METRIC GUIDE

FOR FEDERAL CONSTRUCTION

First Edition

The Construction Subcommittee
of the Metrication Operating Committee
of the
Interagency on Metric Policy

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ACKNOWLEDGEMENTS

The Construction Subcommittee of the Interagency Council on Metric Policy's Metrication Operating Committee has prepared this guide to aid the federal agencies in implementing the metric system of measurement in the federal construction process.

I would like to express my appreciation to Arnold Prima of the Office of the Secretary of Defense, who first voiced a need for the guide and initiated its development; to William Brenner of the National Institute of Building Sciences, who wrote it; to Claret Heider, its editor; and to reviewers William Aird of the State Department, Valerie Antoine and Louis Sokol of the U.S. Metric Association, Bruce Barrow of the Defense Information Systems Agency, Maria Grazi Bruschi of the American Society of Civil Engineers, Ronald Clevenger of the Tennessee Valley Authority, Amitabha Datta of the General Services Administration, Troy Estes of the National Aeronautics and Space Administration, Luther Flouton of the Public Health Service, James Gross of the National Institute of Standards and Technology, Leslie Hegyi, Stan Jakuba of S.I. Jakub Associates, H. Leslie Simmons, Lee Schmidt of the U.S. Air Force, Clark Tufts and Gerald Underwood of the American National Metric Council, and Anthony Welch of the Federal Highway Administration.

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Thomas R. Rutherford, PE
Chairman, Construction Subcommittee

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METRIC IS THE LAW

The Metric Conversion Act

The *Metric Conversion Act of 1975*, as amended by the *Omnibus Trade and Competitiveness Act of 1988*, establishes the modern metric system (System International or SI) as the preferred system of measurement in the United States. It requires that, to the extent feasible, the metric system be used in all federal procurement, grants, and business-related activities by September 30, 1992.

The Executive Order on Metric Usage

Executive Order 12770 (July 25, 1991), *Metric Usage in Federal Government Programs*, mandates that each federal agency:

- Make a transition to the use of metric units in government publications as they are revised on normal schedules or as new publications are developed.

- Work with other governmental, trade, professional, and private sector metric organizations on metric implementation.

- Formulate, approve, and implement a **Metric Transition Plan** by November 30, 1991, and provide it to the Secretary of Commerce.

The Metric Transition Plan is required to include:

The scope of the metric transition task and firm dates for all metric accomplishment milestones for 1991 and 1992,

Initiatives to enhance cooperation with industry as it voluntarily converts to the metric system, and

A schedule of activities to increase the understanding of the metric system through educational information and in publications.

- Designate a **Metric Executive** who is responsible for carrying out the Metric Transition Plan and preparing annual agency progress reports.

The Interagency Council on Metric Policy

To coordinate implementation of the *Metric Conversion Act* among the federal agencies, the Interagency Council on Metric Policy (ICMP) has been established under the Department of Commerce. The ICMP's working arm is the Metrication Operating Committee, which has 10 subcommittees, including one on construction.

The Construction Subcommittee

The task of the Construction Subcommittee is to facilitate the metrication of all federal construction, a $40 billion annual expenditure. During the summer of 1991, the Construction Subcommittee established a goal of *instituting the use of metric in the design of all new federal facilities by January 1994*.

To meet the requirements of the *Metric Conversion Act* and Executive Order 12770 and to help achieve this goal, the Construction Subcommittee has prepared this guide.

WHY METRIC?

Metric Is the International Standard

Developed at the time of the French Revolution, the metric system rapidly spread throughout Europe during the Napoleonic wars. It was promoted in the United States first by Thomas Jefferson and later by John Quincy Adams, but the federal government took no formal action on metric until 1866 when its use as a measurement system was legalized. In 1893, all standard U.S. measures were defined in terms of metric units. In 1902, Congressional legislation requiring the federal government to use metric exclusively was defeated by a single vote. Today, the United States is the last industrialized country to commit to metric.

The modern metric system was established by international agreement in 1960. It now is the standard international language of measurement and the system mandated by the *Metric Conversion Act* for use in the United States.

Metric Is Coherent

The modern metric system is coherent in that only one unit is used for each physical quantity and there are no conversion factors or constants to remember. The meter (and its decimal multiples), for example, is the single metric measure for length while its inch-pound system equivalents include the mil, the inch, the foot, the yard, the fathom, the rod, the chain, the furlong, and the mile, among others.

Metric's coherency, its simple base units, and its use of decimal arithmetic make it an especially logical and useful measurement system.

METRIC IN CONSTRUCTION

The Experience of Other Countries

There has been much speculation about the difficulty of converting to metric in the U.S. construction industry. The experience of the British, Australians, South Africans, and Canadians -- all of whom converted from the inch-pound system to metric in the past 20 years -- indicates otherwise:

- Metric conversion proved much less difficult than anticipated since most work is built in place.

- There was no appreciable increase in either design or construction costs, and conversion costs for most construction industry sectors were minimal or offset by later savings.

- The architecture/engineering community liked metric dimensioning since it was less prone to error and easier to use than feet and inches and since engineering calculations were faster and more accurate because there were no unit conversions and no fractions.

- Metric offered a one-time chance to reduce the many product sizes and shapes that have accumulated over the years but are no longer useful, thus saving production, inventory, and procurement costs.

- Architecture/engineering firms in these countries found that it took a week or less for staff members to learn to think and produce in metric, and most tradespeople took only a few hours to adapt.

Recent Developments in the United States

Several developments should make metric conversion in the United States construction industry easier:

- The use of computer-aided design and drafting systems continues to increase and almost all engineering and cost calculations now are performed on computers. Virtually all HVAC system controls are digitized. Computer-controlled manufacturing operations are now common. In each of these areas, the use of metric is greatly simplified.

