APPENDIX A

SI System and U.S. System of Units

APPENDIX OUTLINE

NOTE

The SI system, although commonly referred to as the International System, is, in fact, an acronym for Le Système International d'Unités, a name given by the thirty-six nations meeting at the eleventh General Conference on Weights and Measures (CGPM) held in Paris in 1960. (CGPM is an acronym for Conférence Générale des Poids et Mesures.)

TABLE 1 PREFIXES IN THE SI SYSTEM

Factor	Prefix	Symbol
10^{12}	tera	T
10^{9}	giga	G
10^{6}	mega	M
10^{3}	kilo	k
10^{2}	hecto	h
10	deka	da
10^{-1}	deci	d
10^{-2}	centi	c
10^{-3}	milli	m
10^{-6}	micro	μ
10^{-9}	nano	n
10^{-12}	pico	p

The system of measurement (or units) commonly used at the present time for the design and construction of buildings in the United States is the foot-pound-second (FPS) system. In this system, the length is measured using the foot or its multiples—the yard and the mile—or its submultiple—the inch. Weight is measured in pounds, kilo-pounds, or ounces. Time is measured in hours, minutes or seconds. Although the United States was the first country to establish the decimal currency in 1785, it is one of the two (or three) countries where (the nondecimal) FPS system is still used.* Therefore, the FPS system, earlier known as the Imperial System of units, is now commonly known as the *U.S. System of Units* or *U.S. Customary Units*.

The system of units used by the rest of the world is the meter-kilogram-second (MKS) system. A rationalized and more commonly used version of the MKS system is called the SI system, popularly known as the International System of Units.

The advantage of the SI system (or the MKS system) lies primarily in that the multiples and submultiples of each unit (the secondary units) have a decimal relationship with each other, which makes computations easier and less susceptible to errors. For instance, the secondary units of length, the centimeter and the kilometer, are related to the base unit, the meter, by 10^{-2} and 10^{3}, respectively. By contrast, the length unit in the U.S. system, the foot, does not bear a decimal relationship with its secondary units, the inch, yard, and the mile.

Twelve prefixes have been standardized in the SI system for use with the base unit to make the secondary units. These prefixes, along with their symbols, are given in Table 1. Note that the prefixes are uppercase for magnitudes 10^{6} and greater and lowercase for magnitudes 10^{3} and lower.

The SI system uses seven base quantities—length, mass, time, temperature, electric current, luminous intensity, and amount of substance. The units corresponding to the base quantities and their symbols are listed in Table 2. Of these, only the first four quantities are of interest to design and construction professionals—length, mass, time, and temperature.

Quantities other than the base quantities, such as force, stress, pressure, velocity, acceleration, and energy, and their units are derived from a combination of two or more base quantities. For example, acceleration is the rate of change of velocity, which, in turn, is the rate of change of distance. Consequently, the units for acceleration are meters per second squared (m/s^2).

Another advantage of the SI system is that there is one and only one unit for each quantity—the meter for length, kilogram for mass, second for time, and so on. This is not so in the U.S. system, where multiple units are often used. For instance, power is measured in Btu per hour and also in horsepower.

RULES OF GRAMMAR IN THE SI SYSTEM

The symbols for units in the SI system are always lowercase unless the unit is named after a person, such as Newton, Pascal, Hertz, or Kelvin. In this case, the first letter of the symbol is in uppercase and the second letter in the lowercase, as in Pa. The exception is, however, made in the case of the liter, which is given the symbol L.

Multiples of base units are given with a single prefix. Double prefixes are not allowed. Thus, megakilometer (Mkm) is incorrect; instead, we use gigameter (Gm). No space is left between a prefix and symbol. Thus, we use km, and not k m.

TABLE 2 BASE QUANTITIES AND THEIR SYMBOLS IN THE SI SYSTEM

Quantity	Unit name	Symbol
Length	meter	m
Mass	kilogram	kg
Time	second	s
Temperature	kelvin	K
Electric current	ampere	A
Luminous intensity	candela	cd
Amount of substance	mole	mol

*Although not yet officially adopted, the SI system is being increasingly used (together with the U.S. System—in a dual-unit format) in several important U.S. publications that regulate building design and construction.

The product of two or more units in symbolic form is given by using a multiplication dot between individual symbols (example N · m). Mixing symbols and names of units is incorrect (example, N · meter).

A space must be left between the numerical value and the unit symbol. Thus, we use 300 m, not 300m. No space, however, is left between the degree symbol and C (Celsius). Plurals are not used in symbols. For instance, we use 1 m and 50 m. Periods are not used after symbols except at the end of a sentence.

In architectural and engineering drawings, dimensions are generally given in millimeters, and when that is done, the use of mm is avoided. For instance, the measurements of a floor tile are given as 300 × 300, and not as 300 mm × 300 mm. Larger dimensions may be given in meters, if necessary. For instance, a building may be dimensioned as 30.800 m × 50.600 m in plan (elevation or section), but it is preferable to dimension it as 30,800 × 50,600.

