TRENDS IN RECOMMENDED LIGHTING LEVELS: An International Comparison

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ABSTRACT

While much focus is placed on energy efficiency as a determinant of lighting energy demand, the lighting level (illuminance) is also a key factor. This paper compiles and compares recommended lighting levels for illustrative commercial and industrial settings in 14 countries. These include offices, classrooms, retail stores, hospitals, and manufacturing activities. The comparison reveals a 2 to 8-fold variation in lighting levels for the activities studied. The general pattern for a given country and activity is that levels increased by up to a factor of ten between the 1930s and the early 1970s; thereafter, levels tended to stabilize or decline. Lighting recommendations have potentially large implications for energy use and may prove useful in explaining differences among countries. Before this can be quantified, more research is required on actual (versus recommended) levels and differences in the efficiency and control strategies of lighting technologies used in each country.

LIGHTING LEVELS IN PERSPECTIVE

Lighting design is in flux. As one indication, a cross-country comparison reveals very rapid changes in recommended lighting levels dating back to the 1930s. Most countries exhibit periods of increasing and decreasing recommended levels, and at any one time there is tremendous variation among countries. This article compiles and compares recommended lighting levels for selected tasks in non-residential buildings in 14 countries, including North America, the former Soviet Union, and most of Western Europe. We also present trends over time 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 lighting levels, but it remains a fertile area for future investigations.

Tremendous effort has been invested in prescribing recommended lighting levels. The most recent edition of the North American IES handbook, for example, specifies levels for approximately 250 interior activities in non-residential buildings and about 300 specific industrial applications. In contrast, the 1991 Dutch recommendations consist of three broad usage categories or situations (e.g. "orientation lighting"), with 7 subcategories (e.g. "perception of large objects", and 17 examples of specific tasks or areas (e.g. "staircases").

Assuming, for the sake of discussion, that all other factors are held constant, changes in lighting levels have corresponding implications for energy use. This paper shows that these trends 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. Given that the efficiency of lighting systems has improved during recent decades, the relative energy implications are even greater.

An examination of lighting levels provides only a very partial description of relevant lighting parameters and the implications for visual performance. The quality of task 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 rather that the rods (scotopic response) play an important role in influencing pupil size (an indicator of brightness perception). Berman found that light sources with equivalent lumen production (i.e. as measured by photopic response) yield very different pupil sizes—the perception of brightness increases with color temperature—and suggests the adoption of a new measure: pupil lumens.[1] These results further complicate the problem of defining meaningful measures of lighting services (both in terms of energy use and illumination quality).

Unfortunately, lighting design is not always done with these factors in mind. As an indication of this, in the United Kingdom, 14 000 copies of the recent lighting handbook [which contains recommended lighting levels] have been sold although approximately 2 000 professional lighting designers are members of CIBSE. For non-specialist lighting designers, lighting levels are a pivotal design parameter.

Further complicating matters, human beings differ in their preferences for illumination intensity and quality. Age, gender, time of day, time of year, etc. affect the desired lighting levels. In addition, human perception of "comfortable", "good", or "pleasant" lighting does not necessarily correlate with the levels that are optimal for task performance.[2] 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.[3]

Ideally, people would 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 "off" modes for luminaires, and wiring configurations that preclude local variation in lighting levels. Fortunately, as technology becomes more sophisticated, 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 not practical or cost-effective. Interior lighting of "common" areas is one instance where individual control is unlikely to be practical. Hence, even in the most technically sophisticated world, there will surely remain a role for lighting levels determined by professional illuminating engineering associations.

METHODOLOGY

We collected current and historic illuminance data directly from country sources where possible. The activities and building types include offices, classrooms, retail stores, hospitals, and manufacturing tasks. The data were supplemented by values in a recent compilation by CEN (The European Committee for Standardization) in which an effort was made to compile comparable estimates. Except where noted, the values represent horizontal maintained luminance values. Several sources report ranges; in this case we averaged the values for the diagrams and—with the exception of North America—show the ranges in the data tables.

It was surprisingly difficult to compile the data, especially historic values. Certain difficulties arose in comparing recommendations for given tasks within and among countries. For example, lighting recommendations tend to become significantly more precisely defined over time. Generalized historic values must be mapped onto specific activities.