- The codes and construction standards of two of the country's three model building code organizations (BOCA and SBCCI) and of NFPA and ASTM contain dual units (both inch-pound and metric) where measurements are specified. Many other standards-writing organizations have added metric measurements to their documents or are preparing to do so.

- The preliminary results of several recent General Services Administration metric pilot projects in the Philadelphia area indicate no increase in design or construction costs.

- American design and construction firms use metric routinely in foreign work with no reported problems.

- The costs of metric conversion in other U.S. industries have been far lower than expected, and the benefits greater. Total conversion costs were less than 1 percent of original estimates at General Motors, which now is fully metric. Rationalization of fastener sizes at IBM during metric conversion reduced fastener part numbers from 38,000 to 4,000. The liquor industry reduced its container sizes from 53 to 7 after converting to metric.

Thus, Americans are increasingly exposed to metric in daily life and now take for granted many metric products. Without fanfare, the United States is moving toward a metric society.

International Competitiveness

For those sectors of the U.S. construction industry that export goods or services, metrication is vital:

- In 1990, U.S. non-lumber construction product exports totaled about $2.8 billion and imports totaled about $4.2 billion.

- Foreign billings for American architecture/engineering/contracting firms amounted to $3.2 billion in 1989 with about a third of this from Europe.*

- The European Community, now the world's largest market, has specified that products with nonmetric labels will not be permitted for sale after 1992.

- The largest U.S. trading partners, Canada and Mexico, are now predominately metric countries.

- During the ongoing U.S.-Japanese Structural Impediments Initiative negotiations, the Japanese have identified nonmetric U.S. products as a specific barrier to the importation of U.S. goods.

Given this situation, some American manufacturers, such as Otis Elevator, are switching to metric to increase their international competitiveness and reduce their parts inventories. Others, such as the wood industry, have shipped exports in metric for many years.

Clearly, it is in the American construction industry's long-term interest to "go metric."

BASIC METRIC

Base Units

There are seven metric base units of measurement, six of which are used in design and construction. (The seventh, mole, is the amount of molecular substance and is used in physics.)

Quantity	Unit	Symbol
length	meter	m
mass*	kilogram	kg
time	second	s
electric current	ampere	A
temperature	kelvin	K
luminous intensity	candela	cd

* "Weight" in common practice often is used to mean "mass."

Celsius temperature (°C) is more commonly used than kelvin (K), but both have the same temperature gradients. Celsius temperature is simply 273.15 degrees warmer than kelvin, which begins at absolute zero. For instance, water freezes at 273.15 K and at 0 °C; it boils at 373.15 K and at 100 °C. To move between Celsius and kelvin, add or subtract 273.15.

Decimal Prefixes

Only two decimal prefixes are commonly used with the base units in design and construction:

Prefix	Symbol	Order of Magnitude	Expression
kilo	k	10^{3}	1000 (one thousand)
milli	m	10^{-3}	0.001 (one thousandth)

The prefixes mega (M) for one million (10^{6}), giga (G) for one billion (10^{9}), micro (m) for one millionth (10^{-6}), and nano (n) for one billionth (10^{-9}) are used in some engineering calculations.

Decimal prefixes to the tertiary power of 10 are preferred. The prefixes deci (d) for one tenth (10^{-1}), centi (c) for one hundredth (10^{-2}), deca (da) for ten (10^{1}), and hecto (h) for one hundred (10^{2}) have limited application in construction.

Plane and Solid Angles

The radian (rad) and steradian (sr) denote plane and solid angles. They are used in lighting work and in various engineering calculations. In surveying, the units degree (°), minute ('), and second (") continue in use.

Derived Units

Fifteen derived units with special names are used in engineering calculations:

Quantity	Name	Symbol	Expression
frequency	hertz	Hz	Hz = s^{-1}
force	newton	N	N = kg×m/s^2
pressure, stress	pascal	Pa	Pa = N/m^2
energy, work, quantity of heat	joule	J	J = N×m
power, radiant flux	watt	W	W = J/s
electric charge, quantity	coulomb	C	C = A×s
electric potential	volt	V	V = W/A or J/C
capacitance	farad	F	F = C/V
electric resistance	ohm	W	W = V/A
electric conductance	siemens	S	S = A/V or W^{-1}
magnetic flux	weber	Wb	Wb = V×s
magnetic flux density	tesla	T	T = Wb/m^2
inductance	henry	H	H = Wb/A
luminous flux	lumen	lm	lm = cd×sr
illuminance	lux	lx	lx = lm/m^2

Liter, Hectare, and Metric Ton

The liter (L) is the measurement for liquid volume. The hectare (ha) is a metric measurement used in surveying. The metric ton (t) is used to denote large loads such as those used in excavating.

Pronunciation

candela	Accent the second syllable, can-**dell**-ah.
hectare	Accent the first syllable: **heck**-tare. The second syllable rhymes with **care**.
joule	Rhymes with **pool**.
kilometer	Accent the first syllable: **kill**-o-meter.
pascal	Rhymes with **rascal**.
siemens	Sounds like **seamen's**.

Rules for Writing Metric Symbols and Names

- Print unit symbols in upright type and in lower case except for liter (L) or unless the unit name is derived from a proper name.

- Print unit names in lower case, even those derived from a proper name.

- Print decimal prefixes in lower case for magnitudes 10^3 and lower (that is, k, m, m, and n) and print the prefixes in upper case for magnitudes 10^6 and higher (that is, M and G).

- Leave a space between a numeral and a symbol (write 45 kg or 37 °C, not 45kg or 37°C or 37° C).

- Do not use a degree mark (°) with kelvin temperature (write K, not °K).

