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ABSTRACT

This report includes a discussion of SI metric units, with examples of the conventions regarding their use adopted in other countries to illustrate the nature of the decisions that must be made by the U.S. building industry. It discusses the relationship of dimensional coordination to the metric conversion effort and its impact on the U.S. building regulatory system. Some of the organizational problems required to involve all segments of the industry in this decision-making process and to implement these decisions in a coordinated way on a national scale are also discussed. (Author/MN)

DEPARTMENT OF COMMERCE · NATIONAL BUREAU OF STANDARDS

NBS TECHNICAL NOTE 915

U.S. DEPARTMENT OF COMMERCE / National Bureau of Standards

Metrication Problems in the Construction Codes and Standards Sector

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[1] Headquarters and Laboratories at Gaithersburg, Maryland, unless otherwise noted; mailing address Washington, D.C. 20234.
[2] Located at Boulder, Colorado 80302.

Metrication Problems in the Construction Codes and Standards Sector

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PREFACE

This report was prepared in response to a request made of the Center for Building Technology in the National Bureau of Standards. This request grew out of the initial meeting of the Construction Codes and Standards Sector of the American National Metric Council. The Sector chairman, Mr. Delmont Thurber, asked for an identification of the problems attending metrication that will probably confront many building codes and standards institutions in the United States.

It was reasoned that a discussion of these problems should begin with a brief description of the new metric units of measurement involved, called SI for Systéme International. Consequently, Part I of this report deals with the SI base units, some of the units derived from them for use in the building industry and, as examples, some of the usage conventions adopted by the British who are changing from the inch-pound system to SI. Since final U.S. decisions in these matters have not yet been made, the SI units and use conventions presented in Part I are offered only as illustrations of the kinds of selection problems to be faced, not as recommendations.

In the building industry it is hard to say more than a few words about metrication without mentioning modular or dimensional coordination. Dimensional coordination has fascinated members of the industry for years, both here and abroad. Proponents say metrication offers an excellent opportunity for the adoption of a national commitment to dimensional coordination as a way for the building industry to "get something out of going metric." This subject is discussed in Part II.

Part III attempts to display some of the many difficult problems requiring cooperative planning and coordination in the codes and standards sector during the metrication/dimensional coördination transition.

Almost everyone involved in the U.S. building codes and standards area has, at one time or another, envisioned ways of effecting desirable improvements in codes and standards activities. In many instances these ideas were never carried out because they often required major or radical departures from traditional practices, involving a national, voluntary and cooperative commitment from a highly competitive, fragmented industry. Since metrication will set the stage for just that kind of nationwide radical change, the "problems" discussed in this report suggest opportunity after opportunity for the building community to cooperatively select and implement many of the most desirable of these improved practices.

At one time, of course a very long time ago, mankind had but one language. Perhaps the worldwide adoption of SI units signals a significant and welcome reversal in the long history of the proliferation of languages.

Metrication Problems in the Construction Codes and Standards Sector

Charles T. Mahaffey

This report is a response to a request for an outline of the problems to be faced by the building standards development and building regulatory sectors of the American building industry. It includes a discussion of the SI metric units themselves, giving examples of the conventions regarding their use adopted in other countries to illustrate the nature of the decisions that must be made by the U.S. building industry. It discusses the relationship of dimensional coordination to the metric conversion effort, its impact on the U.S. building regulatory system and illustrates some of the decisions these sectors need to make. It also discusses some of the organizational problems required to involve all segments of the industry in this decision-making process, and for implementing these decisions in a coordinated way on a national scale.

Key words: Building regulations; dimensional coordination; metric conversion; planning and scheduling.

I. METRIC UNITS TO BE USED

The system of measurement units that the U.S. will be adopting when it "goes metric" is known as the International System of Units - officially abbreviated SI. SI is the system currently being adopted by the English-speaking nations (Britain, Canada, Australia, New Zealand and South Africa) and differs from the metric system long used in Europe and other parts of the world. One of these differences is the appearance of the new SI unit of force - the newton. In countries on the older metric system the kilogram was used to indicate force and mass in a manner similar to the way we now use the pound. While this new coherent separation of mass and force will produce little actual difference in the resulting building design values involved, the concept is quite different. For the U.S., the change to SI metric will include this clarity of concept plus all of the advantages of the decimal measurement base inherent in the metric system. Countries who have been on the metric system have long enjoyed the decimal base advantages but are finding it difficult to appreciate the slight (for the building community) improvement in clarity attached to the newton. However, commitments to change to SI have been made by these countries and this change process is underway.

The foundation of the new system lies in the seven base (and two supplemental) SI units:

SI BASE UNITS

QUANTITY	UNIT	SYMBOL
length	meter	m
time	second	s
mass	kilogram	kg
electric current	ampere	A
temperature	kelvin	K
luminous intensity	candela	cd
*amount of substance	mole	mol

SUPPLEMENTAL UNITS

plane angle	radian	rad
solid angle	steradian	sr

*The mole (a measurement of elementary entities such as atoms, ions, etc.) which has recently been added to SI, probably will have no application in the construction industry.

One of the virtues claimed for SI is its internal coherence. This simply means that the quotient or product of any two unit quantities in the system leads to the unit of the resultant quantity. As an example, when the unit length (m) is divided by the unit time (s), the result is unit velocity (m/s) and when unit length (m) is multiplied by unit length (m), the result is unit area (m^2). If the current U.S. system were coherent and the foot were a unit of length, the square foot would be a coherent unit of area but an acre would not.

The coherence of SI is illustrated by Figures 1 through 6 (courtesy of Britain's Ministry of Public Works).

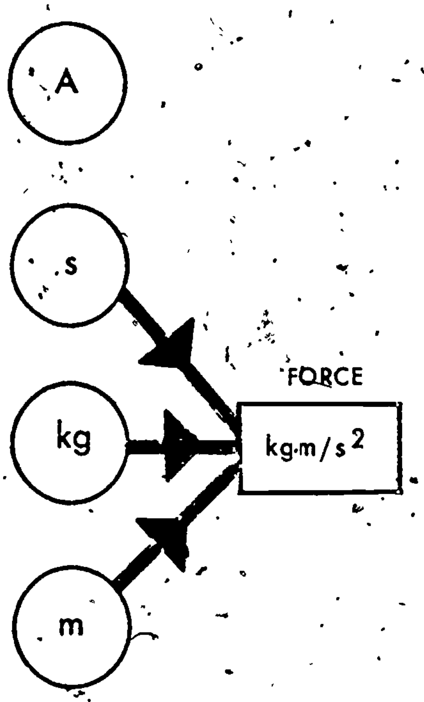

Figure 1 - Three base units - second s, kilogram kg, meter m combine to produce an expression for FORCE kg·m/s^2