Unusual categories for lighting levels must also be addressed in order to make comparisons. In the former Soviet Union, levels for incandescent and fluorescent light sources were published in 1959 and 1971, and they have been averaged in the tables and figures shown here. In 1959, incandescent recommendations were two- to three-times lower than for fluorescent. In 1971, the gap had reduced somewhat. In 1979, only one level was published. As another illustration, the German DIN recommendation has separate recommendations for artificial lighting (DIN 5035) and for artificial lighting in combination with daylighting (DIN 5034). The values in the daylighting recommendation are typically 40% lower than in the DIN 5035 recommendation.

RESULTS

As shown in Figure 1, the comparison of *current* levels reveals a 3- to 7-fold variation for various office building activities; a 2- to 3-fold variation for schools; a 2- to 4-fold variation for retail stores; a 2- to 8-fold variation in hospitals; and a 3- to 5-fold variation among the manufacturing activities studied. The more dramatic variations in each area include: video display terminals (VDTs) where the recommended levels vary from 75 lux to 500 lux, detailed drafting (500 to 2000 lux), chalkboards in schools (300 to 750 lux), general retail lighting (200-750 lux), patient rooms in hospitals (40 to 300 lux), and fine knitting and sewing (500 to 2250 lux).

France and the Netherlands have among the highest levels across the activities and building types we examined. The former Soviet Union, Sweden, and Germany have among the lowest levels. The North American recommendations are average in most cases, and are the lowest of all countries in the case of VDT-based tasks.

Working group 2 of CEN TC/169 is developing recommendations intended for use throughout Europe [the values reported here should be considered preliminary]. Where CIE ISO recommendations apply, they are often identical to CENs proposed levels. As seen in Figure 1, in some cases the standard is within the range of current local recommendations (retail, drafting, classrooms, chalkboards, and operating rooms). In other cases, the recommendations are at or *above* the highest current practice for certain countries (general office lighting, and VDTs).

Figures 2a-2j 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 lux in 1936 to ~500 lux in 1972. In the former Soviet Union, general office lighting was ~25 lux in 1930, rising to 300 lux in 1979. In North America, recommendations for chalkboard lighting rose from ~150 lux in 1938 to 1400 lux in 1972. The proposed CEN recommendations are indicated, where applicable.

After the early 1970s, however, the trend either leveled out or changed direction. General office lighting in Finland fell from 450 lux in 1974 to 225 lux in 1985. Dutch recommendations for reading fell from 750 lux in 1970 to 400 lux in 1991. Even very demanding tasks such as detailed drafting work, and reading the chalkboard show reductions of 50% or more. The most dramatic reduction was from 1500 lux for VDT tasks in the 1972 North American IES recommendations to 75 lux in the forthcoming 1993 recommendations.

Such changes can sometimes be partly explained by changing definitions. As an illustration, Swedish office lighting (on the desk) plunged from 1000 lux in 1970 to 300 lux in 1992. The 1970 values included reading and general desk lighting. The differences between the 1970 recommendation of 1000 lux in the reading field and the 1992 recommendation of 500 lux is still significant, however.

In Germany, Sweden, and the UK—countries for which we have a long historic record—certain current levels have today returned to those prevailing in the 1960s and earlier.

The only countries that have consistently increased lighting levels are France and the former Soviet Union. France today has among the highest lighting recommendations while the FSU still has among the lowest of the countries studied.

The highly dynamic nature of lighting recommendations reflects a variety of factors. In part, the trend reflects changing views about the amount of light needed to perform a given task. In addition, economic considerations play a role. In part, the commercialization of the fluorescent lamp in the 1938 made it possible to dramatically increase light levels without paying a corresponding penalty in energy costs or in excessive heat.

ENERGY IMPLICATIONS

Lighting levels represent an important intersection of lighting design and energy analysis. In both fields, lighting levels are only one of the many relevant parameters for describing lighting systems and their performance. Yet, in both cases, lighting levels serve a useful function in helping to quantify the *service* delivered.

Lighting energy use is a function not only of lighting level but also the efficiency with which that level is provided, special 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 utilization of daylight. Several of these factors are evidenced in Figure 3, which shows installed lighting power (watts) and annual lighting energy use (kWh/m^2-y) for eight non-residential buildings in the Northwestern United States. For each building, the pre-construction predicted values are shown as well as the actual measured values. The large effect of lighting controls (occupancy sensors and dimmable electronic ballasts with daylight sensors) is shown by the wide variation in annual electricity use for a given installed lighting power. Interestingly, in post-occupancy surveys of 200-300 people, no correlation was found between lighting energy use an "lighting satisfaction".