- Do not leave a space between a unit symbol and its decimal prefix (write kg, not k g).

- Do not use the plural of unit symbols (write 45 kg, not 45 kgs), but do use the plural of written unit names (several kilograms).

- For technical writing, use symbols in conjunction with numerals (the area is 10 m^2); write out unit names if numerals are not used (carpet is measured in square meters). Numerals may be combined with written unit names in nontechnical writing (10 meters).

- Indicate the product of two or more units in symbolic form by using a dot positioned above the line ($kg×m×s^{-2}$).

- Do not mix names and symbols (write N×m or newton meter, not N×meter or newton×m).

- Do not use a period after a symbol (write "12 g", not "12 g.") except when it occurs at the end of a sentence.

Rules for Writing Numbers

- Always use decimals, not fractions (write 0.75 g, not ¾g).

- Use a zero before the decimal marker for values less than one (write 0.45 g, not .45 g).

- Use spaces instead of commas to separate blocks of three digits for any number over four digits (write 45 138 kg or 0.004 46 kg or 4371 kg). Note that this does not apply to the expression of amounts of money.

- In the United States, the decimal marker is a period; in other countries a comma usually is used.

Conversion and Rounding

- When converting numbers from inch-pounds to metric, round the metric value to the same number of digits as there were in the inch-pound number (11 miles at 1.609 km/mi equals 17.699 km, which rounds to 18 km).

- Convert mixed inch-pound units (feet and inches, pounds and ounces) to the smaller inch-pound unit before converting to metric and rounding (10 feet, 3 inches = 123 inches; 123 inches x 25.4 mm = 3124.2 mm; round to 3124 mm).

- In a "soft" conversion, an inch-pound measurement is mathematically converted to its exact (or nearly exact) metric equivalent. With "hard" conversion, a new rounded, rationalized metric number is created that is convenient to work with and remember.

Visualizing Metric

A few basic comparisons are worth remembering to help visualize metric:

- One millimeter is about 1/25 inch or slightly less than the thickness of a dime.
- One meter is the length of a yardstick plus about 3-1/3 inches.
- One gram is about the mass (weight) of a large paper clip.
- One kilogram is about the mass (weight) of a softbound model building code book (2.2 pounds).
- One liter is about the volume of a 4 inch cube (100 mm x 100 mm x 100 mm). One liter of water has a mass of 1 kilogram.
- One inch is just a fraction (1/64 inch) longer than 25 mm (1 inch = 25.4 mm; 25 mm = 63/64 inch).
- Four inches are about 1/16 inch longer than 100 mm (4 inches = 101.6 mm; 100 mm = 3-15/16 inches).
- One foot is about 3/16 inch longer than 300 mm (12 inches = 304.8 mm; 300 mm = 11-13/16 inches).
- Four feet are about 3/4 inch longer than 1200 mm (4 feet = 1219.2 mm; 1200 mm = 3 feet, 11¼ inches).

The metric equivalent of a typical 2-foot by 4-foot ceiling grid is 600 x 1200 mm, so metric ceiling tiles and lighting fixtures are about 3/8 inch smaller in one dimension and 3/4 inch smaller in the other.

- Similarly, the metric equivalent of a 4 by 8 sheet of plywood or drywall is 1200 x 2400 mm, so metric sheets are about 3/4 inch narrower and 1-1/2 inches shorter.

- "Rounding down" from multiples of 4 inches to multiples of 100 mm makes dimensions exactly 1.6 percent smaller and areas about 3.2 percent smaller. About 3/16 inch is lost in every linear foot.

References

The metric units in this guide are those adopted by the U.S. government (see the *Federal Register* of December 20, 1990; Federal Standard 376A, *Preferred Metric Units for Use by the Federal Government*; and PB 89-226922, *Metric Handbook for Federal Officials*). They are identical to the units in the following publications, which constitute the standard reference works on metric in the United States:

- ASTM E 621, *Standard Practice for Use of Metric (SI) Units in Design and Construction*,
- ANSI/IEEE 268, *American National Standard Metric Practice*, and
- ASTM E 380, *Standard Practice for the Use of the International System of Units (SI)*.

For editorial matters, also refer to:

- American National Metric Council, *Metric Editorial Guide* and
- U.S. Metric Association, *Metric Units of Measure and Style Guide*.

See the "Metric References" section of this guide for ordering information.

LENGTH, AREA, AND VOLUME

One metric unit is used to measure length, area, and volume in most design and construction work:

- meter (m).

Rules for Linear Measurement (Length)

- Use only the meter and millimeter in building design and construction.
- Use the kilometer for long distances and the micrometer for precision measurements.
- Avoid use of the centimeter.
- For survey measurement, use the meter and the kilometer.

Rules for Area

- The square meter is preferred.
- Very large areas may be expressed in square kilometers and very small areas, in square millimeters.
- Use the hectare (10 000 square meters) for land and water measurement only.
- Avoid use of the square centimeter.
- Linear dimensions such as 40 x 90 mm may be used; if so, indicate width first and height second.

Rules for Volume and Fluid Capacity

- Cubic meter is preferred for volumes in construction and for large storage tanks.
- Use liter (L) and milliliter (mL) for fluid capacity (liquid volume). One liter is 1/1000 of a cubic meter or 1000 cubic centimeters.
- Since a cubic meter equals one billion cubic millimeters, the cubic decimeter and cubic centimeter may be used in limited applications, since they are multiples of 1000 in volume measurement.