LENGTH, THICKNESS, AREA, AND VOLUME

In the U.S. system, the standard unit of length is the foot: 1 ft = 12 in. Long distances are measured in miles. In the SI system, the standard unit of length is the meter. Most dimensions in the SI system are given in millimeters (mm), where 1 mm = 10^{-3} m. Long distances are given in kilometers (km).

1 ft = 0.3048 m; 1 m = 3.281 ft = 39.37 in; 1 in. = 25.4 mm
1 mi = 1.609 km

FLUID CAPACITY

Fluid capacity is usually given in gallons in the U.S. system and in liters (L) in the SI system. The imperial gallon is slightly larger than the U.S. gallon, but the imperial gallon is no longer used as a unit.

1 gal (U.S.) = 4 qt = 3.7854 L
1 L = 0.001 m^3 (by definition) = 0.264 gal

MASS, FORCE, AND WEIGHT

In the U.S. system, the unit of weight (and mass) is the pound (lb); the corresponding unit of mass in the SI system is the kilogram (kg).

1 lb = 16 oz = 7,000 gr (grains) = 0.4536 kg
1 kg = 2.205 lb

Force is defined as mass times acceleration. Because the unit of acceleration in the U.S. system is feet/second^2 (ft/s^2), the unit of force is (lb-ft/s^2). This unit is called pound-force, usually referred to as the pound. In the SI system, the unit of force is (kg · m)/s^2. This complex unit is called the newton (N), after the famous physicist Isaac Newton (1642–1727).

Because the weight of an object is the force exerted on it by the gravitational pull of the earth, the weight of an object is equal to mass × acceleration due to gravity. The acceleration due to gravity on Earth's surface is 9.8 m/s^2. Therefore, the weight of an object whose mass is 1 kg is 9.8 (kg · m)/s^2, or 9.8 N.

We see that in the SI system, there is a clear distinction between the units of mass and the weight of an object. The distinction between the mass and the weight in the U.S. system is rather obscure because the pound is used as the unit for both the mass and the weight of an object.

1 kilogram-force = 9.8 N; 1 lb = 4.448 N; 1 N = 0.2248 lb
1 kilopound (kip) = 1,000 lb = 4.448 kN; 1 kN = 0.2248 kip

PRESSURE AND STRESS

Because pressure, or stress, is defined as force per unit area, the unit for pressure, or stress, in the U.S. system is lb/ft^2 (psf). Other units commonly used are pounds per square inch (psi) and

NOTE

Some countries that have not fully adopted the SI system use kilogram as the unit for mass as well as force (in the same way as pound is used as a unit for mass and weight). In these countries, the unit for stress is kilogram per square centimeter (kg/cm^2) instead of Pa. Weight density is expressed as kilograms per cubic centimeter (kg/cm^3) instead of N/m^3.

kilopounds per square inch (ksi). In the SI system, the unit of pressure, or stress, is N/m^2. This unit is called the pascal (Pa) after the physicist Blaise Pascal (1623–1662). Thus, 1 N/m^2 = 1 Pa.

1 psf = 47.880 Pa; 1 Pa = 0.208 85 psf
1 psi = 6.895 kPa; 1 kPa = 0.1450 psi

In weather-related topics, the unit of pressure is the atmosphere (atm); 1 atm is the standard atmospheric pressure at sea level.

1 atm = 760 mm of mercury (Hg) = 29.92 in. of Hg = 14.69 psi = 2,115.4 psf = 101.3 kPa. For all practical purposes, the atmospheric pressure may be taken as 2,100 psf or 101 kPa.

UNIT WEIGHT OF MATERIALS

Density is defined as the mass per unit volume. Its units are lb/ft^3 in the U.S. system and kg/m^3 in the SI system.

1 lb/ft^3 = 16.018 kg/m^3; 1 kg/m^3 = 0.064 243 lb/ft^3

In building construction, however, we are more interested in weight density of materials instead of the mass density. Weight density (or simply the unit weight) is defined as the weight per unit volume, and its units are lb/ft^3 and N/m^3 in the U.S. system and SI system, respectively.

1 lb/ft^3 = 157.1 N/m^3

TEMPERATURE AND ENERGY

In the U.S. system, temperature is measured in degrees Fahrenheit (°F). This scale was introduced during the early eighteenth century. Zero on the Fahrenheit scale was established based on the lowest obtainable temperature at the time, and 100°F, on the basis of human body temperature as it was then considered to be.

On the Celsius scale (°C), earlier known as the centigrade scale, the zero refers to the freezing point of water, and 100°C to the boiling point of water.

