Trends In Recommended Illuminance Levels: An International Comparison

Evan Mills (1) and Nils Borg (2)

Illuminance levels in perspective

Lighting design is in flux. One indication is that the country-by-country comparison presented in this article reveals very rapid changes in recommended illuminance levels since the 1930s. Building on our previous work, in this paper we compile and compare recommended illuminance levels for selected tasks in non-residential buildings in 19 countries, in the Americas, Western and Eastern Europe, and Asia.[1] We also present historic trends where data are available and discuss the implications for lighting energy use. It is beyond the scope of this paper to quantify differences between recommended and actual illuminance levels, but it remains a fertile area for future investigations.

In North America, and no doubt elsewhere, illuminance level recommendations were originally introduced with the intention of improving worker safety in industry, productivity, and the learning environment in schools.[2] In some cases these guidelines took the form of mandatory standards. Many groups have an interest in influencing the selection of light levels.

Tremendous effort is invested in prescribing recommended illuminance levels. The most recent edition of the *IESNA Lighting Handbook*,[3] for example, specifies levels for approximately 250 interior activities in non-residential buildings and about 300 specific industrial applications, and a similar number of activities and applications are listed in the proposed European CEN *Comité Européen de Normalisation* (the Western European counterpart of ISO) recommendations.[4]

Assuming, for the sake of discussion, that all other factors are held constant, changes in illuminance levels have corresponding implications for energy use. This article shows that changes over time are often quite significant. For example, recommended levels in the former Soviet Union increased by a factor of ten or more since the 1930s. Conversely, levels in many countries have declined by a factor of two or three since the oil crises of the 1970s.

Data collection

We collected current and historic illuminance data directly from national sources, lighting handbooks, and other published materials. The main activities and building types include offices, classrooms, retail stores, hospitals, and manufacturing tasks. Except where noted, the values represent horizontal maintained illuminance values. Several sources report ranges; in this case we present the ranges in tabular form and average values for the diagrams.

It was challenging to compile the data, especially historic values. Certain difficulties arose in comparing recommendations for given tasks within and among countries. Recommended illuminance levels tend to become more rigorously defined over time, with increasing differentiation among building types and tasks. Some countries provide a very high level of specificity in some areas and a very low level in others (e.g., 40 different illuminance ranges for retail lighting settings in Japan but only four for schools).[5] However, the contrary is also true: The Dutch guidelines defer to the lighting designer's ability to draw conclusions from a few generic descriptions of tasks and applications. The 1994 edition of the *CIBSE Guide for Interior Lighting* does indeed provide a long list of tasks and applications, but it also provides a simple flow chart that helps the user select the appropriate level by following a number of yes-and-no questions.[6]

Unusual categories for illuminance levels must also be addressed in order to make comparisons. In the former Soviet Union, separate levels for incandescent and fluorescent light sources were published in 1959 and 1971.[7,8] In 1959, incandescent recommendations were two to

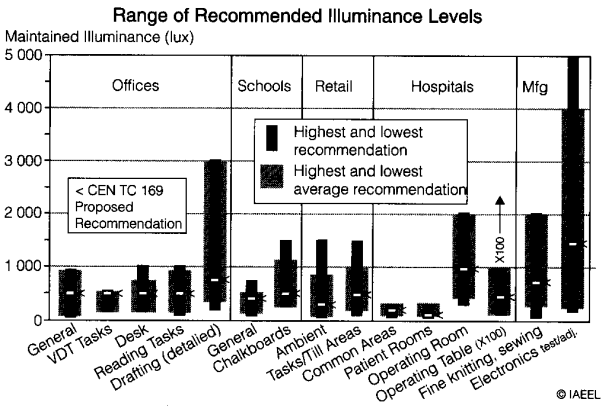

Figure 1— Range of recommended illuminance levels (19 countries). Note: values for hospital operating tables have been reduced by 100x in order to scale to other values. Values of the black bars reflect the extreme high and low endpoints of all national recommendations for a given task. The shaded bars indicate the average values of recommendations when they are expressed as ranges.