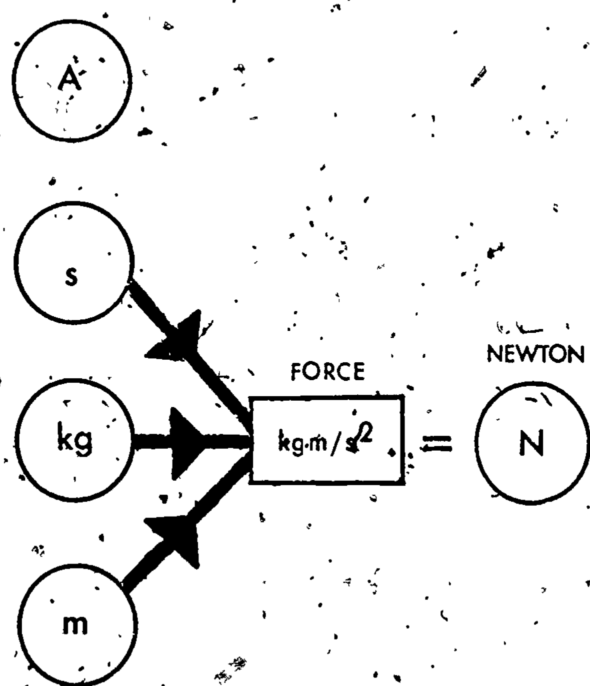

Figure 2 - The expression for FORCE kg·m/s^2 is given the special name newton N

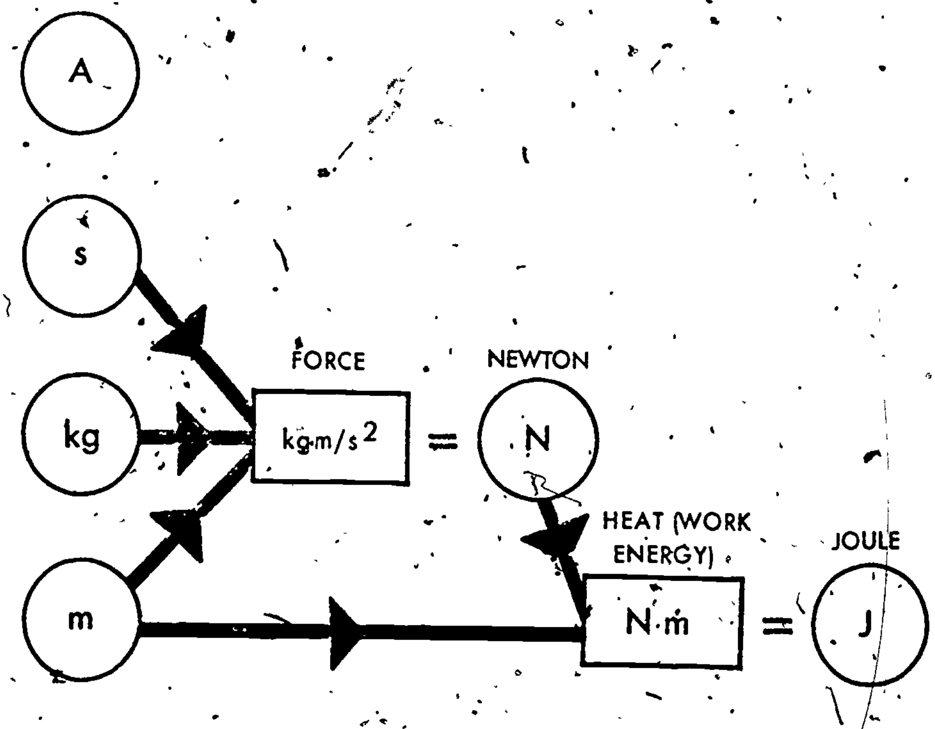

Figure 3 - newton N combines with base unit m to produce the expression for HEAT (WORK,ENERGY) N·m which is given the special name joule J

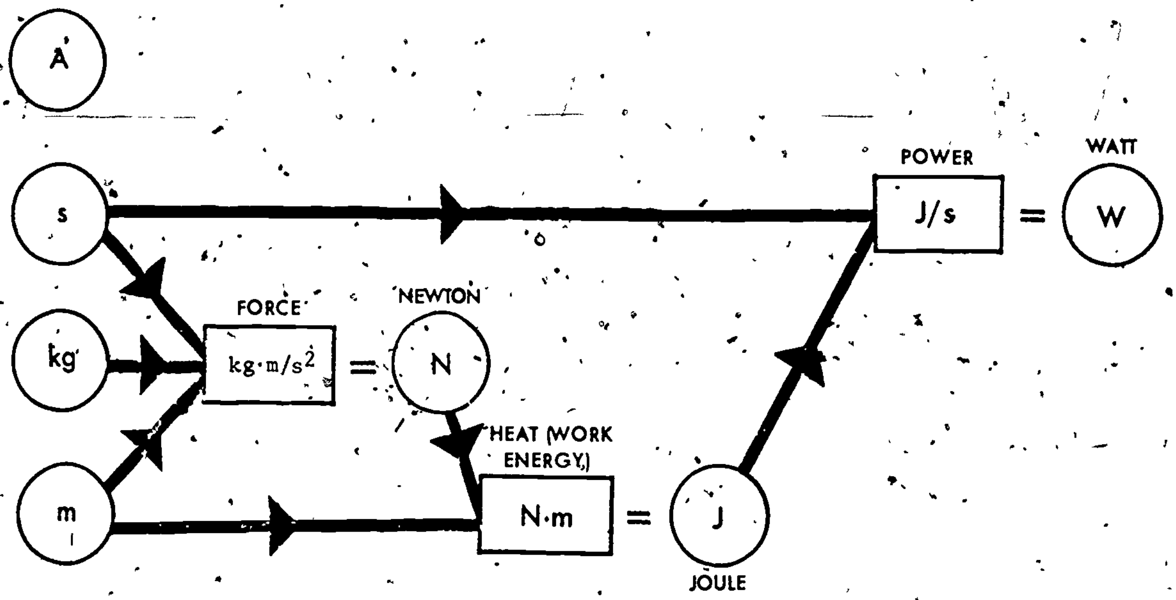

Figure 4 - joule J combines with base unit s to produce the expression for POWER J/s which is given the special name watt W

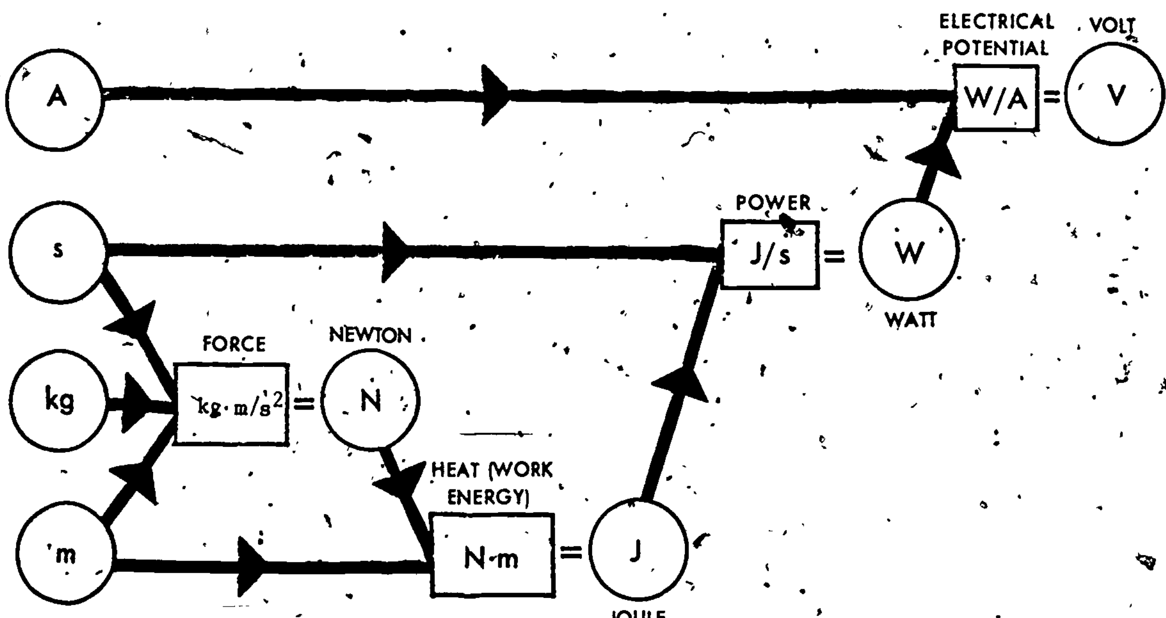

Figure 5 - watt W combines with base unit A to produce the expression for ELECTRICAL POTENTIAL W/A which is given the special name volt V

