Chapter 4: Lighting and energy standards and codes

Topics covered

4 Lighting and energy standards and codes

4.1 Review of lighting standards worldwide

4.1.1 Introduction

The major international organization in charge of coordinating the management of standards, recommendations, and technical reports in the field of lighting is the Commission Internationale de l'Eclairage (CIE). The CIE has published several recommendations for indoor lighting and has contributed to a joint ISO-CIE standard ISO 8995-1 (CIE, 2001/ISO 2002) concerning indoor working places.

The CIE publications related to indoor lighting are listed below:

CIE 49-1981: Guide on the Emergency Lighting of Building Interiors

CIE 52-1982: Calculations for Interior Lighting: Applied Method

CIE 55-1983: Discomfort Glare in the Interior Working Environment

CIE 60-1984: Vision and the Visual Display Unit Work Station

CIE 117-1995: Discomfort Glare in Interior Lighting

CIE 123-1997: Low vision - Lighting Needs for the Partially Sighted

CIE S 008/E: 2001/ISO 8995-1:2002(E): Lighting of Work Places - Part 1: Indoor

CIE 146/147:2002 : CIE Collection on Glare 2002

CIE 161:2004: Lighting Design Methods for Obstructed Interiors

CIE S 010/E:2004/ ISO 23539:2005(E): Photometry - The CIE System of Physical Photometry

CIE 097:2005: Maintenance of Indoor Electric Lighting Systems, 2nd Edition

CIE S 009 / E:2002 / IEC 62471:2006: Photobiological Safety of Lamps and Lamp Systems

ISO 11664-2:2008(E)/CIE S 014-2/E:2006: CIE Standard llluminants for Colorimetry

CIE 184:2009: Indoor Daylight Illuminants

The recommendations of the CIE have been interpreted in different manners in different countries. Hence some differences exist among lighting recommendations worldwide. Furthermore, in the North America, the Illuminating Engineering Society of North America (IESNA) is active in developing its own recommendations. The best known documents are the IES Lighting Handbooks which are regularly updated. The working groups of the IESNA have their own references and it is quite typical that some approaches differ from those of the CIE. For example, IESNA uses the term Visual Comfort Probability (VCP) for glare rating issues (Rea 2000), whereas the CIE glare rating is called the Unified Glare Ratio (UGR) (CIE 1995).

In the Annex 45 work the lighting recommendations worldwide were compared. The comparison is useful in identifying the potential for amending these standards, considering the growing need for the increasing energy efficiency of lighting. The review focused on office buildings.

4.1.2 Data collection

The first task was to collect the documents presenting national lighting recommendations from different countries through network of experts, and to translate the various published criteria of non-English documents into English. The lighting recommendation data was collected from eleven countries/regions, including both industrialised and developing countries. The collected documents related to indoor lighting recommendations from different countries are listed below.

Argentina:
Tonello, G. y Sandoval, J.,"Recomendaciones para iluminación de oficinas" Asociación Argentina de Luminotécnia (AADL), 1997.

Australia:
AS/NZS 1680.0-1998 Interior lighting - Safe movement
AS 1680.1-2006 Interior and workplace lighting - General principles and recommendations.
AS 1680.2.0-1990 Interior lighting: Part 2.0 - Recommendations for specific tasks and interiors.
AS 1680.2.1-1993 Interior lighting: Part 2.1- Circulation spaces and other general areas.
AS 1680.2.2-1994 Interior lighting - Office and screen-based tasks
AS 1680.2.3-1994 Interior lighting: Part 2.1- Educational and training facilities

Brazil:
CIE 29.2-1986: Guide on Interior Lighting

China:
GB 50034-2004 Standard for lighting design of buildings.

Europe:
EN 12464-1:2002: Light and lighting- Lighting of work places- Part 1: Indoor Work Places.

India:
IS 3646 (Part 1):1992, Code of practice for interior illumination: Part 1 General requirements and recommendations for working interiors.
National Building Code of India 2005 (NBC 2005) Part 8, Section 1

Japan:
JIES-008 (1999)- Indoor Lighting Standard.

Nepal:
J.B. Gupta, Electrical installation estimation and costing, S.K. Kataria & Sons. New Delhi 1995, 7th edition.

Russia:
SNiP 23-05-95 Daylight and Artificial Lighting: Construction Standards and Rules of Russian Federation.

South Africa:

SANS 10114-1:2005 - Code of Practice for Interior Lighting.
USA:
ANSI/IESNA RP-1-04, American National Standard Practice for Office Lighting.

4.1.3 Method

The Table 4.1 shows various lighting parameters which were selected in collecting the data. Specifications for collecting data were divided into three categories: individual needs, social needs and environmental needs.

4.1.4 Display using world maps

Details of the lighting recommendations for office lighting are presented in *Appendix A*. In order to give a general view of the consistency of and differences in specifications in lighting standards and codes across the world, the main recommended values are presented on world maps, Figures 4-1 – 4-7. ISO/CIE standard recommendation values are also presented in the map for comparison with the national/regional recommendations. Most lighting recommendations include specifications on:

- Minimum illuminance levels on work planes (Figure 4-1)
- Minimum illuminance when working on computers (Figure 4-2)
- Minimum illuminance in the surroundings (Figure 4-3)
- Luminance ratios near task areas (Figure 4-4)
- Glare rating (Figure 4-5)
- Luminances on the ceiling and shielding angle (Figure 4-6)
- Indoor surface reflectance (Figure 4-7)

These specifications are essential, since they impose the measures to maintain the quality of lighting. These measures are the production of minimum quantities of light (lumen) in room and in task areas, recommendations in the distribution of the light in the task and surrounding areas, recommendations on the glare, etc.

Table 4-1. *Various lighting parameters selected in collecting the data from the national lighting recommendations.*

A. INDIVIDUAL NEEDS	
VISUAL PERFORMANCE	Illuminance (horizontal) on task area Illuminance (vertical) on task area Illuminance (horizontal) on computer (keyboard, mouse) Illuminance for drawing Illuminance of immediate surroundings Illuminance (vertical) on screens
VISUAL COMFORT	Luminance ratio on the task area (luminances on walls, ceilings, task plane, etc.) Ceiling luminance Maximum luminance from overhead luminaries Maximum wall luminance Maximum window luminance Recommended surface reflectances Specification of flicker-free light sources Illuminance uniformity on the task area Discomfort Glare Rating Discomfort glare in the case of use of Visual Display Terminals (VDT) Control of reflected glare and veiling reflections Possible specifications regarding lighting fixtures
COLOR APPEARANCE	Color rendering index (CRI) Correlated color temperature(CCT) Possible use of saturated colors Possible use of color variations of light
WELL-BEING	View to the outside Light quality through lighting modelling Directional lighting Biophilia hypothesis (Expression of recommendations to maximize daylight) Lighting quality / Aesthetics of space Aesthetics of lighting equipment Individual or programmed lighting and daylight control
NON VISUAL EFFECTS	Role of spectral power distribution Daylight exposure through value of daylight factor Daily exposure to daylight Frequency of light (Hz) UV(Ultra Violet) content of light Infra red exposure associated to lighting
B. SOCIAL NEEDS	
	Cost, budget User satisfaction (expressed by reduction of complaints) Impact of lighting quality on productivity through reduction of failures, higher satisfaction and less fatigue Reduction of maintenance through improved quality of equipment Impact of lighting on security issues Impact of lighting on feeling of safety
C. ENVIRONMENTAL NEEDS	
	Reduction of power consumption for lighting through efficient light sources and luminaries Ability of lighting system to minimize peak load demand (use of daylight, adjusted power consumption) Lighting controls (use of daylight, use of occupancy sensors) Reduction of harmonics and power losses in electricity distribution networks Reduction of resources for making lamps (increased life of sources) Reduction of environmental impact (low production of pollutants)