Authors' affiliation: 1. Center for Building Science, Lawrence Berkeley Laboratory, University of California, Berkeley, CA 2. International Association for Energy-Efficient Lighting/ Borg & Co., Stockholm, Sweden

three times lower than for fluorescents. In 1971, the gap had closed somewhat. In 1979, only one level was published. To choose another illustration, the German Deutsche Industrie Norm for schools (DIN 5035, part 4) has separate values for electric lighting and for electric lighting in combination with daylighting.[9] Where the daylight factor D is 1 percent or above in the most unfavorable working position, 300 lx is required, whereas 500 lx is required if the daylight factor is below 1 percent.

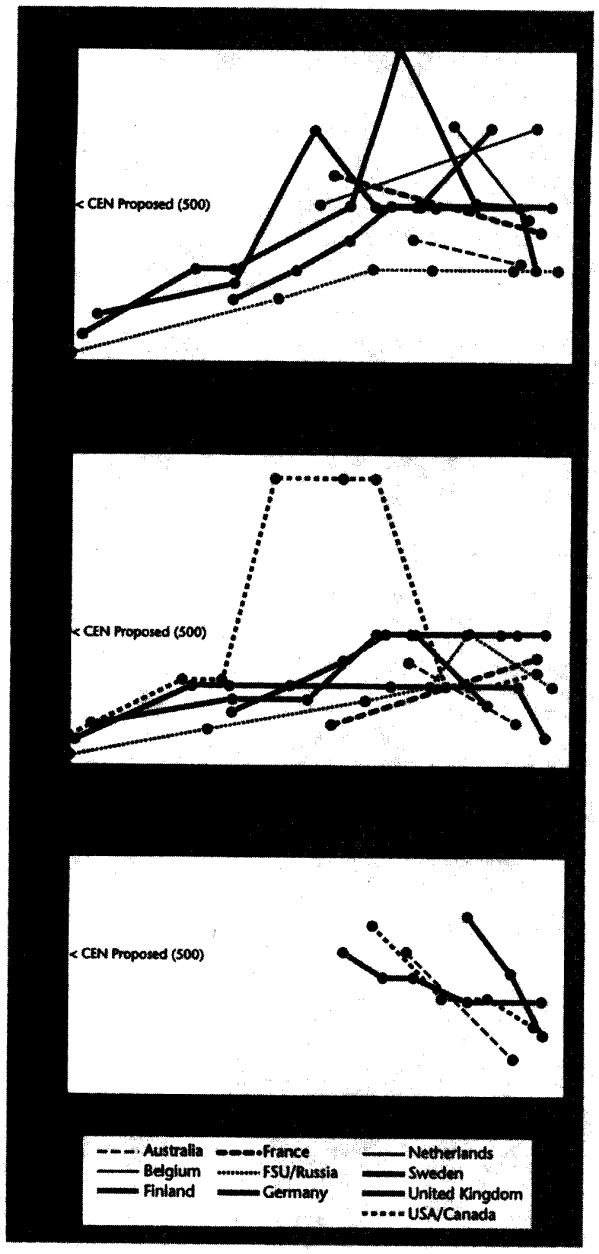

Figure 2a–e— Time trends for illuminance levels for a selection of countries. Where a given country's standard for a given year is expressed as a range, the central or average value is plotted. For the period when the former Soviet Union published separate values for fluorescent and incandescent light sources, these have been averaged. For each country, the most current values plotted are maintained or manipulated average illuminance. Historical values may vary, as some countries expressed their standards in terms of initial illuminance during earlier periods. The absolute difference between initial and maintained illuminance is relatively small in comparison to the changes exhibited over time in the Figures.

Countries vary considerably in the frequency with which they revise their recommendations. For a period of more than four decades (1948–1990), Sweden[10] did not change its recommended illuminance level for general office lighting, while Germany's[11] changed six times. Belgium did not change its recommendation between 1964 and 1992.[12] In Finland, the first recommendations were not published until 1971.[13]

Results

As shown in **Figure 1** and in **Table 1**, the comparison of current maximum and minimum levels reveals a 5- to 20-fold variation for various office building activities across the 19 countries; a 6- to 10-fold variation for schools; a 15- to 30-fold variation for retail stores; a 6- to 10-fold variation in hospitals; and a 25- to 40-fold variation among the manufacturing activities studied. The more dramatic variations in each area include: reading tasks, where levels ranged from 75 to 1000 lx, detailed drafting (200–3000 lx), patient rooms in hospitals (30–300 lx), testing and assembly of electronic components (200–5000 lx), and fine knitting and sewing (50–2000 lx).