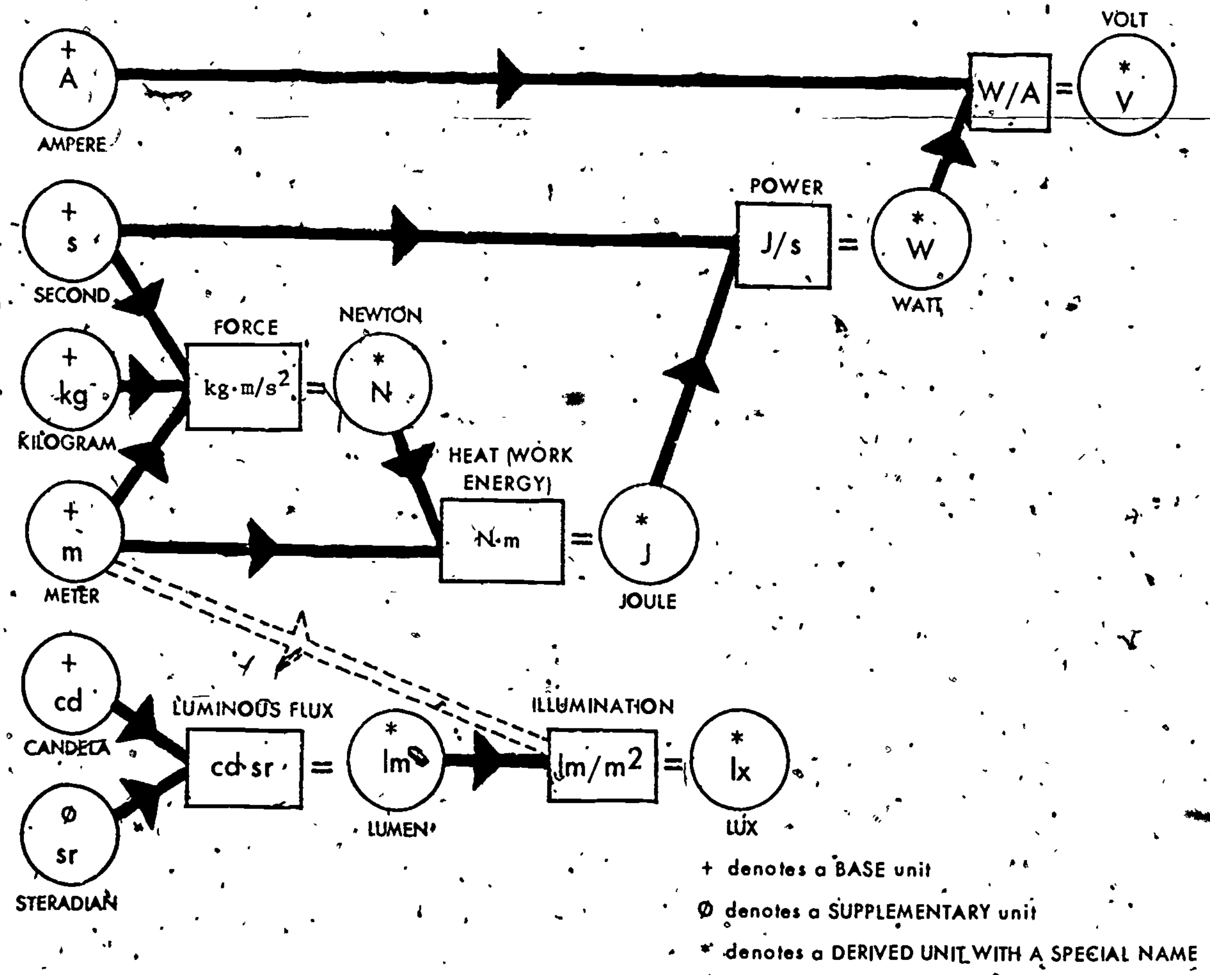

Figure 6 – Derivation and coherence--how "Derived Units" with special names are sequentially derived from the base and supplementary units

As these figures show, the base SI units are combined to make new measurement units, referred to as derived units. These in turn are of two kinds – those expressed in terms of units from which they are derived, and those given special names. The following are examples of each kind of derived unit:

DERIVED UNITS - NAMED AFTER BASE UNIT

QUANTITY	UNIT	SYMBOL
area	square meter	m^2
volume	cubic meter	m^3
density	kilogram per cubic meter	kg/m^3
velocity	meter per second	m/s
acceleration	meter per second squared	m/s^2
luminance	candela per square meter	cd/m^2

DERIVED UNITS - SPECIAL NAMES

QUANTITY	UNIT	SYMBOL	DERIVATION
force	newton	N	$kg \cdot m/s^2$
work, energy	joule	J	$N \cdot m$
power	watt	W	J/s
electric potential	volt	V	W/A
illumination	lux	lx	lm/m^2

In addition to these SI units, there are certain non-SI units (few in number) which probably will continue to be used after the introduction of SI; they are so firmly established in worldwide practice that their elimination would be virtually impossible. Examples of these are:

- for time - the day, hour and minute
- the mass unit - metric ton, which equals 1 000 kg (or approximately 2 200 pounds)
- the area unit - hectare, which equals 10 000 square meters (or approximately 2 1/2 acres)
- for volume - the liter, which equals one-thousandth of a cubic meter (or approximately one quart)

The supplementary units, radian and steradian, probably will not be widely used in the construction industry. The radian is defined as the angle between two radii of a circle which cut off on the circumference an arc equal in length to the radius. Instead of the radian, the construction industry probably will continue to use the familiar degree (°), and decimals of degrees. We probably will not make use of the "grad" or "grade" which is one-hundredth of a right angle, so there will continue to be 90 degrees in a right angle. The solid angle, steradian, also will not become a familiar term in the construction industry. Its definition is as follows: "The solid angle which, having its vertex at the center of a sphere, cuts off an area of the surface of the sphere equal to that of a square having sides of length equal to the radius of a sphere."

An explanatory note about mass and temperature may help the reader.

MASS In commerce, the term "weight" has been used, and probably will continue to be used to mean mass. In physics and sometimes in engineering, the term "weight" has been used to mean a force (acting on mass) related to gravity. Many feel that this latter use of the term "weight" should be avoided because it is contrary to the meaning of the term as used extensively throughout this country, especially, for example, by weights and measures officials.

Designers are accustomed to expressing allowable floor load densities in terms of "pounds per square foot." When they use SI, one method that might be adopted would be to express such load densities in kilograms per square meter. When engineers use these load ratings in computations that involve stress determinations, they will be obliged to change from kilograms per square meter to newtons per square meter. This latter term is given the convenient short name - pascal. In determining a building load, one would add all of the appropriate masses in the building in kilograms, and multiply this total by the applicable value of the acceleration of gravity (g) to get newtons. While the international standardized value of g is 9.80665 m/s^2, g actually varies between 9.77 and 9.83 m/s^2 on the surface of the earth.