For some countries, reductions in lighting levels--if they are in fact reflected in actual practice--may have to some extent offset growth in electricity demand due to increased floor area. The pending European-wide recommendations could have a significant effect on lighting energy use in the future. The proposed levels for classrooms are 40% lower than currently in effect in France and Germany. For retail lighting, the proposed levels are 40% lower than in France and Switzerland, and 60% lower than in the UK. On the other hand, the recommendations for VDT tasks are equal to or higher than current country recommendations. The recent shift in the UK from initial to maintained illuminance will increase energy use where higher wattage lamps are installed as a means of achieving the recommended light levels.

The changing nature of certain activities suggests another potential linkage between lighting levels and energy use. A clear illustration concerns the increasing importance of computers and VDTs in the workplace. VDTs have replaced the drafting table and many paper-based reading and writing activities. When transferred to the computer, these tasks require less illumination than when done with ink and paper. Table 1 shows that this is the case for most of the countries studied.

Fertile areas for further investigation include (1) using information on lighting levels to better understand *current* differences in lighting energy use among countries, and (2) integrating trends in lighting levels into forecasting for *future* lighting energy demand.

CONCLUSIONS

So far, there has been no consensus among countries as to the "right" light level for a specific task and building type—or even within a given country over time. The historical pattern has been that levels increased by up to a factor of ten until the early 1970s and then stabilized or declined. The turn-around was likely 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 towards more precise focusing of light on specific tasks (task lighting over and above ambient lighting). The recent trend is towards a convergence among countries at levels significantly lower than in recent decades.

Moreover, countries vary considerably in the frequency with which they revise their recommendations. For a period of more than four decades (1948-1990) Sweden had one recommendation for general office lighting, while Germany made six changes. Belgium did not change its recommendation between 1964 and 1992. In Finland, the first recommendations were published until 1971.

Illuminance recommendations have potentially large implications for energy use and may explain differences in lighting energy use among countries. Before this can be quantified, however, more research is required.

Perhaps 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 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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Table 1 Comparison of recommended lighting levels (most recent year) [lux, horizontal-maintained]

Recommendation	Austria	Belgium 1992 [1] NBN 255 & L13-006	Denmark	Finland 1986 Finnish IES	France	Germany 1988 DIN 5035	Netherlands 1991 NEN 3087 NSUV	Sweden 1990 [2] Ljuskultur	Switzerland	United Kingdom 1994 IES/CIBSE	USA Canada Mexico 1993 NA IES	former Soviet Union 1979	Proposed European Guideline CEN/TC-169
Offices													
General	500	500	500	150-300	500	500	100-200	100	500	500	300	300	500
VDT Tasks	500	500	500	150-300	500	500	500	200	---	300-500	75	---	500
Desk	---	500-1000	---	500-1000	500	500	400-500	300	---	500	---	---	---
Reading Tasks	---	---	---	500-1000	---	---	400	500	---	300	300	---	500
Drafting (detailed)	750	1000	1000	1000-2000	1000	750	1600	2000	750	750	1500	500	750
Classrooms													
General	300	300	200	150-300	500	300	500	300	300	300	300	300	300
Chalkboards [3]	300	300	500	300-750	500	500	500	300	500	500	750	---	500
Retail Stores													
Ambient	300	300	300	150-300	500	300	300	200	500	500-1000	300	200-300	300
Tasks/Till Areas	500	750	500	500-1000	750	500	500	500	750	500-1000	300	---	500
Hospitals													
Common Areas	100	---	100	---	150	100	150	200	200	---	150	---	100
Patient Rooms	200	---	---	50-100	300	80-120	200	200	200	30-50	75	150	---
Operating Room	---	---	---	1000-2000	2000	1000	2000	750	1000	400-500	1500	400	1000-2000
Operating Table	20-100000	---	---	30000-75000	100000	20-100000	100000	---	50000	10-50000	---	---	20-100000
Manufacturing													
Fine knitting, sewing	2000	1000	---	---	500	---	500	500	500	---	1500-3000	---	500
Electronics: test/adj.	1500	1000	500	---	1000	1000	1000	750	750	---	---	---	1000