Belgium, Brazil,[14] and Japan have among the highest levels for the activities and building types we examined. Australia,[15] China,[16] Denmark, Mexico,[17] the former Soviet Union/Russia, and Sweden have among the lowest levels. The North American recommendations are average in most cases, and the low levels in the three-level recommendation are among the lowest of all countries in a few cases.

Working Group 2 of the European CEN Technical Committee 169 is developing recommendations intended for use throughout Europe.[18] In most cases the standard is within the range of current studied national European recommendations, but a few countries will experience levels lower than their current national recommendations while a few will see levels being raised in some areas.

Figures 2a–2e present historic time trends. Almost without exception, there is a steady increase in levels from the 1930s to the early 1970s. Among the more dramatic cases, the UK's retail lighting recommendations increased from 100 lx in 1936 to 500 lx in 1972. In the former Soviet Union, general office lighting was 25 lx in 1930, rising to 300 lx in 1979. In North America, recommendations for chalkboard lighting rose from 150 lx in

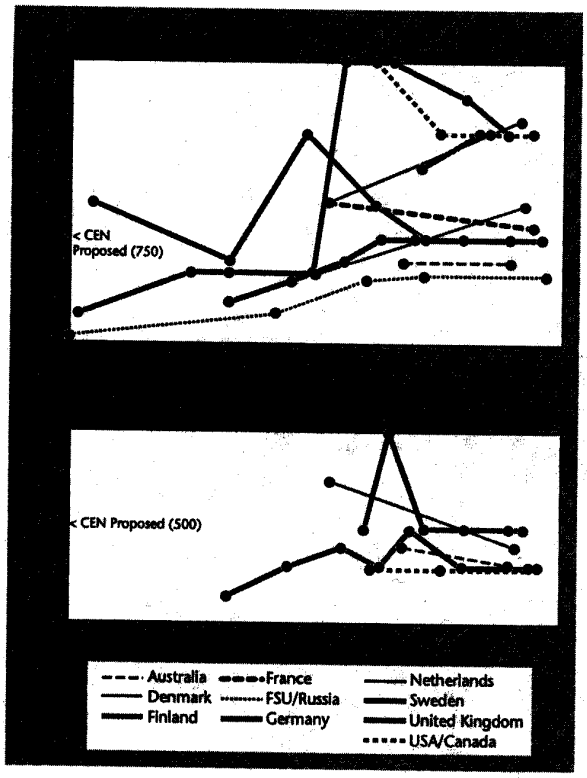

Figure 2b— Time trends for illuminance levels (19 countries).

1938 to 1400 lx in 1972. Limited evidence indicates even lower levels prior to 1930, e.g., 35 lx for detailed drafting in 1915.[19] The proposed CEN recommendations are indicated in the figures, where applicable.

Table 1— Variation factor between highest and lowest recommendation in 19 countries (based on Table 2)

	19-country Low	19-country High	Variation Factor	CEN/TC-169 Proposed European Guideline
Offices				
General	50	1000	20,1	500
VDT Tasks	150	750	5,1	500
Desk	150	1000	7,1	500
Reading Task	75	1000	13,1	500
Drafting (det)	200	3000	15,1	750
Classrooms				
General	75	750	10,1	400
Chalkboards	250	1500	6,1	500
Retail Stores				
Ambient	50	1500	30,1	300
Tasks/Till Area	100	1500	15,1	500
Hospitals				
Common Area	50	300	6,1	200
Patient Room	30	300	10,1	100
Operating Room	300	2000	7,1	1000
Operating Table	100	1000	10,1	450
Manufacturing				
Fine Knitting,	50	2000	40,1	750
Electronics	200	5000	25,1	1500

After the early 1970s, however, the trends either leveled out or changed direction. General office lighting in Finland fell from 450 lx in 1974 to 225 lx in 1985. Dutch recommendations for reading fell from 750 lx in 1970 to 400 lx in 1991.[20] Even very demanding tasks such as detailed drafting work and reading the chalkboard show reductions of 50 percent or more. The most dramatic reduction was from 1500 lx for VDT tasks in the 1972 IESNA recommendations to about 300 lx in the 1993 recommendations. Australian VDT task recommendations have also dropped precipitously from 600 lx in 1976 to 160 lx in 1990.