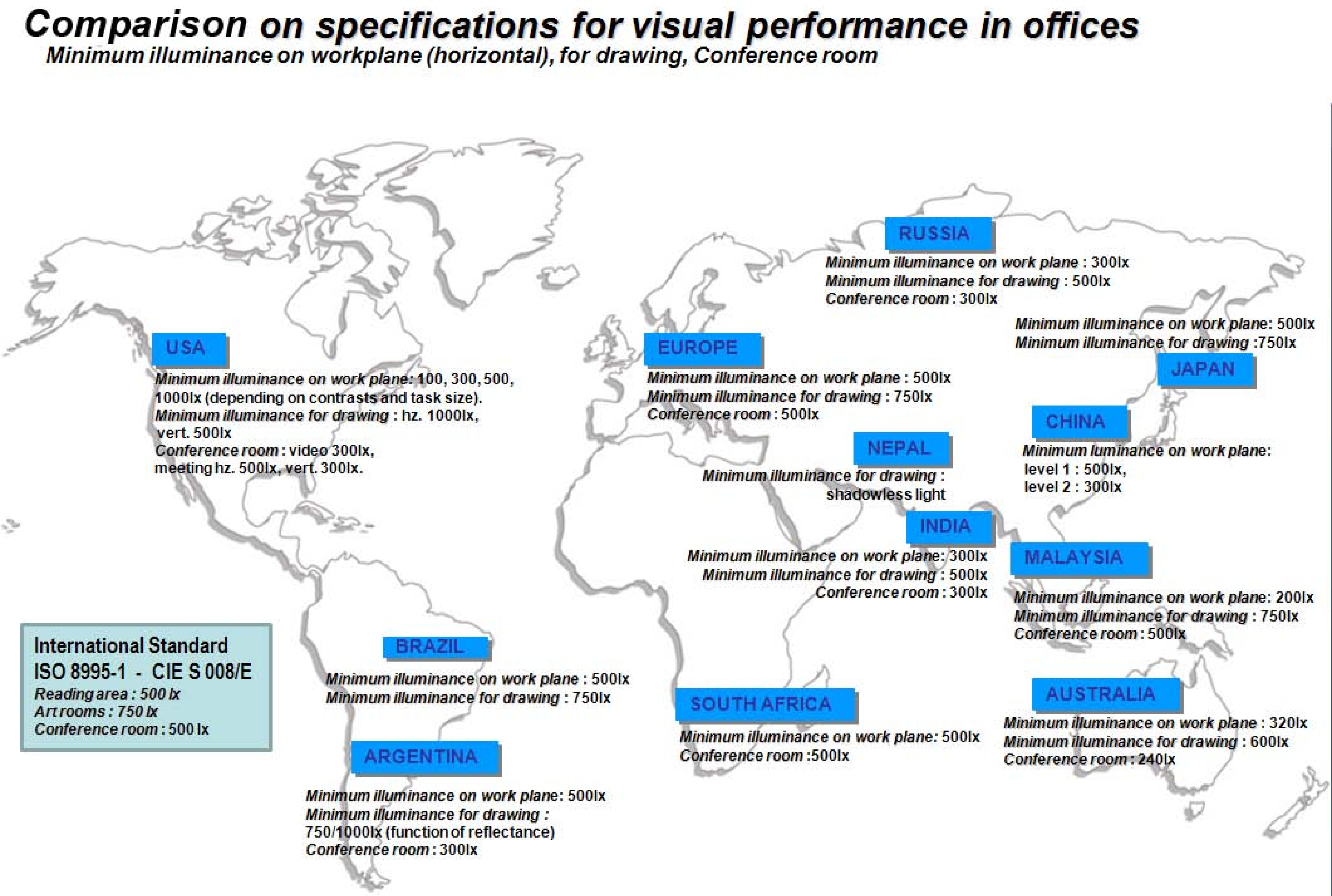

Figure 4-1. *Minimum illuminance on work plane (horizontal) for drawing and minimum illuminance on conference rooms.*

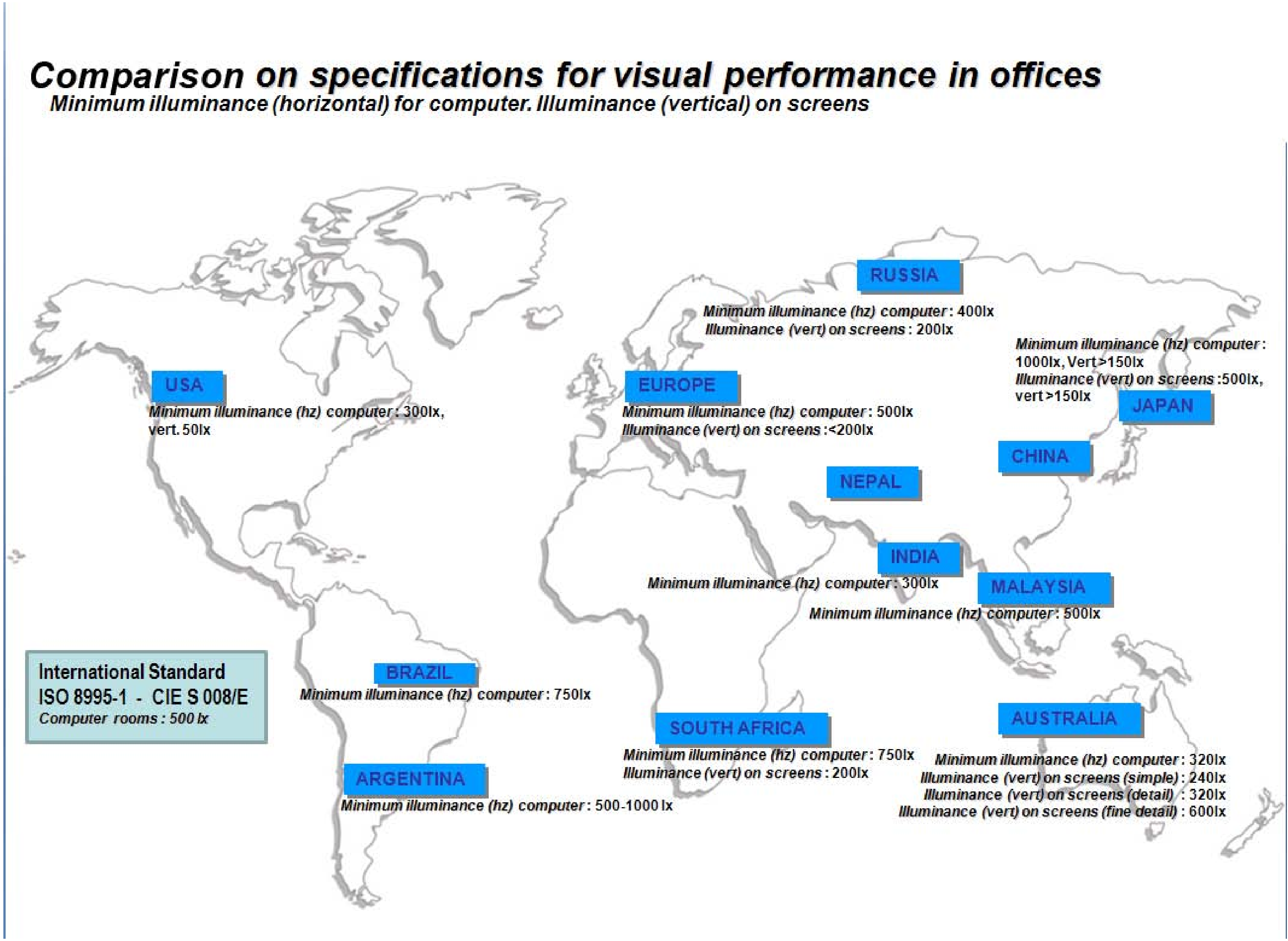

Figure 4- 2. *Minimum illuminance on work plane for offices with computer screens.*

