etched stem thermometers is plus or minus one scale division. For precise work, recalibration is frequently necessary to determine the proper corrections to be applied to the scale readings.

Liquid-in-glass thermometers are calibrated by the manufacturer for either complete or partial stem immersion. If a thermometer which has been calibrated for complete immersion is used at partial immersion, that is, with a portion of the liquid column at a temperature different from that of the bath, an *emergent stem correction* should be made. This correction may be calculated by Equation 1:

$$\text{Stem correction} = Kn\,(t_b - t_s) \qquad (1)$$

where

K = the differential expansion coefficient of the mercury or other liquid in the glass. K may be taken as 0.00016 for Centigrade mercurial thermometers and 0.00009 for Fahrenheit mercurial thermometers. For values of K for other liquids and for specific glasses, see Reference 1.

n = the number of degrees of the liquid column emergent from the bath.

t_b = the temperature of the bath.

t_s = the average temperature of the emergent liquid column of n degrees.

A thermometer can be appreciably affected by radiation from surrounding surfaces. If the temperature to be measured is approximately the same as that of the surrounding surfaces, radiation effects may usually be ignored. If the temperature being measured differs considerably from that of the surroundings, steps should be taken to minimize the effect of radiation.[3] This is usually accomplished either by shielding or by aspiration. Shielding is accomplished by placing highly reflective surfaces between the thermometer bulb and the surrounding surfaces. However, this must be done in such a way that air movement around the bulb is not appreciably restricted.[4] Improper shielding may increase rather than decrease errors. Aspiration is accomplished by drawing a high-velocity stream of air or gas over the bulb of the thermometer.

Industrial-type thermometers are available for permanent installation in pipes or ducts. These instruments are fitted with metal guards to prevent breakage, and are useful for many purposes. However, the considerable heat capacity and conductance of the guards or shields may introduce errors.

To prevent errors in temperature measurements, ample time should be allowed for the thermometer to attain temperature equilibrium with the surrounding fluid. In reading a thermometer, the eye should be at the same level as the top of the liquid column to avoid parallax.

Thermocouples

When two wires made of dissimilar metals are joined by soldering, welding, or merely by twisting, a thermocouple or thermo-junction is formed. An electromotive force, which depends upon the temperature of the junction, is found to exist between the wires. When the wires are joined at two points a thermocouple circuit is formed. If one junction is kept at a temperature different from the other, an electric current flows through the circuit due to the difference in emf developed by the two junctions. This phenomenon is employed for temperature measurements in thermocouple systems, one junction being ordinarily kept at a constant temperature, as in an ice bath, while the other junction is placed at a point at which it is desired to observe the temperature. In practice it is desirable to utilize emf to indicate temperature because, at small or zero current flow, the resistance of the circuit is unimportant. A high resistance millivolt meter is useful in some cases but the potentiometer yields better results. In the potentiometer the electromotive force generated by the thermo-