Sometimes, such changes can be partly explained by changing definitions that follow new concepts in lighting design. As an illustration, Swedish office lighting (on the desk) plunged from 1000 lx in 1970 to 300 lx in 1992. The 1970 values included reading and general desk lighting, while the 1992 recommendations make a distinction between desk and reading. However the differences

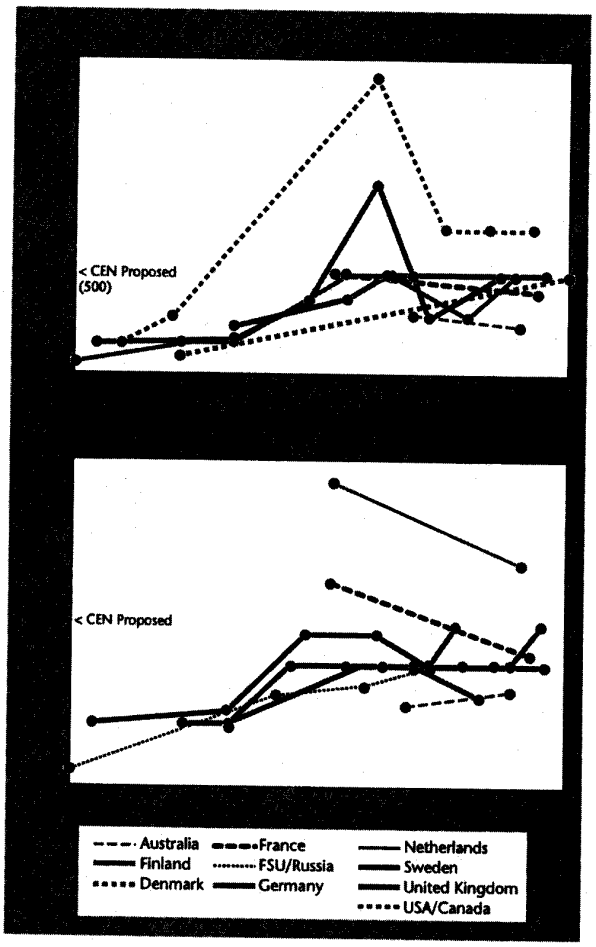

Figure 2c— Time trends for illuminance levels for a selection of countries.

between the 1970 recommendation of 1000 lx (including the reading field) and the 1992 recommendation of 500 lx for reading is still significant.

In Germany, Sweden, and the United Kingdom—countries for which we have a long historic record—current levels for some activities are comparable to those prevailing in the 1960s and earlier.

The dynamic nature of illuminance level recommendations is the result of a variety of factors. In part, the trend reflects changing views about the amount of light needed to perform a given task, but they also reflect a trend toward more comprehensive lighting recommendations when given within a context of other quality-related attributes such as a glare index and color rendering. In addition, economic considerations play a role. For example, the commercialization of the fluorescent lamp in the 1930s made it possible to dramatically increase light levels without paying a corresponding penalty in energy costs or excessive heat.

Energy Implications

The assignment and application of illuminance levels represents an important intersection of lighting design and energy analysis. In both fields, illuminance levels are only one of the many relevant parameters describing lighting systems and their performance. Yet in both cases, illuminance levels serve a useful function in helping to quantify the energy-related service delivered.

Lighting energy use is a function not only of the lighting level but also of the efficiency and utilization factor with which that level is provided, spatial variation, and duration of use. The amount of electricity required to produce a given lighting level can easily vary many fold, depending on the efficiency of lamps and fixtures, application of controls, and daylight utilization.[21] Illuminance standards in many European countries (e.g., Austria,[22] Germany, Netherlands, Russia,[23] Switzerland[24]) require that most types of workspaces have direct access to daylight.