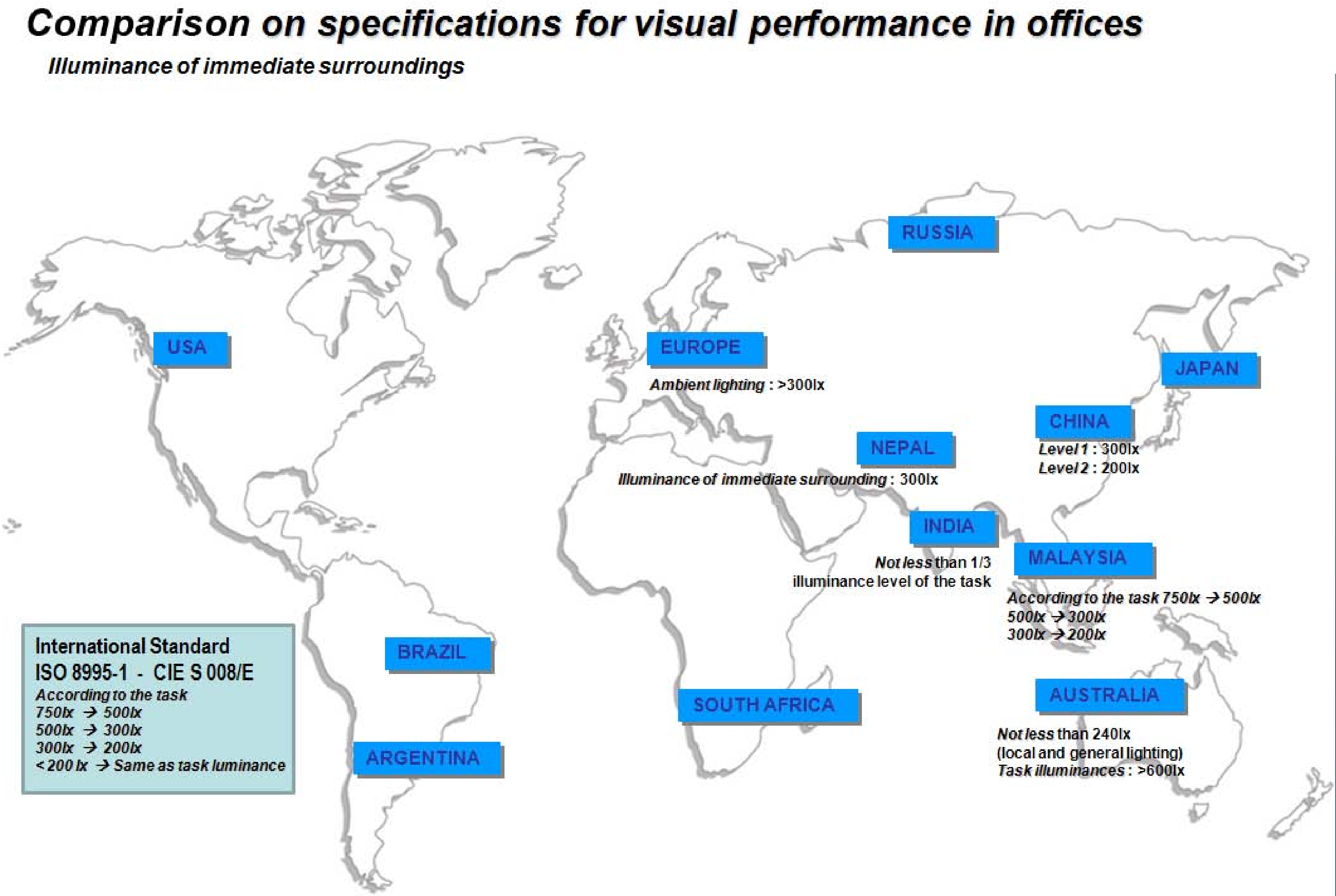

Figure 4- 3. *Illuminance in the vicinity of the work place.*

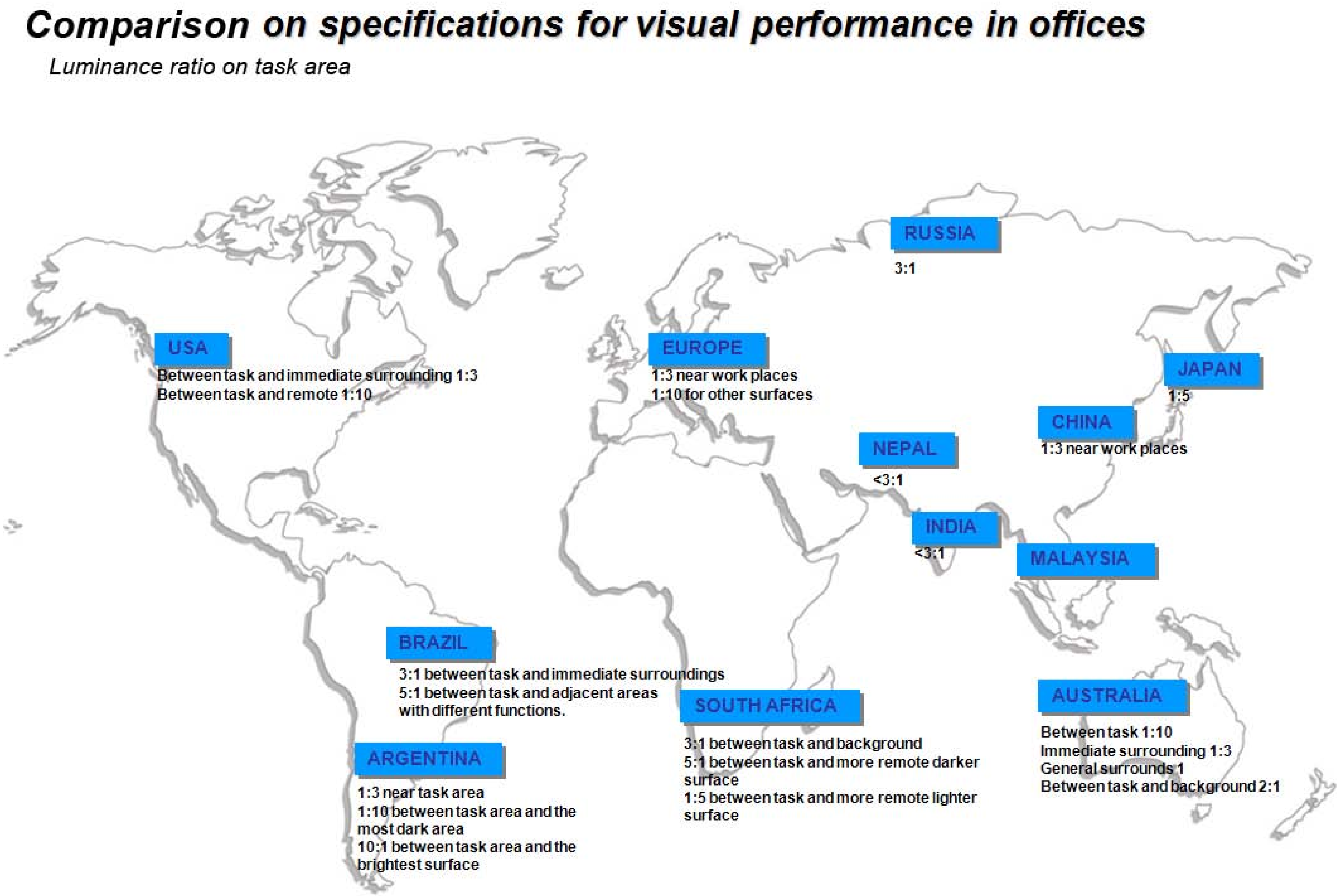

Figure 4-4. *Ratios of luminance in the field of vision.*

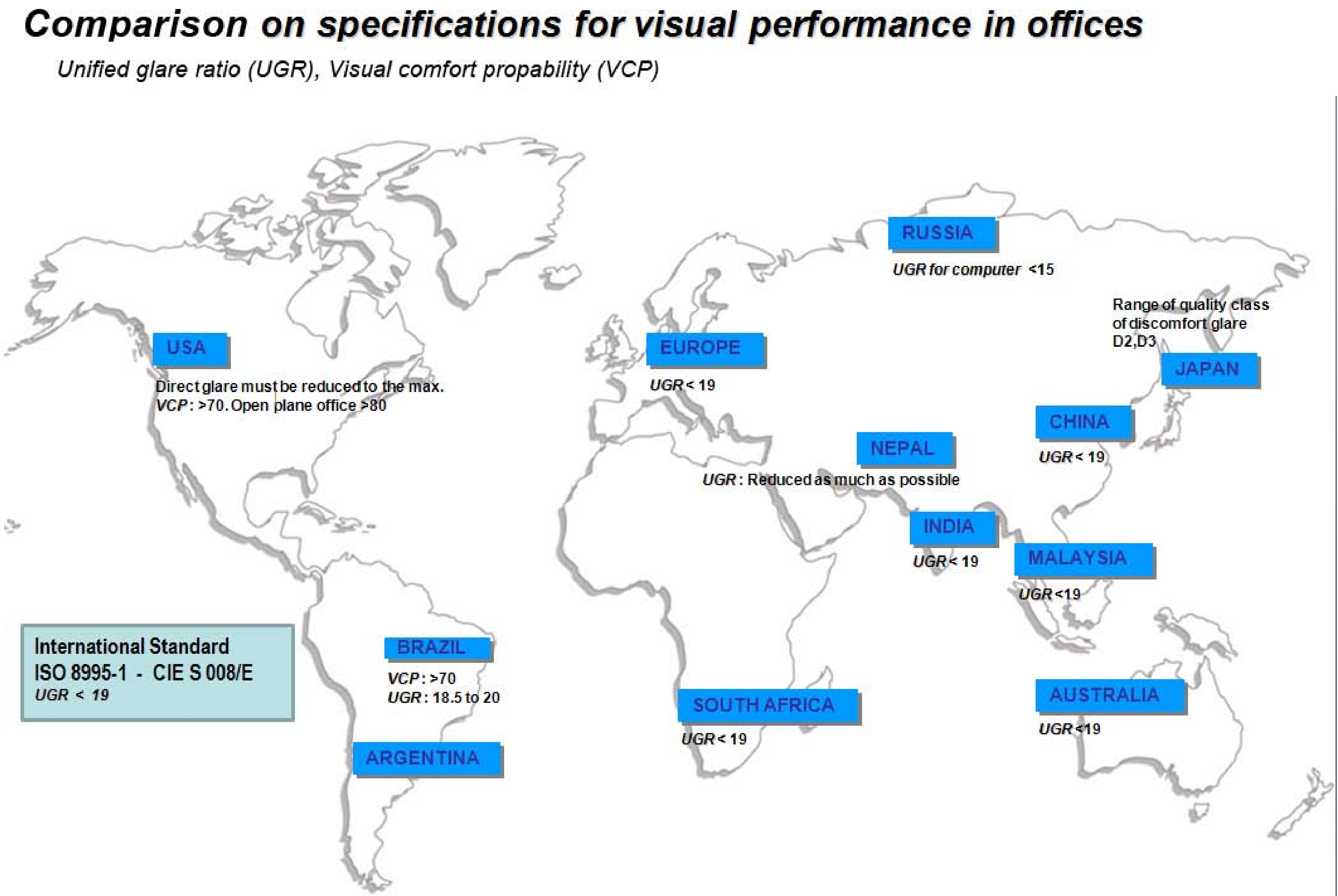

Figure 4-5. *Glare specifications.*

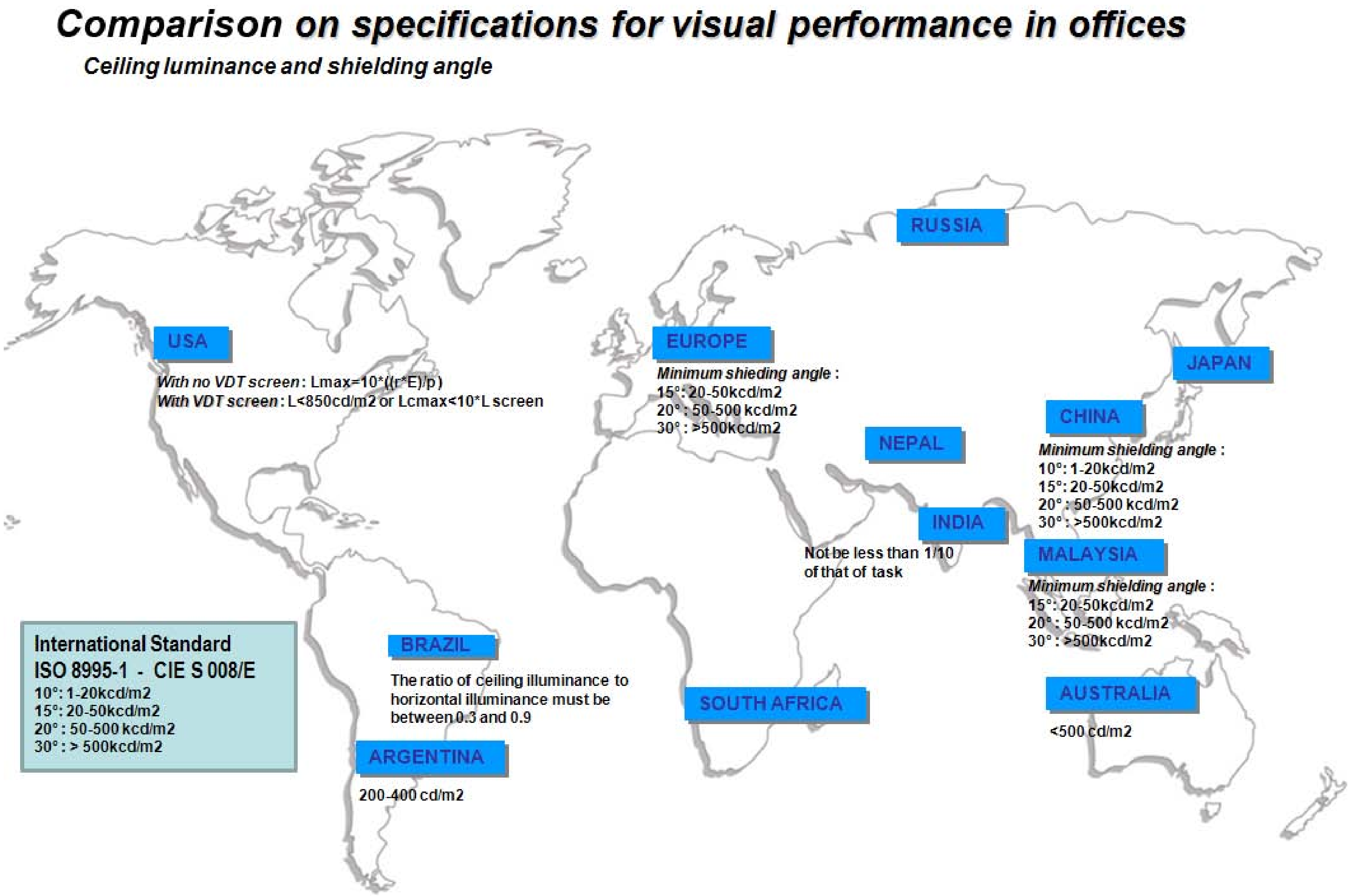

Figure 4-6. *Ceiling luminances and shielding angle.*

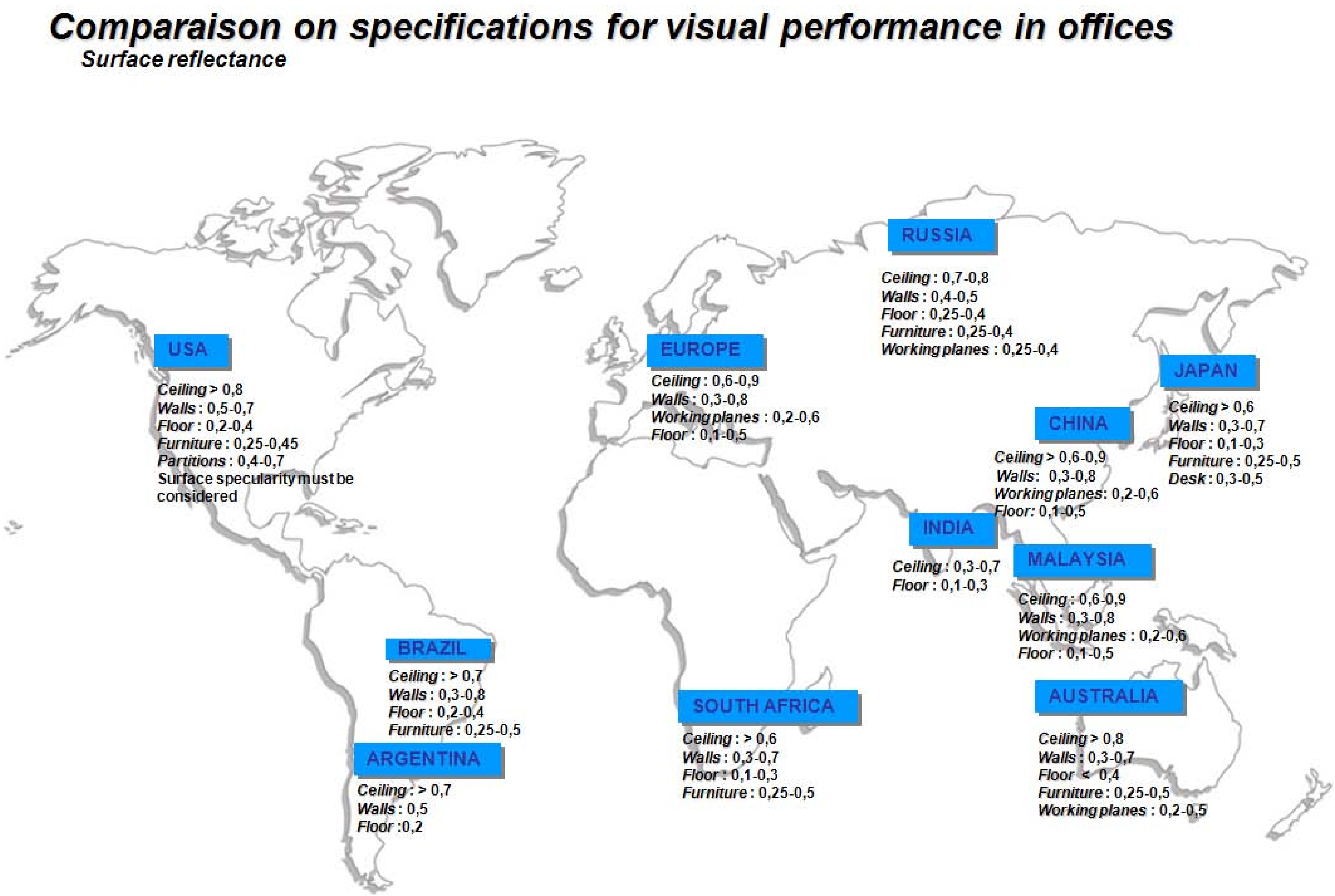

Figure 4-7. *Surface reflectances.*

The summary of the lighting recommendations presented in Figures 4-1 – 4-7 indicate the following.

- Minimum values of illuminance on work planes for office work, drawing and conference rooms vary from 200 to 500 lx, which leads to a total discrepancy of lighting power of 1:2.5 if the lighting uniformities delivered in the rooms are identical.
- Recommendations concern minimum horizontal and vertical illuminance values. The recommendations do not take into account the luminances of computer screens.
- Ratios of luminance in the field of vision are rather consistent and similar to the CIE work recommendations.
- Glare ratings use either the Unified Glare Ratio (UGR) of the CIE or the Visual Comfort Probability (VCP) of the IESNA. These specifications are rather consistent.
- Ceiling luminance and shielding seem to be rather consistent. This is essential with the development of direct/indirect luminaires. However, no specification takes into account the risk of overhead glare, which is an issue under discussion at the CIE.

4.1.5 Recommended illuminance levels

Details of the recommended illuminance values for office lighting found in different national recommendations worldwide are tabulated in *Appendix A*. Basically, the differences in recommended illuminances are not high since they tend to be related to the CIE recommendations. However, there are countries which recommend lower values of minimum illuminance.