Area, Length, and Volume Conversion Factors

Quantity	From Inch-Pound Units	To Metric Units	Multiply by
Length	mile	km	1.609 344
	yard	m	0.914 4
	foot	m	0.304 8
		mm	304.8
	inch	mm	25.4
Area	square mile	km^2	2.590 00
	acre	m^2	4 046.856
		ha (10 000 m^2)	0.404 685 6
	square yard	m^2	0.836 127 36
	square foot	m^2	0.092 903 04
	square inch	mm^2	645.16
Volume	acre foot	m^3	1 233.49
	cubic yard	m^3	0.764 555
	cubic foot	m^3	0.028 316 8
	cubic foot	cm^3	28 316.85
	cubic foot	L (1000 cm^3)	28.316 85
	100 board feet	m^3	0.235 974
	gallon	L (1000 cm^3)	3.785 41
	cubic inch	cm^3	16.387 064
	cubic inch	mm^3	16 387.064

NOTE: Underline denotes exact number.

CIVIL AND STRUCTURAL ENGINEERING

The metric units used in civil and structural engineering are:

- meter (m)
- kilogram (kg)
- second (s)
- newton (N)
- pascal (Pa)

Rules for Civil and Structural Engineering

- There are separate units for mass and force.

- The kilogram (kg) is the base unit for mass, which is the unit quantity of matter independent of gravity.

- The newton (N) is the derived unit for force (mass times acceleration, or $kg \times m/s^2$). It replaces the unit "kilogram-force" (kgf), which should not be used.

- Do not use the joule to designate torque, which is always designated newton meter ($N \times m$).

- The pascal (Pa) is the unit for pressure and stress ($Pa = N/m^2$). The term "bar" is not a metric unit and should not be used.

- Structural calculations should be shown in MPa or kPa.

- Plane angles in surveying (cartography) will continue to be measured in degrees (either decimal degrees or degrees, minutes, and seconds) rather than the metric radian.

- Slope is expressed in nondimensional ratios. The vertical component is shown first and then the horizontal. For instance, a rise of one meter in four meters is expressed as 1:4. The units that are compared should be the same (meters to meters, millimeters to millimeters).

- For slopes less than 45°, the vertical component should be unitary (for example, 1:20). For slopes over 45°, the horizontal component should be unitary (for example, 5:1).

Civil and Structural Engineering Conversion Factors

Quantity	From Inch-Pound Units	To Metric Units	Multiply by
Mass	lb kip (1000 lb)	kg metric ton (1000 kg)	0.453 592 0.453 592
Mass/unit length	plf	kg/m	1.488 16
Mass/unit area	psf	kg/m^2	4.882 43
Mass density	pcf	kg/m^3	16.018 5
Force	lb kip	N kN	4.448 22 4.448 22
Force/unit length	plf klf	N/m kN/m	14.593 9 14.593 9
Pressure, stress, modulus of elasticity	psf ksf psi ksi	Pa kPa kPa MPa	47.880 3 47.880 3 6.894 76 6.894 76
Bending moment, torque, moment of force	ft-lb ft-kip	N×m kN×m	1.355 82 1.355 82
Moment of mass	lb×ft	kg×m	0.138 255
Moment of inertia	$lb \times ft^2$	$kg \times m^2$	0.042 140 1
Second moment of area	in^4	mm^4	416 231
Section modulus	in^3	mm^3	<u>16 387.064</u>

NOTE: Underline denotes exact number.

MECHANICAL ENGINEERING

The metric units used in mechanical engineering are:

- meter (m)
- kilogram (kg)
- second (s)
- joule (J)
- watt (W)
- kelvin (K) or degree Celsius (°C)
- pascal (Pa)
- radian (rad).
- newton (N)

Rules for Mechanical Engineering

- The joule (J) is the unit for energy, work, and quantity of heat. It is equal to a newton meter (N×m) and a watt second (W×s) and replaces a large number of inch-pound units.

- The watt (W) is both the inch-pound and metric unit for power and heat flow. It replaces horsepower, foot pound-force per hour, Btu per hour, calorie per minute, and ton of refrigeration.

- Moisture movement is expressed by the terms "vapor permeance" and "vapor permeability."

- The inch-pound unit "perm" continues to represent the degree of retardation of moisture movement. The lower the value, the greater the retardation.

- The newton (N) is the derived unit for force (mass times acceleration, or $kg \times m/s^2$). It replaces the unit "kilogram-force" (kgf), which should not be used.

Mechanical Engineering Conversion Factors

Quantity	From Inch-Pound Units	To Metric Units	Multiply by
Mass/area (density)	lb/ft^2	kg/m^2	4.882 428
Temperature	°F	K	5/9(°F -32) + 273.15
Energy, work, quantity of heat	kWh Btu ft×lbf	MJ J J	3.6 1 055.056 1.355 82
Power	ton (refrig) Btu/s hp (electric) Btu/h	kW kW W W	3.517 1.055 056 745.700 0.293 071
Heat flux	Btu/(f^2×h)	W/m^2	3.152 481
Rate of heat flow	Btu/s Btu/h	kW W	1.055 056 0.293 071 1
Thermal conductivity (k value)	Btu/(ft^2×h×°F)	W/(m×K)	1.730 73
Thermal conductance (U value)	Btu/(ft^2×h×°F)	W/(m^2×K)	5.678 263
Thermal resistance (R value)	ft^2×h×°F/Btu	m^2×K/W	0.176 110
Heat capacity, entropy	Btu/°F	kJ/K	1.899 1
Specific heat capacity, specific entropy	Btu/(lb×°F)	kJ/(kg×K)	4.186 8
Specific energy, latent heat	Btu/lb	kJ/kg	2.326
Vapor permeance	perm (23 °C)	ng/(Pa×s×m^2)	57.452 5
Vapor permeability	perm/in	ng/(Pa×s×m)	1.459 29
Volume rate of flow	ft^3/s cfm cfm	m^3/s m^3/s L/s	0.028 316 8 0.000 471 947 4 0.471 947 4
Velocity, speed	ft/s	m/s	0.3048
Acceleration	f/s^2	m/s^2	0.3048
Momentum	lb×ft/sec	kg×m/s	0.138 255 0
Angular momentum	lb×ft^2/s	kg×m^2/s	0.042 140 11
Plane angle	degree	rad mrad	0.017 453 3 17.453 3
NOTE: Underline denotes exact number.			