TEMPERATURE It may have been surprising to note in the first table of base units that the unit for temperature is given as "kelvin." For practical purposes, it is unlikely that the construction industry will use "kelvin." The non-SI unit "degree Celsius" whose symbol is °C will be used instead. The term "Celsius" was adopted instead of the more familiar "centigrade" because in France the word centigrade has customarily been applied to angles. There is actually no difference between the temperature intervals on Celsius or kelvin scales. If two such scales were aligned with the Celsius zero (the freezing point of water) opposite 273.15 on the kelvin scale, then 100° (the boiling point of water) on the Celsius scale would be directly opposite 373.15 (273.15 + 100) on the kelvin scale. Degree Celsius is the unit of temperature that probably will be adopted by the U.S. construction industry.

The main feature of SI (or the pre-SI metric system) is its decimal base. All multiples and submultiples of SI units are based on powers of 10. These are quite simply expressed by applying prefixes to the units. By adding these prefixes to SI the range of unit magnitude may be extended from the subatomic (10^{-18}) to the astronomic (10^{18}).

If the U.S. construction industry follows the pattern adopted in other English speaking countries in the selection of preferred multiples and submultiples, preference will be given to the use of decimal multiples and submultiples which are related to the base unit by powers of 1000. In the construction industry the range from 10^{-6} to 10^{6} probably will suffice.

PREFERRED MULTIPLES AND SUBMULTIPLES

PREFIX	SYMBOL	FACTOR	MAGNITUDE
mega	M	10^6	1 000 000
kilo	k	10^3	1 000
milli	m	10^{-3}	0.001
micro	μ	10^{-6}	0.000 001

Note that this chart suggests the exclusion of the centimeter. Many people in the U.S. building industry are not happy with this exclusion, feeling that the centimeter represents a useful and comprehensible sizing unit. Those promoting exclusion, on the other hand, point to the following reasons advanced in other countries:

(1) Use of the centimeter is inconsistent with the approach to adopt preferred prefixes which are ternary powers of 10.

(2) The order of magnitude between centimeters and millimeters is only 10, which increases the likelihood of error.

(3) In drawings, the differences between mm, m, and km are so great as to make it unnecessary to add the unit symbol after each dimension (not possible if centimeters were an accepted submultiple) provided that:

(a) decimals of meter are always taken to three places, such as 3.600

(b) millimeters are always expressed in whole numbers, such as 3600.

The SI units briefly described here will tend to reduce the number of measurement terms used in the building industry. The joule (J) replaces very many traditional units with one coherent unit. Some of these familiar units are the Btu, therm, calorie, and potentially the kilowatt hour (which equals 3.6 MJ).

Another example of technical terms becoming more rational and fewer in number is the emergence of the watt as the basic unit of power. Already recognized universally as the basic unit for electric power, the watt will also be used as a general power term replacing horsepower, foot pound force per second, heat flow rate (expressed in customary units as Btu/h), refrigeration (usually expressed in tons), etc. A 300-horsepower car will be said to be a 225-kilowatt car.

There hardly will be any change in the electrical units. Whereas the term hertz (Hz) is often used for cycles per second, in SI hertz is the recognized unit for frequency.

Indications are that in lineal measurements the meter and millimeter will replace the lineal foot, inches and fractions of inches. The square meter will replace square foot, square yard and "square" (100 ft^2). The cubic meter and liter will replace cubic foot, cubic yard, gallon, quart and pint.

These are some of the essential SI units applicable to construction. Other derived units, like those used in terms as section modulus, are under study by the Construction Industries Coordinating Committee of the American National Metric Council (ANMC). Recently a special working group of a Technical Committee (TC 98) in the International Organization for Standardization (ISO) whose title is "Bases for the Design of Structures," produced a final draft of a whole series of construction engineering terms that reflect the rationality and coherence of SI units. Agreements among the members of the U.S. building community regarding the identification of the SI units to be used in construction must be reached at an early date if the full benefits of the simplicity and internal consistency of the SI metric system are to be realized. To delay the development of this needed national agreement is to create a host of unnecessary problems.

Almost the same set of problems exists in the development of national agreements regarding the conventions applicable to the use of SI units. A few samples of these conventions which have been adopted in other English-speaking countries may help to illustrate the problems involved.

(1) Thousand markers

(a) Dimensions and quantities or values.
- the thousand marker should be provided by a space, not a comma (a comma has been used in Europe as a decimal point).

1 000 000
1 000

(2) Decimal points

(a) In typewritten or other documents produced on machines the use of a period (for a decimal point) on the line is recommended.

0.1
9.9
3.602

(b) When expressing a value less than unity, the decimal point should be preceded by a zero.

0.1
0.01
0.362

(c) Whole numbers may be expressed without a decimal mark.

1
100
3 600

(3) Sizes

(a) If sizes are written in the sequence--length, width, height--and the figures are separated by a multiplication sign, the symbol is only given following the last figure.

325 x 170 mm
1 325 x 700 x 150 mm

(b) If sizes are written in any other sequence each size should be followed by the symbol which should in turn be followed by the identifying word.

125 mm high x 150 mm wide
7 500 mm long x 125 mm high x 75 mm wide

(4) Writing SI symbols

(a) Always use upper and lower case letters properly.

kg kW (not Kg kw)

(b) Always use the same symbol to express singular or plural.

107 m (not 107 ms)

(c) Always leave a single space between numerical value and symbol.

123 mm (not 123mm)

(d) Always write out metric ton or liter. (The symbols "t" or "l" should not be used as "t" may be mistaken for the customary ton, and the typewritten letter "l" may be mistaken for the number 1.)

(e) Always express the size of an item as so much by so much using the symbols that denote the same multiples or submultiples of the SI unit.

2 100 x 710 mm
or 2.100 x 0.710 m
but never 2.100 m x 710 mm

(f) It is recommended that where meters are expressed involving decimals, the dimensions should be written to three places of decimals, which is visually compatible with the expression of the same dimension in millimeters.

3.602 m = 3 602 mm
0.190 m = 190 mm

The adoption of SI units poses many difficult problems during the period of transition. Some of these pertain to the actual SI units themselves and others pertain to the SI usage conventions or practices, as in the foregoing illustrations of practices adopted by other English-speaking countries.

Those who promulgate and enforce building regulations and those responsible for the production of the standards used in building regulations can ill afford a passive role in either the selection of SI units to be used in construction or the conventions adopted regarding their use.

For example, consider the subject of the newton versus the kilogram force. There are some members of the construction industry actively working against the adoption of the SI unit, the newton, feeling that the rather drastic change in thinking it entails is not feasible or useful for the construction area. Opponents of this view claim that the change to metric is going to be traumatic in any case, so why waste the effort on an outdated non-SI system. Many people are recommending that floor load density requirements or capacities be expressed in terms of kilograms per square meter that the floor is designed to carry. The pressures exerted on the foundation are to be expressed in newtons per square meter, or pascals, as would other pressures acting on the building such as wind pressures. They also advocate the technique for expressing the carrying capacities of trucks or cranes in kilograms.