The ISO standard ISO 8995-1:2002 (CIE 2001/ISO 2002) states that in the areas where continuous work is carried out the maintained work plane illuminance should not be less than 200 lx. In all the reviewed recommendations, the minimum work plane illuminances in offices were higher. ISO 8995-1:2002 standard does not give any recommendation for uniformity of illuminance on the work plane, but suggests that the illuminance in the vicinity of the task should not be too low in comparison to the illuminance on task area. For example, the illuminance in the vicinity of task is 300 lx for a task with illuminance of 500 lx, 200 lx for a task with illuminance of 300 lx. However, the illuminance in the vicinity of task should be equal to the illuminance in the task area if the value for task illuminance is below 200 lx. In most countries which were reviewed, the minimum maintained illuminance on desks for regular office work is 500 lx, but lower values are recommended in India (300 lx), Denmark (300 lx), USA (depending on type of task) and Australia (320 lx). Minimum illuminance values for lounges, lobbies and corridors are specified within a range from 50 to 100 lx depending on country.

4.2 Energy codes and policies

4.2.1 Europe – Energy performance of buildings directive

The building sector in the EU area is using 40% of the total EU energy consumption and is responsible for 36% of the CO_2 emissions. There are 210 million households and the area of the households is 15 000 km^2, while the area of offices is 6 000 km^2. The EU building sector offers significant potential for cost-effective energy savings. (Wouters 2009)

The Europe Energy Performance of Buildings Directive (EPBD) offers holistic approach towards more energy efficient buildings. The objective of EPBD is to promote the improvement of energy performance of buildings within the EU through cost-effective measures. The EPBD requires all EU countries to enhance their building regulations and to introduce energy certification schemes for buildings. The countries are also required to have inspections of boilers and air-conditioners.