The unit of temperature in the SI system is the kelvin (K). The preference for Kelvin scale over the Celsius scale is due to the fact that on the Kelvin scale, the temperature is always positive. This is not so on the Celsius or the Fahrenheit scale, on which the temperature may be positive or negative. In other words, 0 K (as we know it now) is the lowest obtainable temperature and is, therefore, called *absolute zero*. The relationship between Kelvin and Celsius temperatures is T °C = (T + 273.15) K. In other words, 20°C = 293.15 K. Other relationships are

T °F = [(1.8)T + 32]°C; T °C = [(0.555 . . .)(T − 32)]°F.

The intervals in both the Kelvin and the Celsius scales are equal. Therefore, the Celsius and Kelvin scales start at different points, but their subdivisions are equal. Note that the word *degree* is not used on the Kelvin scale. (That is, we say 8 Kelvins, not 8 degrees Kelvin.) Although Kelvin is the appropriate scale to use in the SI system, degrees Celsius are also used because of the smaller numbers associated with the Celsius scale.

CONVERSION FROM THE U.S. SYSTEM TO THE SI SYSTEM

The conversion of a physical quantity such as length, weight, or stress from the U.S. system to the SI system simply involves using the appropriate conversion factor. A comprehensive list of conversion factors to convert from the U.S. system to the SI system is given in Table 3. However, when it comes to converting building products' sizes from the U.S. system to the SI system, three types of conversion are possible:

- *Exact Conversion:* This conversion is made simply by multiplying a value given in the U.S. system by the appropriate conversion factor to obtain the corresponding value in the SI system. For example, 12 in. is exactly equal to 304.8 mm.
- *Soft Conversion:* In this conversion, a product's size is not converted, only its description. For example, a manufacturer may decide to continue making 12 in. × 12 in. floor tiles but market them as 305 mm × 305 mm tiles. During the initial period of changes over to the SI system in the building industry, most product sizes will be soft-converted.

- *Hard Conversion:* In hard conversion, the physical size of the product is changed to a new metric equivalent. For example, 12 in. × 12 in. floor tiles will most probably be changed to 300 mm × 300 mm tiles. Hard conversion of a product requires a change in the manufacturing equipment and a great deal of coordination among various related products but has the advantage that the product sizes are rationalized.

TABLE 3 UNIT CONVERSION FACTORS

Quantity	To convert from	To	Multiply by
Length	mi	km	1.609 344*
	yd	m	0.9144*
	ft	m	0.304 8*
	ft	mm	304.8*
	in.	mm	25.4*
Area	mi^2	km^2	2.590 00*
	acre	m^2	4 046.87
	acre	ha**	0.404 687
	ft^2	m^2	0.092 903 04*
	$in.^2$	mm^2	645.16*
Volume	yd^3	m^3	0.764 555
	ft^3	m^3	0.028 3168
	100 board feet	m^3	0.235 974
	gal	L	3.785 41
	$in.^3$	cm^3	16.387 064
	$in.^3$	mm^3	16 387.064
Velocity	ft/s	m/s	0.3048
Rate of fluid flow, infiltration	ft^3/s	m^3/s	0.028 3168
	gal/h	mL/s	1.051 50
Acceleration	ft/s^2	m/s^2	0.3048
Mass	lb	kg	0.453 59
Mass per unit area	psf	kg/m^2	4.882 43
Mass density	pcf	kg/m^3	16.018 5
Force	lb	N	4.448 22
Force per unit length	plf	N/m	14.593 9
Pressure, stress	psf	Pa	47.880 26
	psi	kPa	6.894 76
	in. of mercury (in. Hg)	kPa	3.386 38
	in. of Hg (in. Hg)	psf	70.72
	atm***	kPa	101.325
Temperature	°F	°C	5/[9(°F − 32)]
	°F	K	(°F + 459.7)/1.8
Quantity of heat	Btu	J	1055.056
Power	ton (refrigeration)	kW	3.517
	Btu/h	W	0.293 07
	hp	W	745.7
	Btu/(h-ft^2)	W/m^2	3.154 59
Thermal conductivity	Btu-in/(ft^2-h-°F)	W/(m·°C)	0.144 2
Thermal conductance, or Thermal transmittance, U	Btu/(ft^2-h-°F)	W/(m^2·°C)	5.678 263
Thermal resistance	(ft^2-h-°F)/Btu	(m^2·°C)/W	0.176 110
Thermal capacity	Btu/(ft^2-°F)	kJ/(m^2·°C)	20.44
Specific heat	Btu/(lb-°F)	J/(kg·°C)	4.186 8
Vapor permeability	perm-in	ng/(Pa·m·s)	1.459 29
Vapor permeance	perm	ng/(Pa·m^2·s)	57.213 5
Angle	degree	radian	0.017 453

*Denotes exact conversion
**1 hectare (ha) = 100 m × 100 m
***1 atmosphere (atm) = 29.92 in. of mercury

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