In any case, the steadying voice of the codes and standards sector needs to be heard. Obviously, the decisions made in such matters are going to have a profound effect on the usefulness of the SI system. A vehicle must be found for developing agreements among the building codes and standards promulgators and for advancing these agreements among other important sectors of the building community. If the promulgators of the model building codes were to pursue separate courses in the adoption (or non-adoption) of SI units, or if unreconciled differences between the model codes and the standards promulgators develop, this only will add to rather than diminish the U.S. building industry's problems with metrication. The codes and standards promulgators should consider finding an operational way of working together, not only to ensure a national coherence in the change to SI but to take full advantage of this opportunity to reach an international accord in this vital communication mechanism that SI offers.

These are but a few examples of the kind of conventions that will necessitate the development of a general agreement among all members of the building community. There are many, many more that will surface as the national metric program advances.

In the case of conventions, after agreements have been reached regarding the ones to be used (and code and standard promulgators will need to give serious consideration to maintaining a continuous involvement in this decision process), there is no better way of putting them into practice other than committing them to memory.

Similar problems exist relative to the use of the SI units themselves. Most experienced construction people have, over the years, developed an ability to estimate dimensions or quantities of building materials or components by visualizing the spaces they occupy. With this new system of measurement units, this learning process has to start all over again; all of our key recognition factors will have been changed.

This problem area can be divided into three parts.

(1) Problems associated with learning to estimate dimensions, quantities and values of common objects such as the size of the bathroom mirror, the speed of a passing automobile or the afternoon air temperature.

(2) Problems associated with learning the basic metric sizes of components or fixtures whose dimensions have a functional value such as:

bathtubs
doors
kitchen counter heights
stair treads and risers

Learning to convert the size of these units from customary into metric units and memorizing them will not be easy. However, this kind of exercise (carried through for other base units also) will help establish key recognition points useful in rebuilding a new storehouse of reference values.

(3) The real problem with adopting metric will come when people try to cope with the interrelationships between units which are combinations of a number of units such as those for force, heat U values, power, pressure, etc., even though the units for these combinations have been given simple names. Learning these new units does not particularly help in applying them to basic design problems involving these units. While it is possible to figure out the derivation of the newton (as illustrated in Figures 1 - 4 in this section) this knowledge will not in itself indicate the metric equivalent of 4000 lb. concrete [which is 27.6 MPa (megapascals)]. If, for example, the structural engineer memorizes the facts that concrete strengths of 20.7 MPa and 27.6 MPa are the equivalents of 3000 and 4000 psi respectively, he will be able to recognize an error of any significant magnitude throughout a wide range by relativity. Rounding these metric numbers gives 20 MPa and 30 MPa concrete strengths (the equivalency of 2900 psi and 4350 psi, respectively). Similarly, the mechanical engineer can use a boiler output of 30 kW, which is the approximate equivalent of 100 000 Btu/hr, as a key recognition factor for the whole range.

Learning any new language can be an exasperating experience and metric is no exception. Fortunately, SI has a rational base and is not just a sophisticated evolution of a series of grunts and whistles, so that the amount of material that must be committed to memory is an infinitesimal fraction of what is required to learn to speak English. Learning the basic key recognition points will be the real problem. Once these are under control, the simplicity inherent in SI will become steadily more rewarding.

SI is an international language, and one of the major reasons the U.S. is going metric is that the rest of the technical world has already adopted that language. This action will pose the problem of international cooperation in our conversion efforts. Obviously, to obtain the maximum benefit from this traumatic experience, our new system should be developed in harmony with the emerging international language. What role will the codes and standards promulgating organizations play in the U.S. decisions in this matter?

References:

A great amount of the material in this section has been derived from the following three publications:

Metrication in the Construction Industry No. 1
Metric in Practice

Metrication in the Construction Industry No. 2
Calculations in SI Units

Metrication in the Construction Industry No. 4
Metric Reference Book
Produced by the Ministry of Public Buildings and Works

Sold by Her Majesty's Stationery Office
49 High Holborn
London WC1 England

III. DIMENSIONAL COORDINATION

The basic idea behind dimensional or modular coordination--the establishment of a direct dimensional relationship between the dimensions selected in the design of a building and the size of the components used in its construction--received its initial industrial thrust in the U.S. Alfred Bemis generally is credited with proposing the idea of using a universal basic module - a 4-inch cube, for this design/manufacturing system. After World War II, the ideas generated by Bemis and others were picked up and employed in the U.S.-funded reconstruction programs in Europe utilizing a 100-mm cube, the approximate metric equivalent of Bemis's 4" basic module. It was during this period that the most sophisticated development of the principles of dimensional coordination and their actual application took place.

Designers often make use of graph paper having regularized grid patterns as a sketching medium in the evolution of their working drawings. Bemis reasoned that if all designers would use the same size grids for their drawings, and if component manufacturers were to use similarly sized grids for the sizing of their products, a direct dimensional coordination of buildings and building products would evolve. This should simplify some of the problems of building design and help manufacturers select the most useful size ranges of building products. This combination should eliminate most of the wasteful cutting and fitting at the job site.

This concept and its resulting elaborations proved to be intriguing to designers and manufacturers. However, the cooperation it required between designers and manufacturers never developed to a point in the U.S. where the many claimed advantages could be factually assessed. The designers tended to enthusiastically endorse the concept, saying that just as soon as the manufacturers began producing modular parts they would begin specifying them. The manufacturers, equally enthusiastic over the concept of dimensional coordination, indicated they would begin making such parts as soon as the designers started specifying them. As a result, here and in Europe, the idea never achieved the full potential all believed it had. So while dimensional coordination has been used to a far greater extent in Europe than in the U.S., only Denmark and the Soviet Union had adopted a national program of dimensional coordination until England did so. Since then Australia, South Africa, New Zealand and now Canada all have followed suit.

As at present in the U.S., there was no great enthusiasm in the British building industry for the change to metric. Concerned building industry members in Britain, recognizing the importance of metrication to the nation, strongly urged the installation of a national program of dimensional coordination paralleling that of metrication. This recommendation was adopted and the building industry, with the support of the British government, is embarked on a most ambitious national program of dimensional coordination. Respected industry figures there feel that for the British building industry dimensional coordination is the most important benefit they will derive from going metric. Various practitioners in the British building industry, when asked about the impact of metrication on their activities, usually respond in terms of their opinions regarding dimensional coordination.

The reasons they advanced for at least the initial usefulness of dimensional coordination revolve around the recognized need to change the dimensions of many key building products, brought about by the change to metric. A 4'-0" x 8'0" building panel translated into its exact metric equivalent is 1219.2 x 2438.4 mm. These are extremely awkward numbers. If these are the kinds of numbers that a metric conversion would bring, the building industry easily could do without this kind of "help." But if not these numbers, what numbers? For the fragmented building industry a nightmare of intra- and inter-disciplinary meetings and conferences might be required to produce rationally related sets of new sizes for the hundreds of building products and components involved. This fear was one of the major factors that spurred the English into adopting the concept of dimensional coordination. The principles of dimensional coordination offered a rational way of bringing about new compatible sizes of building products. If all the various trade associations involved would use the same set of sizing principles, each could work out new dimensions more or less unilaterally. Since all dimensions had to be changed anyway, dimensional coordination seemed like the way to go. Fortunately, a Technical Committee (TC 59) of ISO had produced several basic and useful standards covering the principles of dimensional coordination and some of their applications.

TC59 established 100 mm (3.937 inches) as the basic planning module around which the whole fabric of dimensional coordination is built. Theoretically, this basic agreement means that designers can lay out buildings using this module and component manufacturers can produce products compatible with the layout and in size ranges that relate to each other and other products in a rational way, using the same 100 mm module.