All EU member countries have produced a status report in 2008 about the implementation of the EPBD in their country; the compiled country reports are available at the website of Concerted Action of EPBD. Many countries have set new requirements for instance for the U-values (coefficient of thermal transmission) or for the primary energy demand per square meter. (CA EPBD 2008). According to Maldonado et al. (2009), positive aspects of the EPBD are e.g.: new, more demanding building regulations to be in force throughout the EU, and further on the plans call for tougher regulations every five years. There are also now clear targets for what can be considered high-performance buildings in most member states, and the awareness of the importance of building energy efficiency is increased in EU. (Maldonado 2009)

4.2.2 Energy efficient building codes and policies in the US

In the US buildings consume more energy than any other sector of the US economy. Almost three-quarters of the 81 million buildings in the US were built before 1979. The building sector accounts for about 40% of the primary energy use and about for 40% of energy-related CO_2 emissions. The US buildings contribute 9% of the world CO_2 emissions. Lighting consumes about 11% of the energy of residential sector and 26% of the energy of the commercial sector. (Sunder 2009)

The following Actions have building related programs:

- Energy Policy Act (EPAct 2005)
- Energy Independence and Security Act (EISA 2007)
- American Recovery and Reinvestment Act (ARRA 2009)

For instance the EPAct directs R&D for new buildings and retrofits including onsite renewable energy generation and extends the ENERGY STAR programme (Ch. 4.4.1) by adding new energy conservation standards and expands energy efficient product labeling. The EISA upgrades energy standards for appliances, equipment and lighting and mandates the zero-net energy commercial building initiative. The ARRA invests to improve energy efficiency of Federal buildings, schools, hospitals, and low-income houses using existing cost-effective technologies. The application of existing technologies yields efficiency improvements of 30-40%. (Sunder 2009)

4.2.3 Energy efficient building codes and policies in China

Urbanization is speeding up in China. Today the ecological footprint in China is 1.6 global hectares per capita, whereas the world average is 2.2 global hectares per capita. In 2006 the building area in China was estimated to be 175 000 km^2 (175 Mm^2), and the forecast for year 2020 is 30000 000 km^2 (30 Gm^2). (Wang 2009)

Wang gives annual energy consumption in 2004 for commercial buildings (kWh/m^2,a) (government office, hotel, shopping mall, office, comprehensive business building). The majority of the buildings use less than 150 kWh/m^2, a and almost all buildings less than 300 kWh/m^2,a. The 11th Five-Year Plan of China has set a target of improving energy efficiency. The key goal is that energy intensity relative to the country’s gross domestic product should be reduced by 20% from 2005 to 2020. The targets for buildings are to build new energy efficient buildings of 1.6 Gm^2 building area with 50% increase in efficiency and to retrofit about 554 Mm^2 of existing residential and public buildings. In addition, 15 Mm^2 of renewable energy demonstration projects is to be built. (Wang 2009)

4.2.4 Energy efficient building codes and policies in Brazil

In Brazil 47.5% of the total energy consumption is produced by renewable energy, including hydro power and power from sugar cane products. However, the share of non-renewable energy is increasing. Lighting uses 17% of the energy consumption in the residential sector. In commercial buildings the share of lighting energy of the total building energy consumption is from 12% to 57%, being 22% on average. In the public sector lighting uses 23% of the total energy consumption, while HVAC uses 48%, other equipment 15% and other loads 14%. In Brazil there are few laws and standards that include demands for energy efficiency and building performance, these are the Law 9991- 2000 Investments in R&D and energy efficiency by utilities and the Law 10295 – 2001 Energy efficiency law. The standard ABNT 15220 concerns thermal performance and the ABNT 15575 gives minimum performances.

4.2.5 Energy efficient building codes and policies in South Africa

The CO_2 emissions of the total energy in South Africa are divided per sector as follows: residential 13%, commercial 10%, transport 16%, manufacturing 40%, mining 11% and other 10%. The energy efficiency strategy was created in 2004 and building regulations have been renewed recently. The SANS 0204 will set out the general requirements for improving energy efficiency in all types of new buildings. SANS 0204 will be incorporated into National Building regulations. (Milford 2009)

The energy efficiency strategy sets national targets for final energy demand reduction by 2015. The targets are 10% reduction in the residential sector and 15% in the commercial sector. Targets are expressed in relation to the forecast national energy demand in 2015. The means to reach the targets are legislation, efficiency labels and performance standards, energy management activities and energy audits and promotion of efficient practices. In addition there are some local initiatives. The draft for Gauteng energy strategy aims to replace incandescent lamps in government buildings by energy efficient lighting by 2012, and to reduce energy demand by 25% in government buildings by 2014. (Milford 2009)

4.2.6 25 Energy Efficiency Policy Recommendations by IEA to THE G8

The IEA recommendations document reports the outcome of the IEA three-year programme in support of the second focus area of the IEA G8 Gleneagles programme: energy efficiency policies. (IEA 2008). The recommendations cover 25 fields of action across seven priority areas: cross-sectoral activity, buildings, appliances, lighting, transport, industry and power utilities. It is noted that the saving by adopting efficient lighting technology is very cost-effective and buildings account for about 40% of the total energy used in most countries. The fields of action of buildings and lighting are outlined below:

Buildings

- Building codes for new buildings
- Passive Energy Houses and Zero Energy Buildings
- Policy packages to promote energy efficiency in existing buildings
- Building certification schemes
- Energy efficiency improvements in glazed areas

Lighting

- Best practice lighting and the phase-out of incandescent lamps
- Ensuring least-cost lighting in non-residential buildings and the phase-out of inefficient fuel-based lighting

4.3 Energy-related legislation in the European Union

4.3.1 Introduction

Several directives, regulations and other legislations are in force or under development in the European Union. The most important directives and other legislations at European level regarding the lighting sector are listed below:

- EuP, Energy-using Products Directive (EC 2005) which was recast in 2009 by directive of ecodesign requirements for energy related products
- Ballast Directive (EC 2000)
- EPBD, Energy Performance of Buildings Directive (EC 2002)
- ESD, Energy Services Directive (EC 2006)
- EEL, Energy Efficiency Label (EC 1998)

4.3.2 EuP Directive

Directive 2005/32/EC of the European Parliament and of the Council of July 6th 2005 establishes a framework for the setting of ecodesign requirements for energy-using products and amending Council Directive 92/42/EEC and Directives 96/57/EC, and 2000/55/EC of the European Parliament and of the Council. This so called EuP Directive or the Ecodesign Directive defines for which types of products shall be implementing measures shall be done and how (EC 2005).

The directive promotes environmentally conscious product design (*ecodesign*) and contributes to sustainable development by increasing energy efficiency and the level of environmental protection. Ecodesign means the integration of environmental aspects in product design with the aim of improving the environmental performance of the product throughout its life cycle. The EuP directive also increases the security of the energy supply at the same time.

The procedure for creating implementing measures under the EuP directive is defined in the directive. In practice, product groups are identified by the European Commission. Preparatory studies on these products aim to identify and recommend ways to improve the environmental performance of products. The performance of the products is considered throughout their lifetime at their design phase based on a methodology called MEEUP (methodology study for ecodesign of the energy-using products). MEEUP defines eight areas to be included in each preparatory study:

1. Product Definition, Standards and Legislation
2. Economics and Market Analysis
3. Consumer Analysis and Local Infrastructure
4. Technical Analysis of Existing Products
5. Definition of Base Case(s)
6. Technical Analysis of Best Available Technology (BAT)
7. Improvement Potential
8. Policy, Impact and Sensitivity Analysis

The use of MEEUP ensures that all the necessary areas are taken into account in the preparatory studies.

The European Commission writes draft implementing measures, starting from these preparatory studies and consulting the stakeholders in consultation forums. These measures are voted by the Member States and are then given to the European Parliament for the final vote.

According to the EuP directive, the requirements can be generic or specific ecodesign requirements. A generic ecodesign requirement is based on the ecological profile of an EuP, and it does not set limit values for particular environmental aspects. A specific ecodesign requirement is a quantified and measurable ecodesign requirement related to a particular environmental aspect of an EuP, such as energy consumption calculated for a given unit of output performance during usage.

The EuP directive is a product directive and has a direct consequence on the *CE marking* of the new products. Before an EuP covered by implementing measures is placed on the market, a CE conformity marking shall be affixed. A declaration of the conformity shall be issued whereby the manufacturer or its authorised representative ensures and declares that the EuP complies with all relevant provisions of the applicable implementing measure. (EC 2005)

Lighting products have been selected as one of the priority product groups in the EuP directive. Preparatory studies have been prepared for street, office and residential lighting products. The outcome of these studies is two regulations in force and one under construction. The two implementing measures have been published in the form of Commission Regulations and entered into force on the 13th of April 2009 in all Member States:

— Commission Regulation (EC) No 245/2009 of March 18th, 2009 implementing Directive 2005/32/EC of the European Parliament and of the Council with regard to ecodesign requirements for fluorescent lamps without integrated ballast, for high intensity discharge lamps, and for ballasts and luminaires able to operate such lamps, and repealing Directive 2000/55/EC of the European Parliament and of the Council.
— Commission Regulation (EC) No 244/2009 of March 18th, 2009 implementing Directive 2005/32/EC of the European Parliament and the Council with regard to ecodesign requirements for non-directional household lamps.

These regulations give generic and specific requirements for lamps, luminaires and ballasts. The directive 2000/55/EC – the so called ballast directive – is repealed by the regulation 245/2009 one year after the regulation enters into force.

The Preparatory Study for Eco-design Requirements of EuPs on "Domestic lighting – Part 2: Directional lamps and household luminaires" is almost ready and discussion with stakeholders has started.