Field measurements of existing light levels and adjustment of levels to comply with recommendations will in many cases yield energy savings. This is evidenced by one large survey of a major National Laboratory operated by the U.S. Department of Energy. Of nearly 86,000 fluorescent lamps surveyed, 32,000 could be delamped without dropping below 500 lx (**Figure 3**).[25] Another field study conducted by the French Lighting Association illustrated that improving sub-standard light levels need not result in increased energy usage.[26] The French study involved retrofitting luminaires in schools to achieve

Table 2— Data shown are for maintained horizontal illuminances, except in the case of chalkboards in schoolrooms, where vertical illuminaces are specified. In the North American IES recommendations, the middle of three discrete values is used. For IESNA, the case of VDT lighting is more complicated as both "recommended" and "maximum" levels are specified; the recommended levels have not changed between 1981 and 1993, but the maximum level was reduced from 750 lux to 500 lx. The average of these two values is listed in the table. For several countries that express their levels in initial lumens, maintained illuminance has been calculated using the maintenance factor expressed in the recommendations. For Austria, Germany and Switzerland the "nominal illuminance" has been used. This value describes a maintained average level over time, and is the level that closest corresponds to that of the proposed CEN recommendations' maintained illuminance.

	Australia[15] 1990 AS1680.2-1990	Austria[22] 1984 Ônom O 1040	Belgium[12] 1992 & L13-006	Brazil[14] 1990 NBR 5413/82	China[16] 1993	Czech Republic[35] CSN 360450	Denmark[36] DS 700	Finland[13] 1986 Finnish IES	France[37] AFE 1992 &93 1981 (schools) 1997 (VDT)
Offices									
General	160	500	300-750	750-1000	100-150-200	200-500	50-100	150-300	425
VDT Tasks	160	500	500	–	150-200-300	300-500	200-500	150-300	250-425
Desk	320	–	500-1000	–	150	300-500	–	500-1000	425
Reading Tasks	320	–	500-1000	200-500	75-100-150	500	500	500-1000	425
Drafting (detailed)	600	750	1000	3000	200-300-500	750	1000	1000-2000	850
Classrooms									
General	240	300-500	300-750	200-500	75-150	200-500	200	150-300	325
Chalkboards	240	300-500	750-1500	300-750	–	500	500	300-750	425
Retail Stores									
Ambient	160	300-750	200-1500	300-750	75-100-150	200	50-100	150-300	100-1000
Tasks/Till Areas	240	500	500-1500	–	100-150-200	500	500	500-1000	425
Hospitals									
Common Areas	240	200	–	75-150	50-200	50-100	200	–	100
Patient Rooms	–	100	–	100-300	150	100-200	50-200	50-100	50-100
Operating Room	500	1000	–	300-750	–	1000-2000	–	1000-2000	300-1000
Operating Table	–	20000-100000	–	10000-20000	–	10000-20000	–	30000-75000	20000-100000
Manufacturing									
Fine knitting, Sev	800-1200	≥2000	1000-2000	750-1500	50-500	1000-2000	500-1000	–	850
Ecletronics: test	600	1500	1000-2000	3000-5000	200	1000-2000	500-1000	–	625-1750

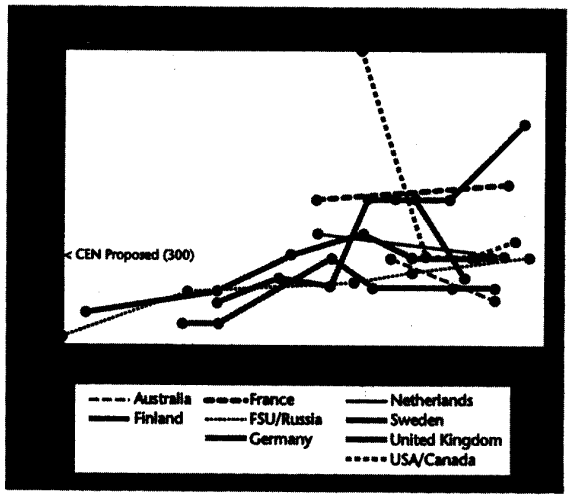

Figure 2d— Time trends for illuminance levels for a selection of countries.