Notes. Where ranges are specified, an average is used. In the North American IES recommendations, the middle of three values is used.
[1]. The Belgian recommendations are considered to be mandatory (minimum) levels. This is the only case of this we are aware of. recommendation.
[2]. Swedish values for office lighting (desk, reading, room) are 1992 updates. [3]. Vertical illuminances: B-chalkboard, CH-chalkboard

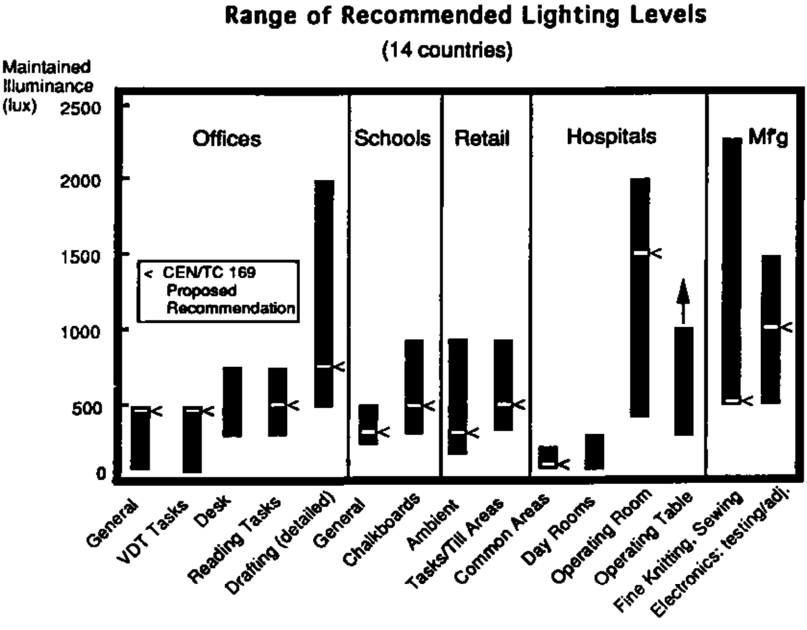
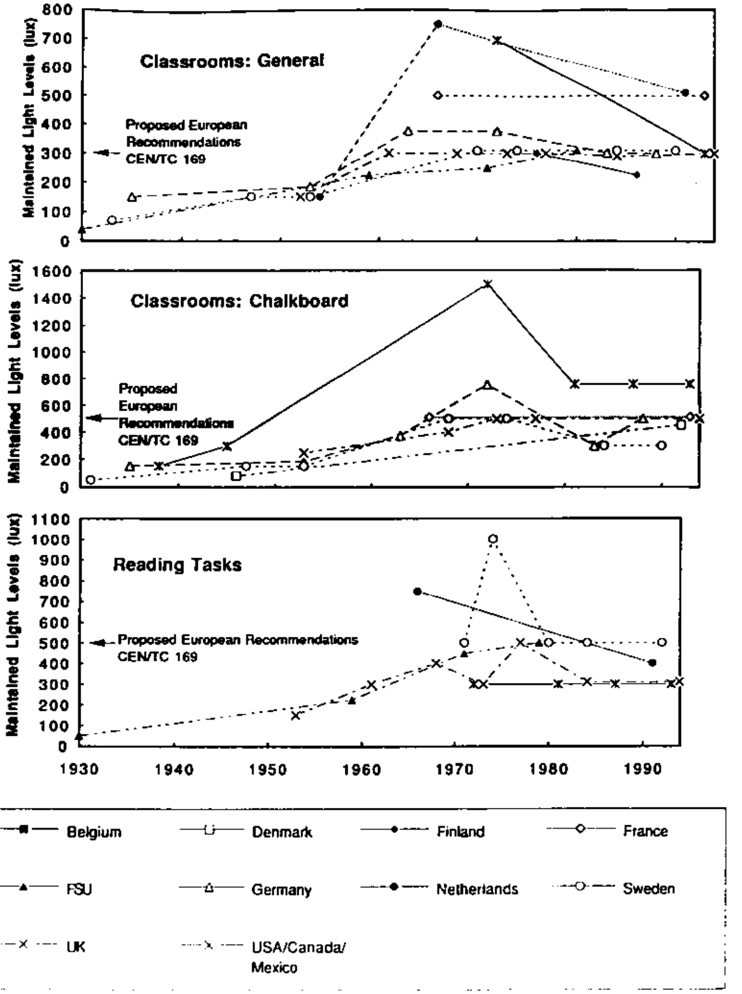
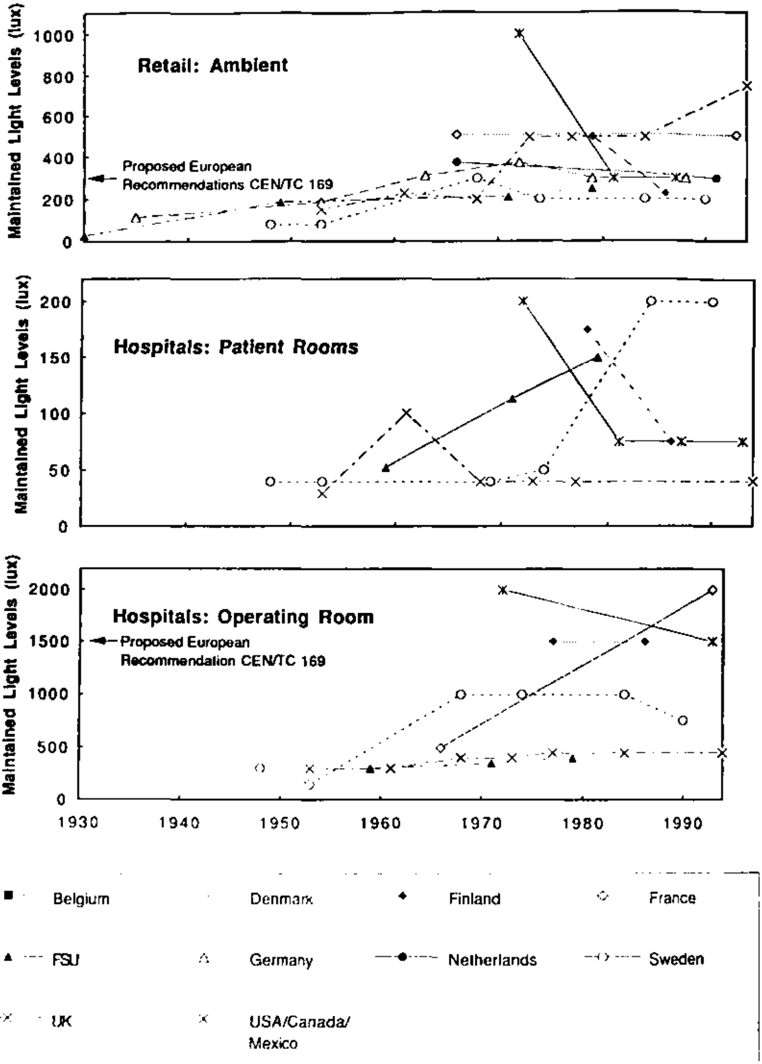
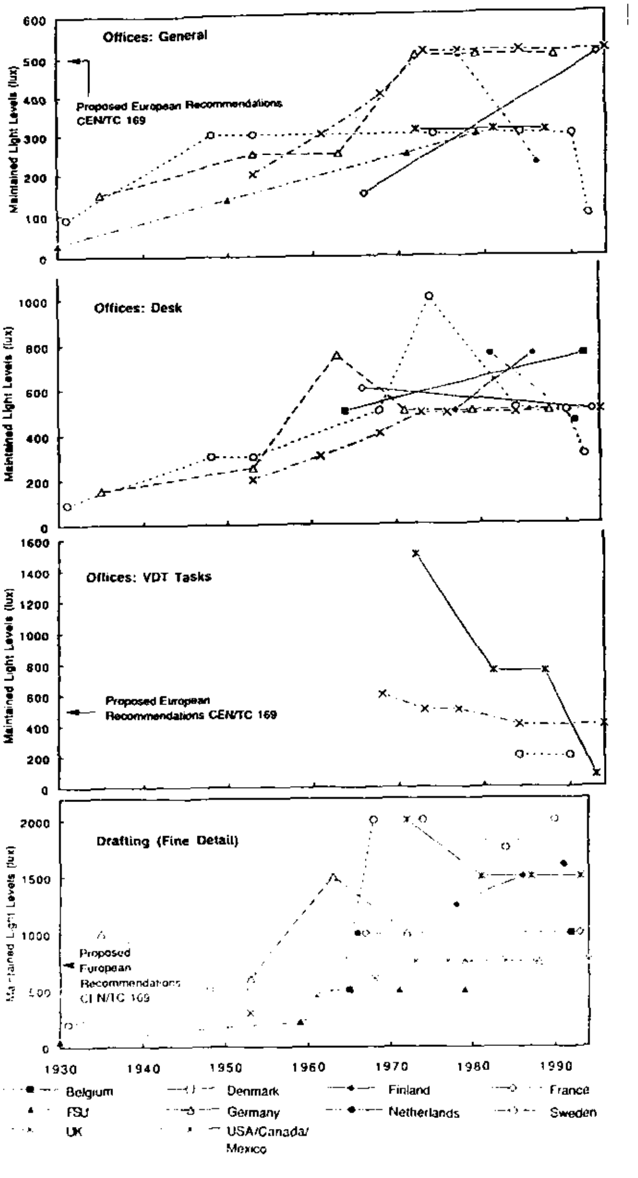