In the lighting sector, there are three implementing measures of the EuP directive:
- Regulation 244/2009 for non-directional household lamps
- Regulation 245/2009 for fluorescent lamps without integrated ballast, for high intensity discharge lamps, and for their ballasts and luminaires
- Regulation under construction for directional lamps and household luminaries

Regulation 244/2009 sets requirements for lamps typically used in households: incandescent lamps, halogen lamps and compact fluorescent lamps with integrated ballast. The following lamps are exempted from the Regulation: (a) non-white lamps (chromaticity coordinates limits defined); (b) directional lamps; (c) lamps having a luminous flux below 60 lumens or above 12 000 lumens; (d) UV- lamps (limits are defined); (e) fluorescent lamps without integrated ballast; (f) high-intensity discharge lamps; (g) incandescent lamps with E14/E27/B22/B15 caps, with a voltage equal to or below 60 volts and without integrated transformer in Stages 1-5. Table 4-2 and Table 4-3 show how the regulation will affect the lamp market.

Table 4-2. *Regulation 244/2009 on Non-directional household lamps.*

Stage	Date	Lamps to be banned (i.e. can not be "placed on the market" anymore)
1	1 Sept 2009	All non-clear lamps not equivalent-class A (any power)
		Clear lamps equivalent-class D, E, F, G with luminous flux ≥ 950 lm (e.g. power ≥ 100 W incandescent lamps, 230 V >60 W halogen lamps)
		Clear lamps with luminous flux < 950 lm equivalent-class F, G
2	1 Sept 2010	Clear lamps equivalent-class D, E, F, G with luminous flux ≥ 725 lm (e.g. power≥ 75 W incandescent lamps, 230 V =60 W halogen lamps)
		Clear lamps with luminous flux < 725 lm equivalent-class F, G
3	1 Sept 2011	Clear lamps equivalent-class D, E, F, G with luminous flux ≥ 450 lm (e.g. power ≥ 60 W incandescent lamps, 230 V ≥ 40 W halogen lamps)
		Clear lamps with luminous flux < 450 lm class F, G or equivalent
4	1 Sept 2012	Clear lamps equivalent-class D, E, F, G any power
5	1 Sept 2013	Enhanced functionality requirements
6	1 Sept 2016	Poor efficiency halogens (C)

The regulation defines maximum allowed power for given luminous fluxes. For lamps with energy label, it is easy to link the regulation requirements with class limits. In the table, the word "equivalent-class" is then used.

Table 4-3. *Regulation 244/2009 on Non-directional household lamps: Requirement for Clear Lamps.*

Stage	Date	Scope	Requirement (allowed energy classes)	GLS ≥ 100 W, or conventional halogen	GLS ≥ 75 W, or conventional halogen	GLS ≥ 60 W, or conventional halogen	GLS < 60 W, or conventional halogen	Halogen B	Halogen C	CFLi	LED
1	1 Sep 2009	for >950 lm (≥80 W)	A B C D E F G								
		for the rest	A B C D E F G								
2	1 Sep 2010	for >725 lm (≥65 W)	A B C D E F G								
		for the rest	A B C D E F G								
3	1 Sep 2011	for >450 lm (≥45 W)	A B C D E F G								
		for the rest	A B C D E F G								
4	1 Sep 2012	for > 60 lm (≥ 7 W)	A B C D E F G								
5	1 Sep 2013	raising quality requirements	A B C D E F G								
6	1 Sep 2016	special cap halogen	A B C D E F G								
		for the rest	A B C D E F G								

Regulation 245/2009 applies to lamps, ballasts and luminaires generally used in tertiary sector i.e. fluorescent lamps without integrated ballast and high intensity discharge lamps. The regulation sets requirements for lamps, ballasts and luminaires separately. The most important effects of the regulation 245/2009 are:

- T8 halophosphate fluorescent lamps phased out from 13 April 2010
- Stand by power consumption 1 W per ballast from 13 April 2010 and 0,5 W per ballast from 13 April 2012
- T10 and T12 halophosphate fluorescent lamps phased out from 13 April 2012
- High pressure mercury lamps phased out from 13 April 2015, retrofit high pressure sodium lamps banned then also

- Allowed ballast energy efficiency indexes A1 BAT, A2 BAT and A2 from 13 April 2017
- Efficacy and performance requirements for high pressure sodium lamps and metal halide lamps

The tertiary sector lighting regulation repeals the so called ballast directive (2000/55/EC). The ballast directive classified the ballasts for fluorescent lamps according to their energy efficiency and banned two of the most inefficient classes: ballasts with energy efficiency indexes (EEI) C and D. The regulation 245/2009 introduces two new EEIs, A1 BAT and A2 BAT, and phases out all other classes but A2 and these two new EEIs from 13 April 2017. This means phasing out all magnetic ballasts as they are not able to reach the energy efficiency requirements.

Both of the regulations on lighting sector use the phrase “placing on the market”. The requirements are set on the placing on the market of the products in the scope. The placing on the market means the first time the product is made available on the EU market. Products not complying with the requirements can not be placed on the market from the given date on. Examples of placing on the market:

- When one company manufactures, stores and sells the product, the placing on the market takes place when the company sells the product,
- In a corporation when the product is transferred from the possession of manufacturing department to the distribution chain, and
- Manufacturing outside the EU, placing on the market takes place when the product is transported to the EU.

After being placed on the market, the product is allowed to be further sold regardless of the requirements.

4.3.3 Energy performance of buildings

The four key points of the Directive 2002/91/EC on the energy performance of buildings are (EC 2002):

- a common methodology for calculating the integrated energy performance of buildings;
- minimum standards on the energy performance of new buildings and existing buildings that are subject to major renovation;
- systems for the energy certification of new and existing buildings and, for public buildings, prominent display of this certification and other relevant information. Certificates must be less than five years old;
- regular inspection of boilers and central air-conditioning systems in buildings and in addition an assessment of heating installations in which the boilers are more than 15 years old.

Deadline for transposition in the Member States was 4.1.2006.

EN 15193- Energy requirements for Lighting LENI

The Lighting Energy Numeric Indicator (LENI) has been established to show the annual lighting energy per m² required to fulfil lighting requirements in the building specifications.

$$\mathrm{LENI} = \frac{W_{\mathrm{light}}}{A} \quad \mathrm{kWh/m^2/year} \qquad (4\text{-}1)$$

where

W_{light} total annual energy used for lighting [kWh/year]

A total useful floor area of the building [m^2]

The LENI can be used to make direct comparisons of the lighting energy used in buildings which have similar categories with different size and configuration.

In CEN/TC 169 *Light and Lighting,* substructure WG 9 (Energy performance of buildings) has developed the standard EN 15193 *Lighting energy estimation* (EN 2007). The standard considers different aspects of energy consumption, namely;

- Installed load. This includes all installed luminaires
- Usage during the day. This can be controlled by using daylight-dependent lighting control and occupancy control systems.
- Usage at night. This can be controlled by using occupancy control
- Use of constant illuminance. This means control of initial illuminance (maintenance control)
- Standby. This represents parasitic power in controlled lighting components
- Algorithmic lighting and scene setting. This includes reduced energy consumption of installed power.

The standard uses the basic formula to measure and calculate the annual lighting energy for a building ($W_{L,t}$):

$$W_{L,t} = \sum[P_n \times F_c \times \{(t_D \times F_o \times F_D) + (t_N \times F_o)\}]/1000 \quad \text{kWh} \tag{4-2}$$

Additionally, the annual parasitic power ($W_{P,t}$) for the evaluation of stand-by power losses and power for emergency lighting completes the energy calculation.

$$W_{P,t} = \sum\{[P_{pc} \times \{t_y - (t_D + t_N)\}] + (P_{em} \times t_e)\}/1000 \quad \text{kWh} \tag{4-3}$$

where

P_n total luminaire power in a zone [W]
F_C constant illuminance factor
t_p time when parasitic power is used [h]
t_D time for daylight usage [h]
t_N time for non-daylight usage [h]
F_D daylight dependency factor
F_o occupancy factor
P_{pc} parasitic power in a zone (which generally means standby losses) [W]
t_y time in a standard year (8760 h)
P_{em} total installed charging power for emergency lighting luminaires in a zone [W]
t_e emergency lighting charging time [h]

The total annual energy used for lighting is
$W_{light} = W_L + W_P$ kWh/year

The standard provides both a quick method and a comprehensive method. An example of the use of the quick method is given below

$$W_{light} = 6A + \frac{t_u \sum P_n}{1000} \quad \text{kWh/year} \tag{4-4}$$

where
$t_u = (t_D \times F_D \times F_O) + (t_n \times F_O)$ is the effective usage hour
A is the total area of the building.

The values t_D, t_N , F_D , Fo are tabulated in EN 15193.
6 A indicates the energy consumption for emergency lighting and parasitic power.
Example for offices:
$t_u = (t_D \times F_D \times F_O) + (t_N \times F_O)$

$t_D = 2250$ h, $t_N = 250$ h, $F_D = 0.8$, $F_O = 0.9$

$t_u = 1845$ h

4.3.4 Energy Efficiency Label

Directive 98/11/EC sets the requirements for energy label for household lamps. In practice, only incandescent and compact fluorescent lamps are included. All other light sources are excluded. It implements the directive 92/75/EEC, which is an "umbrella" labelling directive. It establishes that household appliances shall be labelled according to their energy consumption, and that the product information shall be harmonised.

4.3.5 Disposal phase of Lighting Equipment in Europe

Legislation

The material contents and the disposal of lighting equipment are chiefly regulated by two directives that apply to electrical and electronic equipment:

— The RoHS Directive: Directive 2002/95/EC of the European Parliament and of the Council of 27^{th} of January 2003 on the restriction of the use of certain hazardous substances in electrical and electronic equipment
— The WEEE Directive: Directive 2002/96/EC of the European Parliament and of the Council of 27^{th} of January 2003 on waste electrical and electronic equipment

These directives complement European Union measures on landfill and incineration of waste. Increased recycling of electrical and electronic devices will limit the total quantity of waste going to final disposal. Producers, including manufacturers and importers, will be responsible for taking back and recycling electrical and electronic devices. This will provide incentives to design electrical and electronic equipments in more environmentally friendly and a more efficient way considering waste management aspects fully. Consumers will be able to return their waste equipments free of charge.