improved energy efficiency and illuminance levels for desks, walls, and blackboards that met the existing standards. Field measurements in numerous schools throughout the Former Soviet Union identified illuminance levels below the standards in 70–100 percent of school buildings.[27]

For some countries, reductions in recommended illuminance levels over time may have offset to some extent the past growth in electricity demand due to increased floor area. For the future, the proposed European-wide CEN recommendations could have a significant effect on lighting energy use. For retail (ambient) lighting, the proposed levels are 45 percent lower than in France, 20 percent lower than Belgium's average recommendations, and about 30 percent lower than Finnish retail task lighting recommendations. On the other hand, the recommendations for VDT tasks are higher than most current national recommendations. One major problem in negotiating levels for VDT tasks is that the lighting should be suitable for all tasks performed at the work station, including reading and writing with paper and pencil. The recent shift in the UK from average to maintained illuminance will increase energy use where higher wattage lamps are installed as a means of achieving the recommended light level, wherever nominal values in the 1994 CIBSE recommendations remain unchanged. The proposed CEN recommendations are also defined in terms of maintained levels, even where they replace current recommended average levels.

The presence or absence of task lighting is central to the overall efficiency of illumination. The Japanese illuminating standard provides very extensive guidance on illumination levels required for specific tasks, inviting designers to reduce ambient lighting to as little as one-tenth that of the task illuminance. The Japanese approach to articulating their recommendations facilitates the specification of task lighting by designers.

The changing nature of certain activities suggests another potential linkage between illuminance levels and energy use. A clear illustration is the increasing importance of computers and VDTs in the workplace. VDTs have replaced the drafting table and many paper-

ble 2 (continued)— Comparison of recommended lighting levels (most recent year) [lux, horizontal-maintained]

	Germany[9] 1990 DIN 5035	Japan[5] 1989 JIS 9110-1979	Mexico[17] Mexican IES (Proposed)	Netherlands[20] 1991 NEN 3087 NSVV	Sweden Nutek[10] 1993-94 Ljuskultur* 1990	Switzerland[24] 1997 SLG/SEV 8912	United Kingdom[6] 1994 IES/CIBSE	USA Canada[3] 1993 IESNA	Former Soviet Union /Russia[7,23] 1995 (draft)	Proposed[4] European Guideline CEN TC -169 1996
ices										
;eneral	500	300-750	200	100-200	100	500	500	200-300-500	300	500
'DT Tasks	500	300-750	–	500	300-500	300-500	300-500	300	200	500
)esk	500	300-750	600	400-500	300	300	500	200-300-500	300	500
:eading Tasks	–	300-750	900	400	500	500	300	200-300-500	300	500
)rafting (detailed)	750	750-1000	1100	1600	1500*	1000	750	1000-1500-2000	500	750
ssrooms										
;eneral	300-500	200-750	400	500	300-500	300-500	300	200-300-500	300	300-500
:halkboards	300-500	300-1500	900	500	500	300-500	300	500-750-1000	500	500
ail Stores										
.mbient	300	150-750	200	300	200-500*	500	500-1000	200-300-500	300	300
'asks/Till Areas	500	750-1000	600	500	500*	750	500-1000	200-300-500	300	500
;pitals										
:ommon Areas	200	150-300	60	200	150	300	–	100-150-200	150	200
atient Rooms	100-300	100-200	60-200	150	150	100-300	30-50	50-75-100	300	100
)perating Room	1000	750-1500	600	2000	750*	1000	400-500	1000-1500-2000	400	1000
)perating Table	20000-100000	20000	14000	100000	–	>10000	10000-50000	–	10000-500000	10000-100000
ıufacturing	75	750-1500	600-1100	500	750*	750-1500	–	1000-1500-2000	–	750
ine knitting, Sev	1000-1500	1500-3000	–	1000	750-1000	750-1000	–	1000-1500-2000	–	1500

based reading and writing activities. When the medium is the computer, these tasks require less illumination than when it is ink and paper. **Table 2** shows that VDT tasks correspond to lower recommended illumination compared to drafting or reading tasks for most of the countries studied.