ELECTRICAL ENGINEERING

The metric units used in electrical engineering are:

- meter (m)
- second (s)
- candela (cd)
- radian (rad)
- steradian (sr)
- ampere (A)
- coulomb (C)
- volt (V)
- farad (F)
- henry (H)
- ohm (W)
- siemens (S)
- watt (W)
- hertz (Hz)
- weber (Wb)
- tesla (T)
- lumen (lm)
- lux (lx)

Rules for Electrical Engineering

- There are no unit changes for electrical engineering except for the renaming of conductance from "mho" to siemens (S).

- The candela (cd) is the unit for luminous intensity and is already in common use; it replaces candle and candlepower.

- The lux (lx) is the unit for illuminance and replaces lumen per square foot and footcandle.

- Luminance is expressed in candela per square meter (cd/m^2) and replaces candela per square foot, footlambert, and lambert.

Electrical Engineering Conversion Factors

Quantity	From Inch-Pound Units	To Metric Units	Multiply by
Power, radiant flux	W	W	1 (same unit)
Radiant intensity	W/sr	W/sr	1 (same units)
Radiance	$W/(sr \times m^2)$	$W/(sr \times m^2)$	1 (same units)
Irradiance	W/m^2	W/m^2	1 (same units)
Frequency	Hz	Hz	1 (same value)
Electric current	A	A	1 (same unit)
Electric charge	A×hr	C	3600
Electric potential	V	V	1 (same unit)
Capacitance	F	F	1 (same unit)
Inductance	H	H	1 (same unit)
Resistance	W	W	1 (same unit)
Conductance	mho	S	100
Magnetic flux	maxwell	Wb	10^{-8}
Magnetic flux density	gamma	T	10^{-9}
Luminous intensity	cd	cd	1 (same unit)
Luminance	lambert cd/ft^2 footlambert	kcd/m^2 cd/m^2 cd/m^2	3.183 01 10.763 9 3.426 26
Luminous flux	lm	lm	1 (same unit)
Illuminance	footcandle	lx	10.763 9
NOTE: Underline denotes exact number.			

CONSTRUCTION TRADES

The metric units used in the construction trades are as follows. The term "length" includes *all* linear measurements (that is, length, width, height, thickness, diameter, and circumference).

	Quantity	Unit	Symbol
Surveying	length	kilometer, meter	km, m
	area	square kilometer hectare (10 000 m^2) square meter	km^2 ha m^2
	plane angle	degree (non-metric) minute (non-metric) second (non-metric)	° ' "
Excavating	length	meter, millimeter	m, mm
	volume	cubic meter	m^3
Trucking	distance	kilometer	km
	volume	cubic meter	m^3
	mass	metric ton (1000 kg)	t
Paving	length	meter, millimeter	m, mm
	area	square meter	m^2
Concrete	length	meter, millimeter	m, mm
	area	square meter	m^2
	volume	cubic meter	m^3
	temperature	degree Celsius	°C
	water capacity	liter (1000 cm^3)	L
	mass (weight)	kilogram, gram	kg, g
	cross-sectional area	square millimeter	mm^2
Masonry	length	meter, millimeter	m, mm
	area	square meter	m^2
	mortar volume	cubic meter	m^3
Steel	length	meter, millimeter	m, mm
	mass	metric ton (1000 kg) kilogram, gram	t kg, g
Carpentry	length	meter, millimeter	m, mm

	Quantity	Unit	Symbol
Plastering	length	meter, millimeter	m, mm
	area	square meter	m^2
	water capacity	liter (1000 cm^3)	L
Glazing	length	meter, millimeter	m, mm
	area	square meter	m^2
Painting	length	meter, millimeter	m, mm
	area	square meter	m^2
	capacity	liter (1000 cm^3) milliliter (cm^3)	L mL
Roofing	length	meter, millimeter	m, mm
	area	square meter	m^2
	slope	millimeter/meter	mm/m
Plumbing	length	meter, millimeter	m, mm
	mass	kilogram, gram	kg, g
	capacity	liter (1000 cm^3)	L
	pressure	kilopascal	kPa
Drainage	length	meter, millimeter	m, mm
	area	hectare (10 000 m^2) square meter	ha m^2
	volume	cubic meter	m^3
	slope	millimeter/meter	mm/m
HVAC	length	meter, millimeter	m, mm
	volume	cubic meter	m^3
	capacity	liter (1000 cm^3)	L
	airflow	meter/second	m/s
	volume flow	cubic meter/second liter/second	m^3/s L/s
	temperature	degree Celsius	°C
	force	newton, kilonewton	N, kN
	pressure	kilopascal	kPa
	energy, work	kilojoule, megajoule	kJ, MJ
	rate of heat flow	watt, kilowatt	W, kW
Electrical	length	meter, millimeter	m, mm

	Quantity	Unit	Symbol
	frequency	hertz	Hz
	power	watt, kilowatt	W, kW
	energy	megajoule kilowatt hour	MJ kWh
	electric current	ampere	A
	electric potential	volt, kilovolt	V, kV
	resistance	ohm	W

DRAWINGS

Drawing Scales

- Metric drawing scales are expressed in nondimensional ratios.
- Nine scales are preferred: 1:1 (full size), 1:5, 1:10, 1:20, 1:50, 1:100, 1:200, 1:500, and 1:1000. Three others have limited usage: 1:2, 1:25, and 1:250.