RoHS Directive

The first directive, RoHS, is mainly related to the production phase of the products, as it deals with the *material composition* of the products. It is not allowed to put on the market products with hazardous substances (heavy metals: lead, mercury, cadmium and hexavalent chromium) and brominated flame retardants [polybrominated biphenyls (PBB) or polybrominated diphenyl ethers (PBDE)] exceeding fixed limits (EC 2003a). The RoHS directive is strongly related to the disposal phase. The absence or limited amount of hazardous substances will limit the generation of hazardous waste.

As the RoHS directive is a harmonizing directive, it approximates the legislation in Member States. The aim of the directive is to protect human health and the environment, and to encourage environmentally sound recovery and disposal of waste electrical and electronic equipment.

The directive includes a list of exemptions. Some hazardous substances may be present in different components of equipments used for lighting. For example:

- Lead in soldering alloys, electronic components, and in glass,
- Cadmium in glass, and
- Mercury in discharge lamps (fluorescent lamps, high pressure sodium lamp etc.) (EC 2003a).

WEEE Directive

The second directive, WEEE, aims to prevent the generation of waste from electrical and electronic equipment. It promotes the reuse, recycling and other ways of recovery of such waste to reduce the disposal. The directive obliges producers to be responsible for the collection, treatment, recovery and environmentally sound disposal of WEEE. It applies also to lighting equipment in which the following products are included:

- Luminaires for fluorescent lamps except luminaires in households,
- Straight (linear) fluorescent lamps,
- Compact fluorescent lamps,
- High intensity discharge lamps, including high pressure sodium lamps and metal halide lamps,
- Low pressure sodium lamps, and
- Other lighting or equipment for the purpose of spreading or controlling light except filament bulbs (EC 2003b).

Ballasts are not explicitly mentioned. In the common case where luminaires are equipped with ballasts, the ballasts are considered as part of the luminaire. There is a trend to consider separate ballasts also as products under WEEE directive. Bare LEDs are not included in the directives as lamps. However, when LEDs are equipped with reflectors, lenses, they are considered as luminaires and then as products under the scope of WEEE directive.

Example: the lamps case

In the following, material composition, and disposal phase and recycling techniques of lamps will be discussed.

Material composition of lamps

Lamps are made of components which can be grouped as:

- lamp structure (lamp envelope, metal support parts, cap)
- electrical parts (electrodes, filaments, wiring, ballast)
- lamp envelope additives (inert gas, getter, emitter, mercury, sodium, metal-halides, fluorescent powder)

The component materials are selected for their chemical or physical properties for optimal light emission properties. The average material composition of lamps is described in Table 4-4. HID lamp group includes many different lamp types. Metal-halide lamps (MH) are selected to represent indoor applications and high-pressure sodium (HPS) lamps are selected to represent outdoor applications.

Table 4-4. *Material composition of typical lamp representatives (ELC 2009a).*

Lamp Group	Example	Weight [g]					
		Total	Glass	Metals	Electronics	Plastics	rest
GLS	60W	33	30	3	--	--	0.01
Halogen	35W	2.5	2	0.5	--	--	0.01
Fluorescent	36W	120	115	3	--	--	2
CFL-integrated	11W	120	65	4	25	25	1
CFL-non-integrated	13W	55	40	3	--	10	2
HID	MHL400W	240	195	42	--	--	3
	HPS150W	150	105	44.5	--	--	0.05

The rest are the lamp envelope additives including electrodes, capping paste and ceramic parts (ELC 2009a).

Disposal Phase of lamps

The main goals of lamp recycling are the recovery of the mercury and the neutralisation of the sodium metal. Gas discharge lamps contain mercury, whereas incandescent lamps are free from mercury and other environmental sensitive substances. Recycling of glass and metal from incandescent lamps is not a common practise as it is not economically feasible.

Recycling techniques for fluorescent lamps

Basically, two types of techniques are utilized for recycling of fluorescent lamps. One technique is known as end cut, a process by which both ends of the fluorescent tube are removed before the materials are separated and processed to a high purity product. The other technique is known as shredder (crush and sieve). It crushes the complete product and the various ingredients are separated and processed after crushing. All the recovered materials can be re-used in different types of applications. Table 4-5 shows an overview of the material components and their outlet channels. The lamp manufacturers buy many fractions of the recovered materials. They use these material fractions to substitute for the virgin material and this last process closes the life cycle loop (ELC, 2009b).

Table 4-5. *Overview of recovered materials and their customers* (ELC 2009b).

Materials	Customer
Glass	Lamp industry Glass industry Glass bricks/concrete bricks
Metal Alu-cap Brass Fluorescent powder, glass powder (mercury containing or mercury-free)	Lamp industry Controlled landfill
Mercury after distillation	Mercury industry Lamp industry

General considerations on disposal phase for the final user

The RoHS and WEEE directives are important not only in terms of environmental issues, but also in the life cycle analysis (LCA) framework. Although studies have shown that the main environmental impact of lighting equipment occurs during their useful life time (energy consumption during operation), the disposal phase is still to be correctly taken into account. With the progressive shift from incandescent lamps to energy efficient lamps, it is important to consider proper disposal of these energy efficient light sources containing environmentally sensitive substances like heavy metals.

The manufacturers are responsible for the process during production. The consumer of the products should also be involved actively in the disposal process to reduce the harmful effects of the environmentally sensitive substances. This will help the end users get the maximum benefit of the products. In practice, there are at least two important aspects:

- Procedures, infrastructures, availability of physical tools (containers for collection of burned out lamps)
- Knowledge and consciousness of the various types of consumers (building energy managers, technical officers).

The practical adoption of the WEEE directive is in progress, but the situation is different in the different Member States.

4.3.6 Notes

Dedicated legislation on lighting design is unavailable. Requests in this context are made by various stakeholders to deal properly with energy savings in lighting installations. Also a complementary legislation on installation phase is advisable.

A very important consequence of the legislation is the driving effect on the market trends. For example, the Energy Label helps consumers to choose the right product by showing the energy efficiency of different products on a common scale. The Ecodesign regulations, establishing minimum requirement for products and putting those products on the market, will in practice progressively ban a number of less efficient products. These regulations, in turn, will provide the buyers with comprehensive product information, helping them to select the most appropriate products.

It is important to highlight that the full process of developing a regulation involves intensive discussion with stakeholders and interested parties to guarantee that the regulation will be effective and the objectives are really achievable. For example, a sufficient timeframe is given to manufacturers to redesign their products, cost impacts for consumers and manufacturers (particularly small and medium enterprises) are taken into account, and particular emphasis is given for market surveillance and conformity assessment.

4.3.7 Review of standards on electric and electromagnetic aspects

IEC standard

The harmonic emission limits for lighting equipment were at first specified in the standard IEC 1000-3-2, entitled "Harmonic limits for low voltage apparatus <16A" in which lighting equipment is defined as *class C* equipment (IEC, 2005). The International Electrotechnical Commission (IEC) sets forth the limits for harmonics in the current of small single-phase or three-phase loads (less than 16 A current per phase) in Electromagnetic compatibility (EMC)-Part 3-2: Limits for harmonic current emissions (from IEC 61000-3-2). The last edition of this standard is IEC 61000-3-2 Ed. 3.0 b: 2005.

CENELEC standard

The text of the IEC standard was approved by CENELEC as European Standard EN 61000-3-2 “Limits for harmonic current emissions (equipment input current up to and including 16A per phase)”. IEC standard describes a total harmonic distortion (THD_i) for current of less than 33% and a power factor (PF) of more than 0.95 for lighting equipment. No limits apply for lamps with integrated ballasts, dimmers, and so-called semi-luminaries with an active power of less than 25W. In practice, this means that there are still no emission limits for integral compact fluorescent lamps. Equipment that draws current between 16A and 75A per phase is covered by IEC/TS 61000-3-12. Harmonics measurement and evaluation methods for both standards are governed by IEC 61000-4-7.

European Union EMC Directive

The EU Electromagnetic Compatibility (EMC) Directive also deals with harmonic emission levels. The European EMC Directive does not specify emission levels, as it is rather general. For lighting equipment, manufacturers must show that they comply with the EMC Directive by giving reference to other standards which are listed in the EU's official journals.

ANSI/IEEE standards

The US standards do not specify any emission limits for equipment. IEEE Standard 519-1992 "Recommended Practices and Requirements for Harmonic Control in Electrical Power Systems" only provides the guidelines for permissible injections of harmonic currents from individual customers (including only for lighting) into the power system (IEEE, 1992). The IEEE Single Phase Harmonics Task Force (P1495) is developing a standard for single phase loads of less than 40 A. There is, however, still no agreement on what such limits should be, or whether limits are even needed. Most of the ongoing works by the IEEE regarding harmonic standards development has shifted to modifying the Standard 519-1992 (McGranaghan 2001).

IEEE Standard 519-1992 provides recommended limits for harmonic levels at the point of common coupling (PCC) between the customer and the power system (the location from where other customers could be supplied). The recommended voltage distortion limit for the PCC is 5% for the total harmonic distortion (THD_i) and 3% for individual harmonics. The task force working on the revision to Standard 519 is considering higher limits for the interiors of the facility and making these limits frequency-dependent. The limits specified in IEC for low-voltage systems allow THD_i of 8% and include limits for individual harmonic components, which decrease with frequency.