In practice, however, the number of possible multiples of 100 mm proved to be too large and it was necessary to provide some way of narrowing this range to some feasible number. The dimensional flexibility needed by the designers, and the practical size range limitations needed by the product manufacturers, were satisfied by agreements on what are known as preferred dimensions. The following set of preferences, worked out in Britain, are illustrative of the basic standards that have to be developed in the U.S.:

1st preference	300 mm (approximately 12")
2nd preference	100 mm (approximately 4")
3rd preference	50 mm (approximately 2")
4th preference	25 mm (approximately 1")

In effect, this table indicates that for dimensions over 100 mm, first preference should be given to increments of 300 mm with second preference given to multiples of 100 mm (multiples of 100 mm are referred to as multimodules).

In a horizontal direction the preferred multimodules would be 300, 600, 900, 1200, 1500, 3000 and 6000 mm. Of these, 300, 600 and 1200 mm would be particularly preferred. In a vertical direction first preference is given to 300 and 600 mm while increments of 100 mm would be acceptable up to 3000 mm. The third and fourth preferences, 50 and 25 mm, are submodules used only for thin sections.

This kind of dimensioning approach is being adopted by the several English-speaking nations currently making the switch to metric. Each one of these nations has carefully studied the approaches used in other highly industrialized countries and has tailored its programs accordingly. The U.S., being the last to convert to metric, has an excellent opportunity not only to assess the usefulness of a national program of dimensional coordination, but to selectively evaluate these various program approaches for U.S. conditions. The bases for all of these approaches are derived from the standards that have been and still are being developed by the ISO Committee TC 59. A few words giving a picture of the U.S. relationship with this committee may be of help.

The USA vote in ISO standards activities is cast by the American National Standards Institute (ANSI). ANSI casts these votes on instruction from national committees, organized for this purpose under ANSI procedures. Such national committees are called USA Technical Advisory Groups or USATAGs. In the case of TC59, the USA holds a voting position but cannot vote because a USATAG for TC59 does not exist. Until the advent of metrication there has not been much USA interest in the subject of international standards for dimensional coordination. Recently, ANSI requested the Center for Building Technology (CBT) of the National Bureau of Standards to take on the responsibility of organizing and servicing such a national committee for TC59. The CBT has accepted this responsibility and plans to begin the organization of a committee that can not only develop a USA response to ISO actions, but also can develop and advance USA initiatives in this subject area.

Many international standards have been produced by TC59 and many more are in the pipeline. Thirty-one nations are members of TC59 and are variously involved in some twenty-five subcommittees and working groups. At a recent plenary meeting (Stockholm - October 1974), the delegates voted to add performance requirements (for buildings and components of buildings) to future TC59 activity plans.

The addition of a TC59 work program that would lead to the international "harmonization" of building regulations is under study and will be an agenda item at the next TC59 meeting.

While it may be too early to assess the cost/benefit value of the British dimensional coordination effort on its own merits (and not just as a way of facilitating a metric conversion), it is interesting to note that Canada, Australia, South Africa and New Zealand all have studied the British program and all have opted to tie a national program of dimensional coordination to their metrication efforts. There is a strong trend developing in this direction in the U.S. in current discussions within the American National Metric Council. If this trend continues, the U.S. building industry also will choose to implement a national program of dimensional coordination as its way of "getting something out of going metric."

If the decision is made to tie dimensional coordination to metrication, decisions on many fundamental codes and standards revisions will be required early in the conversion program. In some cases, where codes originate dimensional requirements, decisions on such code changes must lead. In other cases, changes in reference standards (such as dimensional lumber) will have to occur before code decisions can be reached. Obviously, before any dimensional changes in codes or reference standards can be initiated, national agreements--standards--have to be established, not only regarding the SI units to be used in construction, but also the principles behind the application of dimensional coordination.

As an example of a dimensional change originating in codes, consider the familiar 22" unit of exit width. Translated into metric, 22" is equal to 558.8 mm. This awkward number should be rounded to some new dimension. Applying the principles of dimensional coordination might require some serious rethinking of the whole area. Rounding 558.8 mm to 600 mm fits a first preference 300 mm multimodule but 600 mm translates into 23 5/8", while 500 mm, a second preference number, is only 19 11/16". Proponents of dimensional coordination will point out (vigorously) that it not only makes good sense to use corridor widths that relate to dimensionally coordinated space layouts of buildings but, if the many claimed construction productivity advantages are to be realized, all building spaces (and the components that fill them) have to be dimensionally coordinated. Proponents of a simple rounding - say to 550 or 560 mm (21 5/8" and 22 3/64" respectively), might claim that this 22" unit of exit width is so well accepted that it would be foolish to make a drastic change just for a slavish devotion to a design principle. Others might say that the 22" unit was established a long time ago when people were generally smaller and that the increase to 600 mm would be reasonable. A decision in this matter will not be simply developed. Obviously, because it affects the dimensions of doors, windows, stairs, etc., (besides corridors), many segments of the industry must be involved in this decision. A way of precluding unilateral actions in matters of such industry-wide impact will have to be devised and implemented.

In such code subject areas as elevators, the American National Standard Committee A17 (sponsored by the American Society of Mechanical Engineers and operating under ANSI procedures) may find much useful information in the current activities of Subcommittee 7 of ISO TC 59. This very active international standards committee is hard at work devising many applications of dimensional coordination in SI units to the whole field of elevators. Certainly, all of the dimensions, quantities and values presently contained in the A17 document will have to change to some new SI equivalent. The dimensional coordination work being done in TC 59 could provide guidance in arriving at a new metric A17 American National Standard.

Since industry discussions already have started on this subject of dimensional coordination, promulgators of codes and standards are faced with making some basic decisions in the near future. Obviously, they should be involved in these discussions, but how, when and where they can be represented most effectively needs to be decided.

III. Planning for Metrication/Dimensional Coordination

In a Committee Report (from the House of Representatives' Committee on Science and Technology) accompanying H.R. 8674 (the bill entitled "Metric Conversion Act of 1975" that as Public Law 94-168 President Ford signed on December 23, 1975) the following comment appears.

> "The choice before the Congress is not whether we should move to the metric system. That conversion is underway. The choice is between the conversion process in an entirely uncoordinated fashion, as is the case now, or going forward with the conversion process on a coordinated basis. The testimony heard by the Committee indicated that there is wide agreement on the desirability of going forward on a coordinated basis. Furthermore, it is apparent that many sectors of the national community which are now considering conversion are only awaiting a firm statement from Congress committing the United States to the conversion before they, too, adopt the metric system."

The Committee Report further states:

> "The bill declares that it shall be the policy of the United States to change to the metric system in a coordinated manner and that the purpose of this coordination shall be to reduce the total cost of the conversion."

From these statements, it is obvious that a well-coordinated approach to metric conversion is deemed essential. However, attaining coordination in an industry as fragmented and centerless as the building industry may be as elusive as it is essential. Certainly, a great amount of patient planning involving all parties at interest will be required if the time frame involved is to be reduced so as to minimize conversion costs.

The significance of this time frame is highlighted by the experience of the Australians. They reasoned that the longer the transition period, the longer a dual product line may have to be dealt with by designers, manufacturers, and constructors, and the longer this condition lasted the more expensive the conversion process was going to be. The Australians invested heavily in developing a carefully detailed planning and scheduling program for the conversion of their building industry and virtually have completed this conversion in less than five years. On the other hand, the private building sector of Britain still is far from completing its conversion after almost nine years of effort. Canada, just starting its construction metrication effort, has studied the British, South African and Australian programs and has found it expedient to borrow heavily from the Australian experiences.