Lastly, certain advances in energy-efficient lighting technologies have relevance in discussions of how illuminance standards should be articulated. Historically, assumed lamp lumen depreciation on the order of 20–30 percent is embedded in standards, and in how designers interpret those standards. Today, new light sources, such as 16 mm (T5) triphosphor fluorescent lamps, experience minimal depreciation. Similarly, dimming ballasts allow for automated lumen maintenance over time. Such technologies reduce the burden on illuminance standards to anticipate reductions in delivered illuminance over time.

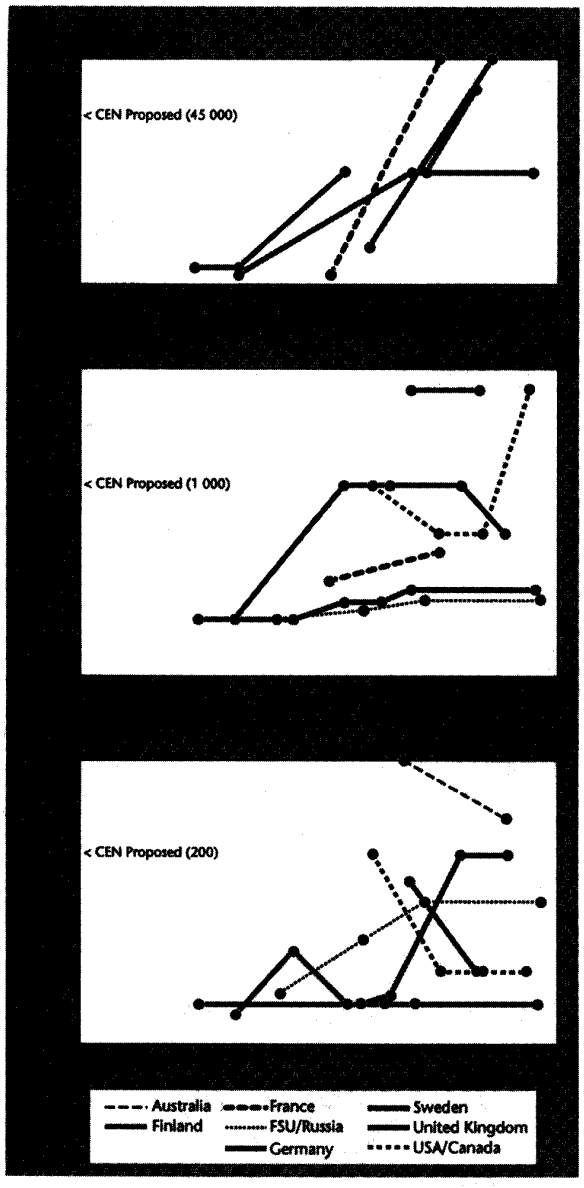

Figure 2e— Time trends for illuminance levels for a selection of countries.

Fertile areas for further investigation include (1) using illuminance level information to better understand current differences in lighting energy use from country to country; (2) integrating trends in illuminance levels into forecasts of future lighting energy demand; and (3) understanding how energy and other factors work together to affect the choice of light-level recommendations.

Beyond the lux

An examination of illuminance levels provides only a partial description of relevant lighting parameters and their implications for visual performance and comfort. The quality of illumination is a function of many other factors, including horizontal vs vertical illuminance, glare, contrast, color rendition, color temperature, and flicker. In one relatively new discovery, researchers have observed that perceived brightness is not simply a function of the cones in the retina (photopic response), but that the rods (scotopic response) also play an important role by influencing pupil size (an indicator of brightness perception). Berman found that light sources with equivalent lumen production (i.e., according to the internationally accepted definition) yield very different pupil sizes—the perception of brightness increases with color temperature—and suggests the adoption of a new measure: pupil lumens based on proper weighting of the photopic and scotopic response of the retina.[28] These results complicate the problem of defining meaningful measures of lighting services (both in terms of energy use and illumination quality).