Comparison Between Inch-Foot and Metric Scales

Inch-Foot Scales	Ratios	Metric Scales		Remarks
		Preferred	Other	
Full size	1:1	1:1		No change
Half full size	1:2		1:2	No change
4" = 1'-0" 3" = 1'-0"	1:3 1:4	1:5		Close to 3" scale
2" = 1'-0" 1-1/2" = 1'-0" 1" = 1'-0"	1:6 1:8 1:12	1:10		Between 1" and 1-1/2" scales
3/4" = 1'-0" 1/2" = 1'-0"	1:16 1:24	1:20	1:25	Between 1/2" and 3/4" scales Very close to 1/2" scale
3/8" = 1'-0" 1/4" = 1'-0" 1" = 5'-0" 3/16" = 1'-0"	1:32 1:48 1:60 1:64	1:50		Close to 1/4" scale
1/8" = 1'-0" 1" = 10'-0" 3/32" = 1'-0"	1:96 1:120 1:128	1:100		Very close to 1/8" scale
1/16" = 1'-0"	1:192	1:200		Close to 1/16" scale
1" = 20'-0"	1:240		1:250	Close to 1" = 20'-0"
1" = 30'-0" 1/32" = 1'-0" 1" = 40'-0"	1:360 1:384 1:480	1:500		Close to 1" = 40'-0" scale

Inch-Foot Scales	Ratios	Metric Scales		Remarks
		Preferred	Other	
1" = 50'-0" 1" = 60'-0" 1" = 1 chain 1" = 80'-0"	1:600 1:720 1:792 1:960	1:1000		

Metric Units Used on Drawings

- Use only one unit of measure on a drawing. Except for large scale site or cartographic drawings, the unit should be the millimeter (mm).

- Delete unit symbols but provide an explanatory note ("All dimensions are shown in millimeters" or "All dimensions are shown in meters").
- Whole numbers always indicate millimeters; decimal numbers taken to three places always indicate meters.

- Where modules are used, the recommended basic module is 100 mm, which is similar to the 4-inch module used in building construction (4 inches = 101.6 mm).

Drawing Sizes

- The ISO "A" series drawing sizes are preferred metric sizes for design drawings.

- There are five "A" series sizes:

```
A0       1189 x 841 mm  (46.8 x 33.1 inches)
A1       841 x 594 mm  (33.1 x 23.4 inches)
A2       594 x 420 mm  (23.4 x 16.5 inches)
A3       420 x 297 mm  (16.5 x 11.7 inches)
A4       297 x 210 mm  (11.7 x 8.3 inches)
```

- AO is the base drawing size with an area of one square meter. Smaller sizes are obtained by halving the long dimension of the previous size. All AO sizes have a height to width ratio of one to the square root of 2.

- Of course, metric drawings may be made on any size paper.

SPECIFICATIONS AND PUBLICATIONS

Specifications

All measurements in construction specifications should be stated in metric. Until existing specification systems are fully converted, the specifier may:

- Specify metric products. Check to see if the products to be specified are available in metric sizes.

- Refer to metric or dual unit codes and standards. ASHRAE, ASME, and ACI, among others, publish metric editions of some standards. Two of the country's three model code groups (BOCA and SBCCI) as well as ASTM and NFPA publish their documents with dual units (both metric and inch-pound measurements). In addition, most handicapped accessibility standards and a number of product standards are published with dual units. The metric measurements are virtually exact, "soft" numerical conversions that, over time, will be changed through the consensus process into rationalized, rounded "hard" metric dimensions. For now, use the "soft" metric equivalents.

See the "Metric References" section of this guide for sources of metric and dual unit codes and standards.

- Convert existing unit measurements to metric. Follow the conversion rules below.

Standards, Criteria, and Product Information

For organizations that publish construction standards, criteria, or product information:

- Review all active documents and develop a realistic conversion schedule.

- For most documents, the conversion to metric will be editorial; however, for complex documents, a parallel document or a metric appendix may have to be created and maintained for some time. For very simple documents with only a few measurements, footnotes may be sufficient.

- Follow the conversion rules below.

Conversion Rules

- Use ASTM E621, *Standard Practice for the Use of Metric (SI) Units in Building Design and Construction*, as a basic reference.

- Follow the rules for usage, conversion, and rounding in ASTM E380, *Standard Practice for Use of the International System of Units (SI)*, Sections 3 and 4, or ANSI/IEEE 268, *American National Standard Metric Practice*, Sections 3.5 and 4.

- Wherever possible, convert measurements to rounded, rationalized "hard" metric numbers. For instance, if anchor bolts are to be imbedded to a depth of 10 inches, the exact converted length of 254 mm might be rounded to either 250 mm (9.84 inches) or 260 mm (10.24 inches). The less critical the number, the "rounder" it can be, but ensure that allowable tolerances or safety factors are not exceeded. When in doubt, stick with the exact "soft" conversion.

- Round to "preferred" metric numbers. While the preferred numbers for the "1 foot = 12 inches" system are, in order of preference, those divisible by 12, 6, 4, 3, 2 and 1, preferred metric numbers are, in order of preference, those divisible by 10, 5, 2 and 1 or decimal multiples thereof. NBS Technical Note 990, *The Selection of Preferred Metric Values for Design and Construction*, explains the concept of preferred numbers in detail and states in its foreword:

> It is widely recognized that a transfer to a metric technical environment based upon a "soft conversion,"--that is, no change other than the description of the physical quantities and measurements in metric units--would cause considerable longer term problems and disadvantages due to the encumbrance of the resulting awkward numbers. The overall costs of soft conversion could greatly outweigh any savings due to its short term expediency.
>
> [Technical Note 990] provides a rational basis for the evaluation and selection of preferred numerical values associated with metric quantities. Precedent has shown that the change to metric units can be accompanied by a change to preferred values at little or no extra cost, especially in specifications, codes, standards, and other technical data.