Developing and scheduling a plan for the conversion process in the codes and standards sector will need to take into account the necessity of putting together an organizational structure capable of cooperatively: (a) identifying the problems to be faced not only in the codes and standards area, but also in the industry as a whole; (b) establishing priorities among these problems; and, (c) timing, coordinating and monitoring appropriate responses among codes and standards sources.

Some of the problems for which priority determinations need to be made are contained in the following subject areas:

1. Now that the "firm statement" by Congress has been made, what can and/or needs to be done until the United States Metric Board is formed?

2. What SI units and their use conventions will be selected by the U.S. building industry?

3. What will be the nature and extent of the U.S. dimensional coordination effort and what effect will this have on standards and codes development activities?

4. How is a nationally uniform date to be developed in the U.S. on which metric-based building regulations are to become effective?

5. How is a building community consensus to be developed in the U.S. regarding a target date--M day--on which actual construction with metric-sized products could take place?

6. What will be the nature of the training programs required and when should they be instituted?

7. What other benefits to the U.S. building community, relative to the development and promulgation of building codes and standards, might be derived from the many opportunities for cooperating inherent in this national metrication effort?

Preplanning

Some large segments of American industry (such as the automobile industry) already have made a metric conversion commitment. All 50 States now are committed to changing to the metric system in their education departments. These and other similarly important decisions clearly support the belief that the metric conversion of the U.S. already is underway. Concerned individuals in the building industry, cognizant of these trends, have found that the evolving activities connected with the American National Metric Council (ANMC) offer many opportunities to begin identifying some of the problems that will have to be faced. The Construction Industries Coordinating Committee (CICC) within the ANMC which is composed of seven Sectors (Design, Products, Labor, Users, Contractors, Codes and Standards, Real Estate) is beginning to function as a broad-based forum for the discussion of the industry's unique problems.

The major promulgators of model construction codes or regulations (such as those pertaining to buildings and the plumbing, electrical, elevator, etc., installations in buildings), the major promulgators of standards used or referenced in such model codes, and organizations representing the administration of actual building regulations (as different from model regulations) can, through the Construction Codes and Standards Sector of the CICC, begin now to plan for the organizational structure they will need to cooperatively deal with their share of the metric conversion problems of the building community. This structure should be broad enough to permit the dozens of organizations involved to be able to participate, yet concise enough to permit action decisions to emerge.

Setting up such a structure will not be easy. The groups that need to be brought together have never found it necessary in the past to fully interact with one another in the same way that the metrication program will demand. Many intra- and inter-Sector meetings will be required before the problems and their priorities can be fully developed and a Sector work plan and schedule prepared. Setting up such an organizational structure, and finding ways of funding the participation of appropriate representatives at the meetings are some of the initial preplanning problems to be faced.

Selection of SI Units

Highest on the list of problem priorities is the establishment of a national standard regarding the SI units to be used in the building industry. The many questions involved both with the units themselves and the conventions regarding their use have to be settled soon. Little attention can be paid to the actual application of the metric units until it is known what SI working units the building community will select. Although it would appear that the ANMC route is the most appropriate forum, since all segments of the building industry (and other industries) are represented there, a way needs to be found for developing a codes and standards "position" and of ensuring that this position is understood and given adequate consideration by others. More than just a few discussion meetings will be required. Drafts of recommended SI working units have to be developed and studied along with the units adopted in other countries. The units recommended by ISO have to be given careful consideration, for this one-time opportunity to establish an international technical language for the building industry should not be wasted either by precipitate or a "muddle through" effort.

Dimensional Coordination

Paralleling the importance of deciding on the SI units to be used is the question of dimensional coordination. If, as some maintain, dimensional coordination is destined to become the dominant theme in the metrication of the building industry, this decision, one way or another, need not and should not be delayed until after the official metrication program is initiated. Many decisions, particularly those related to the establishment of preferred dimensions, have to be made before a clear understanding of the impact of dimensional coordination can be developed. If dimensional coordination is to become a national goal (and the codes and standards sector should have a voice in that decision), then the rapid completion of suitable national standards establishing the bases for applying the principles of dimensional coordination to buildings and building components would become a top priority standards' problem. These standards would have to be completed before any serious work on new product standards that involve size changes can be started.

Neither the principles of dimensional coordination nor the corresponding erection techniques, of themselves, will have much bearing on the safety aspects of a building. These are design, manufacturing, and erecting practices that, in their implementation, will not cause building regulatory enforcement officials much in the way of problems. However, the application of these principles to familiar products could cause a reevaluation of old permissible uses. Using these principles to arrive at new sizes of dimension lumber, for instance, could result in thinner and/or narrower lumber sections. This could affect existing span tables for headers, joists and rafters. Similarly, if the thickness of gypsum board is reduced, this reduction plus those that may be connected with dimension lumber may be cause to reevaluate the fire ratings or sound transmission characteristics of constructions involving combinations of such materials. In all cases, those responsible for the promulgation of safety standards need to be aware of product and/or system safety performance changes that may result from new metric-sized product standards.

While the organizations responsible for the promulgation of building codes and building standards may find it impractical to train all of their members in the principles of dimensional coordination and their application, selected staff members, trained in the subject, will be needed. Not only should these people be afforded every opportunity to comprehend this complex subject and be able to interact with their peers in similar organizations, with experts in the U.S. building industry and with those in the international area, but they should be able to convey the significance of such a national program to the members of their organizations. Codes and standards organizations are going to be faced with the problem of selecting and training personnel for this specialized task.

Regulatory Coordination

Even after agreements have been reached regarding the complex technical problems connected with the selection and appropriate application of SI units and preferred dimensions, how to coordinate the timing of their introduction into the nation's regulatory system is going to be a particularly difficult problem. Consider this problem just as it relates to the model building and plumbing codes and those special regulatory type standards like A17 (elevator) or C1--the American National Standard Electrical Code. Those responsible for the promulgation of these independently produced documents (each group having a distinct generating constituency) not only have to participate in the development of agreements on the uniform bases and techniques of making both the metric and dimensional coordination changes needed, but also on the staging of the revised editions required and the establishment of coordinated publication dates. If more than one edition seems to be required, should the first revised edition contain both metric and customary units or should only metric appear? Should rounding of the metric values be attempted in the first stage or should all such changes be made after the promulgation dates of preferred dimension standards? Could not some old and arbitrary dimensional differences among some of these model documents be cooperatively resolved during this size conversion process? While there are many more examples of these kinds of problems facing the regulatory sector, the purpose in stating some of them is not to present a hopeless picture but to illustrate the pressing need for a new era of communication among the principals involved. While the number and nature of these problems may appear overwhelming, the ease with which these principals will solve them will depend on the conversion teams they establish among themselves and with other industry teams. The key problem area seems to lie not in dealing with the new units themselves, but in timing and coordinating the introduction of these units into the regulatory system.