The harmonic filter working group, which is part of the capacitor subcommittee, has completed a harmonic filter design guide known as IEEE Standard 1531 (IEEE, 2003). A number of differences between European and US power systems (IEEE 2002) suggest that any harmonic limits for the US should be different from the IEC standard. The European system uses no neutral on overhead medium voltage distribution and a cable sheath for the underground portion, and they use delta wye transformers to step down the voltage to 400/230 V. As a result, it is less susceptible to tripled (3, 6, 9 etc.) harmonic distortion than the US system. The European system includes extensive 400/230 V secondary distribution, creating higher-impedance utility distribution than the US system. The US system has higher secondary impedance beyond the point of common coupling, however, because of smaller distribution transformers used.

Harmonic Currents Limits

European Standards

The International Electrotechnical Commission (IEC) adopted a philosophy of obliging manufacturers to limit their products consumption of current harmonics in their standard IEC 61000-3-2 (IEC 2005). This standard applies to all single-phase and three-phase loads rated at less than 16 A current per phase. The standard classifies electrical loads as shown in Table 4-6. The standard as originally published used the classifications on the left side of the table, with the special waveform defined in Figure 4-8. The special waveform is the limiting envelope for the current waveform. The current has to fall within this waveform for each half cycle 95% of the time. After negotiations with manufacturers who opposed to the limits, Amendment A14, with its classifications on the right side of the Table 4-6, was published. The manufacturers had three years time by which they could use either of the sets of classifications (IAEEL 1995, Fenical 2000). The amendment A14 has been in force since January 1st 2004. The harmonic current limits are for individual harmonics, and do not specify total harmonic distortion (THD_i). These limits are given in Table 4-7 and Table 4-8.

Table 4-6. *EN 61000-3-2 equipment (lighting) classification.*

Classifications (original)	Amendment A14 Classifications
Class A: Balanced 3 phase equipments, single phase equipment not in other classes.	**Class A:** Balanced 3 phase equipments, household appliances excluding equipment identified as class D, tools (except portable), dimmers for incandescent lamps (but not other lighting equipment), and audio equipment, anything not otherwise classified.
Class C: Lighting equipment over 25 W.	**Class C:** All lighting equipment except incandescent lamp dimmers.

Another important clarification in the version of November 2005 is that the current harmonics measurement must be done on the line conductor and not on the neutral conductor (IEC, 2005). However, for single phase applications this can be done on the neutral conductor but not in three-phase applications where the values can differ significantly if the EUT is not balanced.

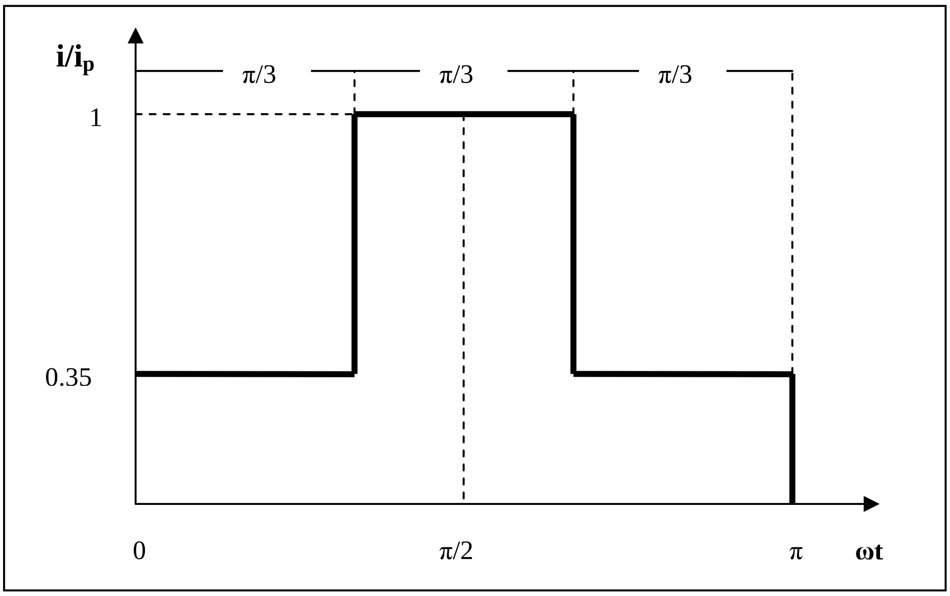

Figure 4-8. *Limiting envelope for the current waveform.*

Table 4-7. *Harmonics limit for Class A equipment (IEC 2005, Abidin 2006).*

Harmonic order n	Maximum permissible harmonic current (A)
Odd harmonics	
3	2.30
5	1.14
7	0.77
9	0.40
11	0.33
13	0.21
15≤ n ≤ 39	2.25/n
Even harmonics	
2	1.08
4	0.43
6	0.3
8≤ n ≤ 40	1.84/n

Table 4-8. Harmonics limit for Class C equipment *(IEC 2005, Abidin 2006).*

Harmonic order n	Maximum permissible harmonic current (% of fundamental)
2	2
3	30 x circuit power factor
5	10
7	7
9	5
11≤ n ≤ 39	3

American Recommendations

IEEE has drafted a guide to limit harmonic current consumption by single-phase loads rated less than 600 V and 40 A (Pacificorp 1998, IEEE 1992). This draft guide divides the loads into two classes. They are listed below:

1. "*Higher wattage nonlinear loads like heat pumps and EV battery chargers as well as large concentrations of lower wattage devices like computer workstations and electronic ballasts found in typical commercial offices and businesses (Pacificorp 1998)*". The recommended maximum levels of current distortion allowed for these loads are shown in Table 4-9. The guide also suggests a minimum power factor of 0.95 for the high wattage loads. Maximum THD_i is 15% and Maximum 3rd harmonic current is 10%.

2. "*Lower wattage nonlinear loads not concentrated in a small area (Pacificorp 1998)*". Table 4-9 shows the recommended limits. For these loads maximum THD_i is 30% and maximum 3rd harmonic current is 20%.

Table 4-9. *Recommended Full-Load Harmonic Current Limits for Equipment.*

Equipment	Limit (% THD_i for current)
All lighting, motor drives, and other equipment sharing a common electrical bus or panel with sensitive electronic loads	15
All fluorescent lighting, including compact fluorescent	30

Electrical devices, such as computers and fluorescent lighting systems, can send harmonic wave forms at many frequencies back onto the power supply line, thereby distorting the waveform of the supply current. For 4 feet long lamps, the American National Standards Institute (ANSI) recommends a THD_i limit of 32% but some electric utilities only provide financial incentives for ballasts that produce THD_i of less than 20%. Ballasts that produce THD_i of less than 10% are available for installations with critical power requirements (Lightcorp 2009).

Fluorescent – electronic ballasts shall comply with the following ratings (Indiana 2006).

— minimum power factor 98%
— maximum THD_i 20%
— maximum 3rd harmonic distortion 10%

The electronic ballasts also are to comply with the FCC (Federal Communications Commission) Regulations, Part 15, and Subpart J for electromagnetic interference.

4.4 Examples of lighting related energy programs

4.4.1 ENERGY STAR

The ENERGY STAR program was initiated in the US but has now spread globally, works with manufacturers, national and regional retailers, state and local governments, and utilities to establish energy efficiency criteria, label products, and promote the manufacture and use of ENERGY STAR products. ENERGY STAR products include clothes washers, refrigerators/freezers, dishwashers, room air-conditioners, windows, doors and skylights, residential water heaters, compact fluorescent lamps, and solid state lighting luminaires. In 2006 the ENERGY STAR program lowered the total energy consumption of t he year by almost 5%. On the ENERGY STAR webpage (www.enenrgystar.gov) there is information about the products that have qualified to achieve the ENERGY STAR. For instance for CFLs there is list of products with wattage, light output, lamp life, color temperature, and model type. To qualify a bare CFL lamp efficacy should be at least 50 lm/W, if the lamp power is less than 10 W, 55 lm/W 10 W ≤ lamp power < 15 W and 65 lm/W when lamp power is more than or equal to 15 W. Detailed specifications are given for e.g. color quality (CRI ≥ 80), starting and run-up time, and power factor. The lamp life is considered with rapid cycle stress test and lumen maintenance during burning hours (ENERGY STAR 2008). For CFLs, the ENERGY STAR webpages provide a buyers guide and information on how they work, their recycling, and the amount of mercury.

4.4.2 Top Runner program

The Top Runner program was created in Japan as a countermeasure for the increase of energy consumption on residential, commercial and transportation sectors. The program is incorporated in the Japanese legislation for energy conservation, and requires manufacturers to improve the energy performance of their machinery and equipment. Few examples of the products involved are fluorescent lamps, computers, freezers, refrigerators, TVs, VCRs.

Expectations regarding the role of energy conservation are increasing due to global environmental problems. Therefore, the requirements for improving the energy efficiency of machinery and equipment as much as possible are now a reality. The Top Runner program has come into existence in light of this situation. The Top Runner program uses, as a base value, the value of the product with the highest energy efficiency on the market at the time of the standard establishment process and sets standard values by considering potential technological improvements added as efficiency improvements. Naturally, target standard values are extremely high.

For target achievement evaluation, manufacturers have to make sure that the weighted average value meets or exceeds the target standard value. While this system gives manufacturers substantial technological and economic burdens, the industry should conduct substantial prior negotiations on possibility of achieving standard values and adopt sales promotion measures for products that have achieved target values.

With fluorescent lamps, target fiscal year was fulfilled in FY 2005, the total luminous efficacy (lm/W) was improved by approximately 35.7% from FY 1997. It was initially assumed that the improvement rate was approximately 16.6% (Top Runner 2008).

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