- Use hand calculators or software conversion programs that convert inch-pounds to metric. They are readily available and are indispensable to the conversion process. Simply check with any store or catalogue source that sells calculators or software.

- Be careful with the decimal marker when converting areas and volumes; metric numbers can be significantly larger than inch-pound numbers (a cubic meter, for instance, is one billion cubic millimeters).

MANAGEMENT AND TRAINING

The American National Metric Council and the U.S. Metric Association recommend the following management and training measures:

- Top level commitment. Top level management must provide a firm commitment to metric. This includes:

Announcing a formal metric policy,

Forming a metric committee, and

Appointing a metric coordinator to chair the committee and act as the organization's metric representative.

- Metrication schedule. Develop an organization-wide metrication schedule with milestones and a completion date.

- Metric organizations. Consider joining the American National Metric Council and the U.S. Metric Association.

- Metric publications. Begin a metric reference library. See the Metric References section of this guide.

- Training objectives. Write carefully worded, measurable training objectives with the goal of "enabling employees to perform their jobs with the same or greater degree of efficiency using metric."

- Define the learner population. Determine who needs to know metric and to what extent they need to know it. Some employees may require an in-depth working knowledge of metric whereas others may never need to know it at all. Most probably will need to know only a few metric units.

- Determine training needs. There are three kinds or levels of training:

Metric awareness training to help all employees overcome fear and resistance to change,

Management training to educate the people responsible for the transition to metric, and

Implementation training to teach specific metric skills to specific employees.

- Timing. Training should take place just prior to when an employee will use the new knowledge on the job; earlier training is ineffective.

- Train only as needed. Train only as necessary to meet the goal of "enabling employees to perform their jobs with the same or greater degree of efficiency using metric." Training is not a panacea, and massive training programs are wasteful. Often, training can be performed completely on-the-job.

- Train people to "think" metric. Link metric measurements to familiar objects. Avoid comparisons to inch-pounds as much as possible.

- Monitor the metrication program. Make sure training matches the organization's metric transition schedule. If something changes, adjust either the training or the schedule.

- Don't hide costs. There is a cost to metric conversion, both in time and money. Plan for it in advance, and monitor costs as transition takes place.

METRIC REFERENCES

American Concrete Institute (P.O. Box 19150, Detroit, MI 48219; phone 313-532-2600):

- ACI 318M-89/318RM-89, *Building Code Requirements for Reinforced Concrete and Commentary*. Metric edition of ACI 318-89/318R-89. $78.50.

- ACI 318.1M-89/318.1RM-89, *Building Code Requirements for Metric Structural Plain Concrete and Commentary*. Metric edition of ACI 318.1-89/318.1R-89. 14 pp. $14.95.

American Congress on Surveying and Mapping (5410 Grosvenor Lane, Suite 100, Bethesda, MD 20814; phone 301-493-0200):

- *Metric Practice Guide for Surveying and Mapping*. 11 pp. 1978. $10.00.

American Institute of Steel Construction (Metric Publications, One East Wacker Drive, Suite 3100, Chicago, IL 60601-2001; phone 312-670-5414):

- *Metric Properties of Structural Shapes with Dimensions According to ASTM A6M* (metric version of Part I of the *Manual of Steel Construction*). 92 pp.

- *Metric Conversion: Load and Resistance Factor Design Specification for Structural Steel Buildings*. 159 pp.

American National Metric Council (Washington, D.C.; phone 410-727-0882):

- *ANMC Metric Editorial Guide*. Fourth edition. 16 pp. $5.00.

- *SI Metric Training Guide*. 17 pp. $5.00.

- *Metrication and the Consumer*. $5.00.

- *Metrication for the Managers*. $15.00.

American National Standards Institute, Inc. (11 West 42nd St., New York, NY 10036; phone 212-642-4900):

- ANSI/IEEE 268, *American National Standard Metric Practice*. 48 pp. 1982. $52.50.

- ANSI/AWS A1.1, *Metric Practice Guide for the Welding Industry*. 1989. $20.00.

- ANSI/IEEE 945, *Preferred Metric Units for Use in Electrical and Electronics Science and Technology*. 1984. $45.00.

- ISO 1000, *SI Units and Recommendations for the Use of Their Multiples and Certain Other Units*. 1981. $48.00.

American Society for Testing and Materials (1916 Race St., Philadelphia, PA 19103; phone 215-299-5585):

- ASTM E380, *Standard Practice for Use of the International System of Units (SI)*. 35 pp. 1992. $23.00.

- ASTM E621, *Standard Practice for the Use of Metric (SI) Units in Building Design and Construction*. 37 pp. 1984. $23.00.

- ASTM E713, *Guide for Selection of Scales for Metric Building Drawings*. 3 pp. $15.00.

- ASTM E577, *Guide for Dimensional Coordination of Rectilinear Building Parts and Systems*. $15.00.

- ASTM E835, *Guide for Dimensional Coordination of Structural Clay Units, Concrete Masonry Units, and Clay Flue Linings*. $15.00

- All other ASTM standards are published in metric or with dual units.