Figure 1 Range of recommended lighting levels (14 countries). Note: values for operating table have been reduced by 100x in order to scale to other values.



Figures 2a-j Historic development of recommended lighting levels. Values for the former Soviet Union for 1959 and 1971 are the average of recommended incandescent and fluorescent light sources. UK values are initial lumens, with the exception of 1994 (maintained). The proposed CEN recommendations are also indicated.


Retail: Ambient
Maintained Light Levels (lux)
1000
800
600
400
200
0
Proposed European
Recommendations CEN/TC 169
Hospitals: Patient Rooms
Maintained Light Levels (lux)
200
150
100
50
0
Hospitals: Operating Room
Maintained Light Levels (lux)
2000
1500
1000
500
0
Proposed European
Recommendation CEN/TC 169
1930
1940
1950
1960
1970
1980
1990
Belgium
Denmark
Finland
France
FSU
Germany
Netherlands
Sweden
UK
USA/Canada/
Mexico


Offices: General
Proposed European Recommendations CEN/TC 169
Maintained Light Levels (lux)
Offices: Desk
Maintained Light Levels (lux)
Offices: VDT Tasks
Proposed European Recommendations CEN/TC 169
Maintained Light Levels (lux)
Drafting (Fine Detail)
Proposed European Recommendations CEN/TC 169
1930
1940
1950
1960
1970
1980
1990
Belgium
Denmark
Finland
France
FSU
Germany
Netherlands
Sweden
UK
USA/Canada/Mexico

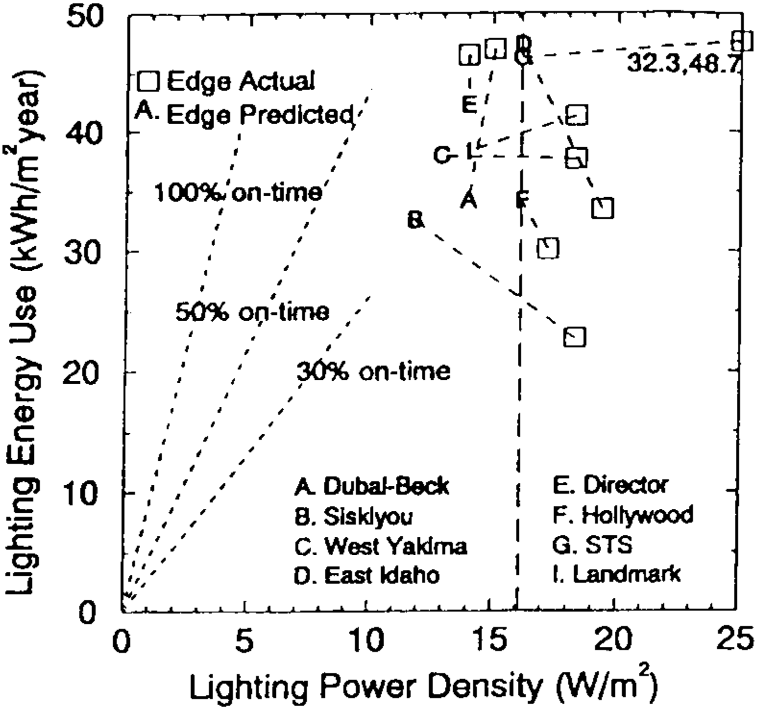


Figure 3 Lighting power density versus annual lighting energy use for eight office buildings, based on pre-construction design estimates, post-construction building audits, and end-use metering. The dashed vertical line at 16 W/m^2 represents the maximum lighting power density allowed by the regional building code.[4]