While the foregoing has been concerned with the timing and coordination of the introduction of SI and dimensional coordination into the model documents used in the building regulatory system, a similar problem of timing and coordination exists regarding the introduction of these model documents into the actual body of State and local laws. Provision must be made for the many enacting jurisdictions at the State and local level to act in concert, not only regarding the utilization of the agreed upon SI units and preferred dimensions, but also on the promulgation dates. Since it is unlikely that Federal legislation will mandate these changes or their timing, this area of responsibility would seem to rest with the States. It seems quite obvious that the design, manufacturing, distributing and erection segments of the industry will have trouble enough dealing with their technical problems connected with metrication/dimensional coordination without being burdened by a failure on the part of the regulatory sector to agree on a uniform effective date for metric-based building regulations. If the 8,000 - 14,000 jurisdictions in the U.S. each were to unilaterally select such an effective date, extremely serious and undesirable problems for the rest of the building community could result. These problems could be disastrously compounded if the building, electrical, plumbing, etc. departments within each of these many jurisdictions also were to unilaterally select the effective dates for their particular branch of metric regulations. Somehow, the States, in cooperation with their local jurisdictions, will have to devise a mechanism for achieving a uniform statewide effective date for metric based building regulations. The burden will be on them and their associates in the Construction Industries Coordinating Committee to utilize this mechanism in a fashion that will enable the selection of a date on which metric based building regulations are to become effective throughout the 50 States.

Consideration needs to be given to the special problems connected with the big cities and with the coordination problems related to Federal regulations affecting the design and construction of buildings.

Training

Considerable attention needs to be given to devising effective training programs for the personnel engaged in codes and standards activities. The nature and extent of the training programs to be developed particularly will be dependent on the roles assigned to the trainees.

In order to discuss this problem area, it helps to make assumptions regarding some of these roles. In the case of such standards' committees as A17 (elevator), C1 (electrical), and A41 (masonry), for example, at least two committee members of each committee may have to be designated as metric officers and given the responsibility for guiding the committee's application of metric units.

If one of these selected committee members was either familiar with the subject of dimensional coordination or had the architectural or design engineering background to absorb training in this subject, the other member could be trained to handle the committee's internal and external metric conversion, resulting in a pair of committee experts covering both dimensional coordination and metrication.

The model code organizations probably would want several, if not all of their technical staff members to become proficient in both subject areas. The training of these "metric officers" should enable them to assist their members to correctly interpret and apply the new SI units and dimensional coordination principles, as required, to the several types of model codes involved. In fact, these trained staff members could be used to devise and manage, or even implement, appropriate training programs for the enforcement officials. These trained staff members could develop the essential coordination recommendations needed to harmonize the conversion of the model codes. They also could be used to ensure that regulatory needs be given proper consideration in appropriate external decision-making meetings.

The big city building departments also will need to name one or more "metric officers," having responsibilities and duties similar to those of the model code organizations.

The States, too, each will need to identify metric construction officers able to become proficient in both subject areas. While the degree of their involvement in the technical content of codes may vary from State to State, they must accept responsibility for devising and implementing ways of scheduling statewide metric code change dates in concert with other States. They must also ensure that adequate and timely State-sponsored training programs for code officials, tradesmen, builders, etc., are carried out; (a) in concert with the scheduled appearance of metric codes, (b) in concert with other States, and, (c) in a manner consistent with the national metrication program adopted by the building community.

Federal building agencies and the many individual local and State agencies that control the construction of public buildings (schools, hospitals, offices, etc.) each will find it expedient to identify metric officers. The potential impact of the purchasing power of these public construction agencies on the orderly metric conversion of the building industry (and on the successful implementation of a national program of dimensional coordination) cannot be overstated. Though they are not part of the regulatory system, their participation in the development of the regulatory conversion program, and especially their cooperation in support of the metric/dimensional coordination decisions, is important to any planning program developed by the Construction Codes and Standards Sector. A forum for their metric officers to interact with those of the codes and standards sector needs to be developed.

All of the metric officer types discussed thus far will require very similar training programs. These will necessarily be something more than simple familiarization programs in either subject area. The responsibilities of contributing to the development of an American program and of explaining and/or defending this program with their associates will demand that they receive exceptionally well-rounded training. The nature of such a training program may make it especially attractive to the "metric officers" in architectural and engineering firms and those associated with large component manufacturers or their trade associations. It should be recognized that America does not have a storehouse of experts in either metric or dimensional coordination. In fact, we probably will find it expedient to import our dimensional coordination training programs and many of the teachers.

Training programs for building code inspectors need not get as far into the subject of dimensional coordination as for other members of the codes and standards sector. The training that inspectors need must enable them to clearly understand the SI units and their building applications. Unintentional errors on the job site, brought about by the construction tradesmen's unfamiliarity with metric usage are to be expected. This condition will persist and will be cause for increased vigilance on the part of trained inspectors.

Equal in importance to the subject matter of these training programs is the timing involved. The British experience indicates that training can be wasted if given too early. Costly errors can result if training programs are given either too early or too late, a fact which reemphasizes the significance of devising a way of cooperatively establishing firm dates regarding the introduction of the new metric building regulations. Similarly, the establishment of the date when plans in SI first can be accepted have to be scheduled in relation to the training programs involved.

Consider the implementation problems of scheduling training programs in the metropolitan area around Washington, D.C. In Montgomery County, Maryland, the county seat--Rockville--has a building department (and code) separate from that of the rest of the County. Montgomery County's building department (and code) is separate from that of the neighboring Prince George's County and all three have little or no connection with the Maryland State code agency in Annapolis. A somewhat similar situation exists among the cities and counties across the Potomac River in Virginia, including the complexities involved in the introduction of a new statewide code. In the center of these jurisdictions is the city of Washington itself, with a completely independent building department that has developed its own set of codes. The planning that can be visualized for the metric conversion of all of these codes, the timing of the introduction and effective dates of these metric codes and the scheduling of the training programs involved in this single metropolitan area, illustrate the nature and extent of the intra- and interstate cooperating and coordination that will be required.

Other Benefits

The simplicity and universality of SI, once the initial learning difficulties are mastered, truly will be appreciated by the building community. This benefit will be recognized relatively early from an American national viewpoint and later from an American international viewpoint.

It may be true that a successful national program of dimensional coordination will produce a far more efficient use of all U.S. resources in design, manufacture and construction. It is certain that metrication will require a complete rewriting of the entire data base for U.S. building technology; text books, design manuals, trade catalogs, etc.,—the entire reference literature of the industry, including building standards and codes. This suggests a never to be repeated opportunity to reassess traditional practices, procedures and processes with an eye towards effecting long-desired beneficial changes that were always too upsetting to carry out. However, metrication in the fragmented, centerless building industry has been described as a "management exercise with technical overtones." This is an apt description since an orderly framework of planning, scheduling, coordination and control must be voluntarily imposed (often over technical considerations), if the conversion is to proceed in accordance with predetermined timing and budgets. If such an administratively oriented organizational structure can be fashioned that demonstrates an ability to guide this industry through the all-pervasive problems of metrication and dimensional coordination, it in itself might be the single most important future benefit to be gained by the building community. Any mechanism developed and utilized by this industry to effect changes as deep as metrication should be of future use, especially as an instrument for continually effecting desired transactional improvements among the many distinct but interdependent groups within the building community.

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This report is a response to a request for an outline of the problems to be faced by the building standards development and building regulatory sectors of the American building industry. It includes a discussion of the SI metric units themselves, giving examples of the conventions regarding their use adopted in other countries to illustrate the nature of the decisions that must be made by the U.S. building industry. It discusses the relationship of dimensional coordination to the metric conversion effort, its impact on the U.S. building regulatory system and illustrates some of the decisions these sectors need to make. It also discusses some of the organizational problems required to involve all segments of the industry in this decision-making process, and for implementing these decisions in a coordinated way on a national scale.

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