American Society of Heating, Refrigerating, and Air-Conditioning Engineers (1791 Tullie Circle, N.E., Atlanta, GA 30329; phone 404-636-8400):

- *SI for HVAC&R*. 1986. 11 pp. Free on request.
- *Psychrometric Charts SI*. Charts 1 through 7. $10.00.
- *1991 Handbook -- HVAC Applications*. SI edition. $114.00.
- *1989 Handbook -- Fundamentals*. SI edition. $114.00.
- *1990 Refrigeration Handbook*. SI edition. $114.00.
- *1992 Handbook -- HVAC Systems and Equipment*. SI edition. $114.00.

American Society of Mechanical Engineers (22 Law Dr., Box 2300, Fairfield, NJ 07007; phone 1-800-834-2763 ext. 426):

- SI-1, *Orientation and Guide for Use of SI (Metric) Units*. 1982. $12.00.
- SI-2, *SI Units in Strength of Materials*. 14 pp. 1976. $12.00.
- SI-3, *SI Units in Dynamics*. 20 pp. 1976. $12.00.
- SI-4, *SI Units in Thermodynamics*. J. W. Murdock and L.T. Smith, eds. 55 pp. 1976. $12.00.
- SI-5, *SI Units in Fluid Mechanics*. J. W. Murdock and L.T. Smith, eds. 36 pp. 1976. $12.00.
- SI-6, *SI Units in Kinematics*. 14 pp. 1976. $12.00.
- SI-7, *SI Units in Heat Transfer*. J. W. Murdock, ed. 36 pp. 1977. $12.00.
- SI-8, *SI Units in Vibration*. 13 pp. 1976. $12.00.
- SI-9, *Guide for Metrication of Codes and Standards Using SI (Metric) Units*. 33 pp. 1980. $13.00.
- SI-10, *Steam Charts, SI (Metric) and U.S. Customary Units*. J.H. Potter, ed. 128 pp. 1976. $28.00.
- *ASME Steam Tables in SI (Metric) Units for Instructional Use*. 19 pp. 1977. No charge.
- All other ASME standards, except the *Boiler and Pressure Vessel Code*, are published either in separate SI editions or with dual units.

BSP Professional Books, Oxford, U.K. (available through the AIA Bookstore, 1735 New York Ave., Washington, D.C. 20006; phone 202-626-7475):

- *Neufert Architect's Data*. Ernst Neufert, author. 2d International (metric) Edition. 433 pp. 1980. $52.50.

Building Officials and Code Administrators International (4051 W. Flossmoor Rd., Country Club Hills, IL 60477-5795; phone 312-799-2300):

- *BOCA National Building, Fire, Mechanical, and Plumbing Codes*. All recent editions are published with dual units.

Canadian Standards Organization (178 Rexdale Blvd., Rexdale, Ontario M9W 1R3; phone 416-747-4044):

- CAN/CSA-Z234.2, *Canadian Metric Practice Guide*. 82 pp. 1989. $28.00 Canadian.

- CSA Special Publication Z372, *Metric Editorial Handbook*. 46 pp. 1980. $15.00 Canadian.

- CSA Special Publication Z351, *Glossary of Metric Units*. 57 pp. 1980. $13.00 Canadian.

R. S. Means Company (Box 800, Kingston, MA 02364; phone 617-585-7880):

- *Means Building Construction Cost Data*, Metric Edition.

National Fire Protection Association (1 Batterymarch Park, P.O. Box 9101, Quincy, MA 02269-9101; phone 1-800-334-3555):

- NFPA 101, *Life Safety Code*. Includes dual units. 1991. 327 pp. $33.75.

- NFPA 13, *Installation of Sprinkler Systems*. Includes dual units. 1991. 130 pp. $24.50.

- ANSI/NFPA 70, *National Electrical Code*. Includes dual units. 1993. 775 pp. $32.50.

- All other NFPA standards are published with dual units.

Southern Building Code Congress International, Inc. (900 Montclair Road, Birmingham, AL 35213-1206):

- *Standard Building Code*. The 1991 edition is published with dual units.

Underwriters Laboratories, Inc. (333 Pfingston Road, Northbrook, IL 60062; phone 708-272-8800):

- Virtually all UL standards contain dual units.

U.S. Government Printing Office (Superintendent of Documents, U.S. Government Printing Office, Washington, D.C. 20402; phone 202-783-3238):

- NIST Special Publication 330, 1991 Edition, *The International System of Units (SI)*. 56 pp. August, 1991. $3.50.

- NIST Special Publication 811, *Guide for the Use of the International System of Units*. Arthur O. McCoubrey, author. 34 pp. September, 1991. $2.50.

- "Metric Conversion Policy for Federal Agencies; Rule." 15 CFR Part 19, Subpart B. *Federal Register*, January 2, 1991.

- "Metric System of Measurement: Interpretation of the International System of Units for the United States; Notice. *Federal Register*, December 20, 1990.

U.S. Metric Association (10245 Andasol Avenue, Northridge, CA 91325; phone 818-363-5606):

- *Style Guide to the Use of the Metric System*. $3.00.

- *Freeman Training/Education Metric Materials List*. 1991. $38.00.

- *SI Metric Style Guide for Written and Computer Usage*. $2.00

- *Metric Vendor List*. $28.00.

Water Environment Federation (601 Wythe St., Alexandria, VA 22314; phone 703-684-2400):

- MO6, *Units of Expression for Wastewater Treatment Management*. 47 pp. $15.00.

John Wiley and Sons (Professional Reference and Trade Group, 605 Third Avenue, New York, NY 10158; phone 1-800-225-5945, ext. 2497):

- *The Architect's Studio Companion: Technical Guidelines for Preliminary Design*. Edward Allen and Joseph Iano, authors. Includes dual units. 468 pp. 1989. $52.95.

- *Wiley Engineer's Desk Reference*. S.I. Heisler, author. Includes dual units. 566 pp. 1984. $54.95.

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