Power Quality and Utilisation Guide

Leonardo ENERGY

Energy Efficiency

Lighting

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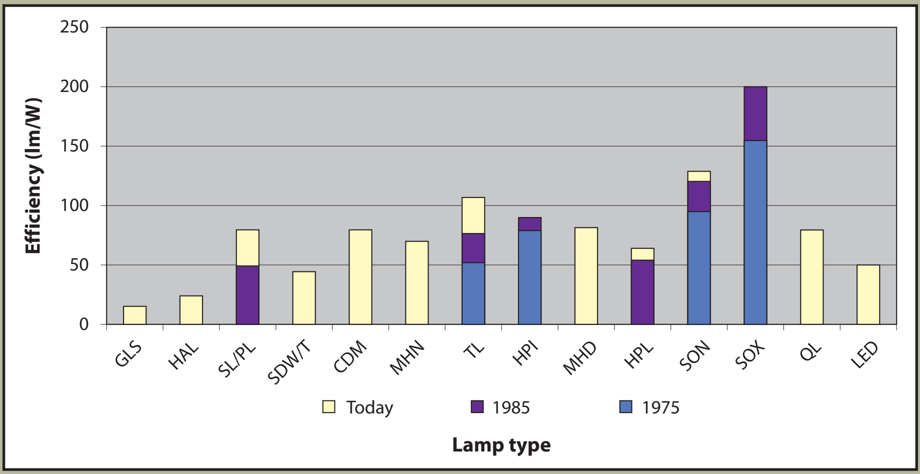

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Energy Efficiency

1. Introduction

Energy consumption via lighting systems is significant. There are nevertheless many ways to save energy in every sector. The global electricity consumption for lighting in 2005 is estimated at 2651TWh (terawatthours), i.e. 19% of total global electricity consumption.

Today the global light production (in lumen) can be divided as follows on the different sectors:

- 44 % for lighting of commercial and public building,
- 29 % for industrial lighting,
- 15 % for residential lighting,
- 12 % outdoor lighting (streets, security, road signs and car parks).

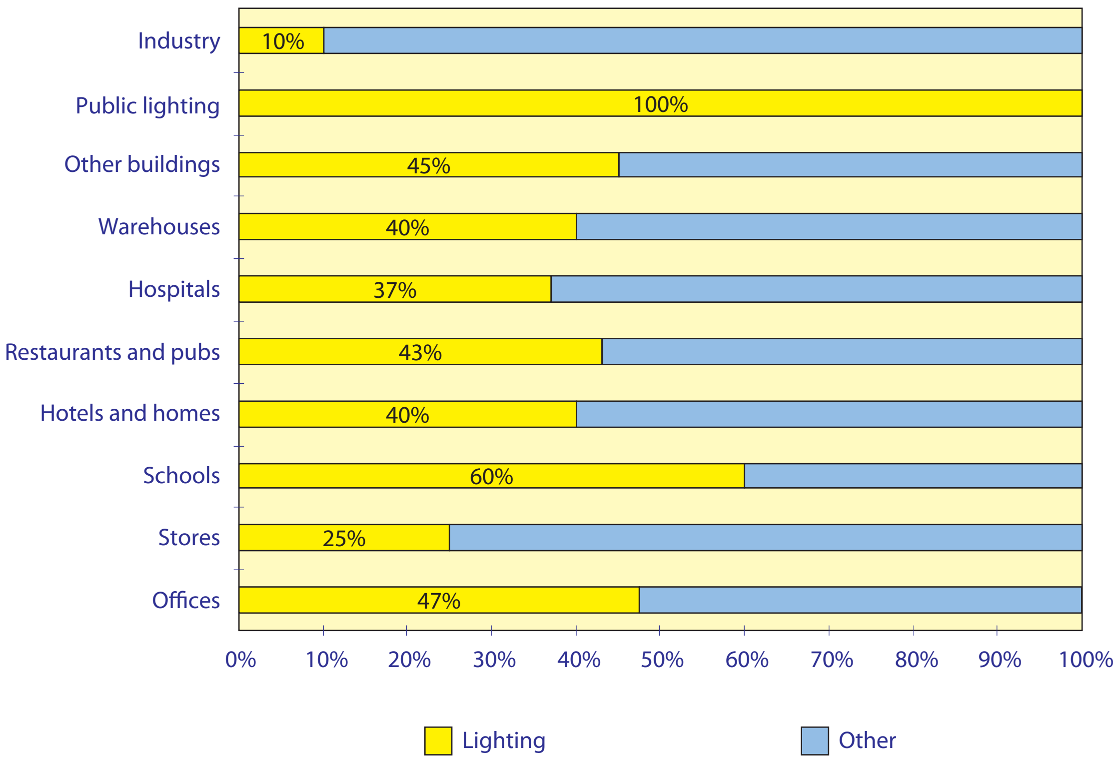

Figure 1 – Energy consumption in different sectors

It is estimated that over the last decade global demand for artificial light grew at an average rate of 2.4% a year. The average lighting system had an efficacy of more or less 18 lumens per watt (lm/W) in the early sixties, in 2005 it reached 50 lm/W.

In office buildings lighting is often the biggest consumer of electric energy. Studies have shown that in the service sector the share of the lighting (for the greater part fluorescent lighting) is, on average, 37% to 45% of the entire electricity consumption. Estimations for the energy consumption due to lighting in the different sectors are given in figure 1. We see that the share of lighting in the industry is estimated at 10%**.** According to estimations 35% of the share of lighting can actually be saved by means of relighting or efficient use of lighting in the industry.

2. Technical aspects of lighting

2.1 Definitions in lighting

When talking about lighting, the following terms are used:

Luminous flux (lumen, lm): Total amount of visible light power emitted by a light source. This value is reported on the package of a light bulb.