Further complicating matters, human beings differ in their preferences for illumination intensity and quality. Age, gender, time of day, time of year, and other factors affect the desired illuminance levels. In addition, human perception of "comfortable," "good," or "pleasant" lighting does not necessarily correlate with the horizontal levels that are optimal for task performance.[29] Recommendations stated in terms of minimum luminances and luminance variations of walls and ceilings also tend to have an influence on the preferred lighting levels.[30] Yet another important issue is the relative quality of fixed versus fluctuating light levels. A review of the literature on this topic indicates that more research is needed.[31]

Ideally, people should be able to choose the level that suits them best. In the past this has not generally been possible due to rigidities created by centralized control of lighting systems, restrictions to 100 percent "on" or

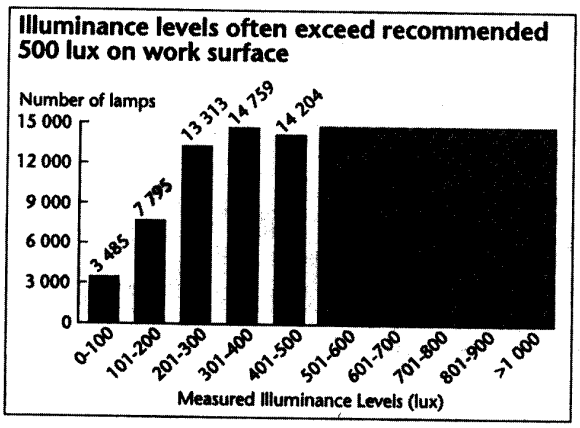

Figure 3— Illuminace levels often exceed recommended 50 fc on work surface. Survey results from Oak Ridge National Laboratory, From Kuliasha.[25]

"off" modes for luminaires, and wiring and control configurations that preclude local variation in illuminance levels. Fortunately, as technology becomes more flexible, opportunities are created for more precise and individualized control. Relatively new technologies such as daylight-linked controls for artificial lighting systems, occupancy sensors, hand-held lighting controls with dimming options, and glazings with variable transmittance, are opening up new possibilities for returning control of lighting to the occupants of buildings. Nonetheless, there will always be circumstances in which individual control is neither practical nor cost-effective.

A trend has begun toward more sophisticated and flexible formulations of illuminance and associated lighting design recommendations. In many European countries, glare criteria, and recommendations on color rendering have been present since the 1960s. In others, as in the most recent Japanese standard for office lighting, glare criteria have only recently been introduced alongside illuminance levels.[32] The current proposed Russian standard specifies disability glare indices, and recommended rates of luminaire cleaning, indices for all lighting applications and color rendering indices and color temperature ranges for industrial and residential settings.[33] As mentioned above, various standards and guidelines explicitly call for daylighting. There is also a trend toward specifying illuminances for specific types of activities rather than for types of architectural settings, as well as a more holistic approach that combines task and building lighting.[34]

Some of these trends demand more technical competence on the part of the designer, while others give the designer more freedom to interpret the standards. The draft review proposal for CEN guidelines specifically says that the guidelines are intended to be used in such a way that they don't impose restrictions on the designer or on the process of technological innovation to find better solutions. In any case, the role of lighting design education takes on a greater importance.

Conclusions

Today there is no consensus among countries as to the "right" light level for a specific task and building type—even within a given country over time. The historical pattern has been an increase in illuminance by up to a factor of ten until the early 1970s, followed by stabilization or decline. It is likely that the turnaround was driven by a combination of economic factors (increasing energy costs), new perspectives on lighting design (more light is not necessarily better light), and a pronounced trend toward more precise focusing of light on specific tasks (task lighting over ambient lighting). The current tendency among countries is toward a convergence at levels significantly lower than in recent decades.

Illuminance recommendations have large potential implications for energy use and may explain differences in lighting energy use from country to country. Before this can be quantified, more research is required including true *in situ* surveys of actual illuminance levels.

Many groups—including lighting manufacturers, lighting engineers, electric utility companies, architects, unions, and employers—have an interest in influencing illuminance levels recommendations. It is also important to note that many other countries—especially in the developing world—adopt lighting recommendations from Western countries.

In all probability, the future will see a more sophisticated integration of energy and non-energy considerations in lighting design. Although it has been a convenient measure of lighting energy services, the "lux" is only an approximate and incomplete indicator. What is needed are sophisticated, quantitative methods (and visualization tools) that can identify least-energy/maximum-quality lighting design solutions.

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11. Germany. Op cit.

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18. Op cit. CEN.

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