Luminous intensity (candela, cd = lm/sr): is a measure of the luminous flux emitted by a light source in a particular direction, measured in lumens per steradian.

Illuminance (Lux, lx): the amount of light arriving on a surface. (1lux = 1lm/m^2) This value is used in light calculations and design plans.

Luminance (cd/m^2): measure of the density of luminous intensity in a given direction. It describes the amount of light that passes through or is emitted from a particular area, and falls within a given solid angle. Luminance is often used to characterize emission or reflection from flat, duffuse surfaces. The luminance indicates how much luminous power will be perceived by an eye looking at the surface from a particular angle of view. Luminance is thus an indicator of how bright the surface will appear. In this case, the solid angle of interest is the solid angle subtended by the eye's pupil.

Colour rendering (-): The colour rendering of a light source is an indicator for its ability of realistically reproducing the colour of an object. Colour rendering is given as an index between 0 and 100, where lower values indicate poor colour rendering and higher ones good colour rendering.

Colour temperature (K): The colour temperature is an expression used to indicate the colour of a light source. According to international standards, the lamp colour is compared with the colour of a black body radiator at a certain temperature. It's expressed in degrees Kelvin (K). Below 3300K, the source is considered as "warm light". Above 5300K, the source is considered as "cold light".

2.2 Levels of lighting

When designing a lighting system, the minimum amount of lighting should be considered. Specific work requires a specific amount of light, which is necessary to do the task efficiently. The minimum required levels of light for different applications are given in Table 1.

Application	Minimum illuminance in lux
Offices	
• General office work (intermittent reading and writing)	300
• Continuous reading and writing	500
• Drawing	500
• Drawing with special visual requirements	700
• Archives, corridors, halls, staircases, dressing rooms, toilets, dining-rooms	100
Sales rooms	
• Sales rooms	500
• Passage ways	200
• Storage, packing, loading points, reception of goods	100
Schools	
• Class rooms	300
• Drawing rooms	500
Industry	
• Passage ways, staircases, storage of raw material, storehouse for cars	50
• Treatment of large products, machine rooms, elevators, storage, packing, loading points, reception of goods	100
• Simple assembly, mechanical treatments, cutting and packing of meat, woodwork, coachwork	200
• Simple machine work, control, repair	300
• Accurate machine work and assembly, textile work, precise soldering and welding	500
• Tasks with special visual requirements like treatment of coloured cotton, wool, silk and artificial fibres	700
• Tasks with extreme visual requirements like treatment of jewels, clockworks, precision-instruments, sorting out tobacco, dosing and mixing colours, final control of textile	1000

Table 1 – Minimum levels of lighting

The levels in table 1 are the minimum levels that a lighting system should have at the end of its life-cycle. When designing a lighting system the values in this table still have to be multiplied by a planning factor that takes into account a decrease in the light production of lamps and armatures over the life span because of deterioration of light intensity. This factor is also called maintenance or design factor.

Considering for example a design factor of 1.25, the required minimum intensity is 400lx. The system should now be designed at 1.25 x 400 = 500lx. This will ensure that the minimum intensity is guaranteed during the life span.

2.3 Life span

The most frequently used term is **average or median life span**: this is the number of operational hours under standardized ageing conditions in the laboratory, after which 50% of the lamps is defective (a lamp is defective when it does no longer burn, when it is flickering or when the stream of light has decreased to 70% of the nominal stream of light.). Usually, this is where the confusion starts, because in America the definition for average or median life span is restricted to the life span where 50% of the lamps have fallen out (or, in other words, no longer produce light). Because of this difference in definition, the life span in a catalogue of an American manufacturer will be much higher than the life span of the same type of lamps from European manufacturers.

The economic or useful life span is the life span for usage in real circumstances when x% has fallen out. This percentage is determined by local requirements or commitments and the cost price of single light relamping compared to group relamping. In general, it is assumed that the useful or economic life span of fluorescence lamps for functional inside lighting is the one where 20% of the lamps are defective (30% for outside lighting).

2.4 Critical elements in lighting

The following four elements should be taken into account to assure an appropriate visual perception:

1. Level of lighting

   As explained in paragraph 2.2, the minimum illuminance necessary for its designed purpose depends on the application. Table 1 gives a good overview of common applications. Proper lighting makes work less tiresome. The (statistical) percentage of tired workers will decrease with increasing lux.

2. Luminance in the field of vision

   Appropriate lighting reduces the (statistical) number of errors made when performing a task.

3. Absence of irritating reflection (glare)

   The luminance limitation should always be considered. This will be further discussed in paragraph 3.2. The type of armature will play an important role concerning this topic. The measure that is used to determine how much light is coming out of a lighting fixture in a particular direction is luminous intensity.

4. Color rendering

   This element indicates the ability of the light source to realistically produce the colour of an object. The differences of the various types of lamps are discussed in paragraph 3.1

Besides these technical elements, also the esthetical facet is usually taken into account.

3. Energy savings techniques

3.1 Efficiency of light bulbs

The last decade the light bulb has evolved. Nowadays, there are many types of light bulbs, each with their specific energy efficiency. The energy efficiency is expressed in lumen / watt.

By making the right choice concerning the type of lamp for a certain application, a lot of energy can be saved. That is why we always have to consider the energy consumption, the light quality and the investment cost.

In the following table (table 2) different types of lamps are compared with regard to life span, efficiency, light colour and colour rendering.

Type of lamp	*Average life span (hr)*	*Efficiency (lm/watt)*	*Light colour*	*Colour rendering*
Incandescent lamp				
Normal lamps	*1 000*	*6 – 15*	*Extra warm white*	*Very good*
Halogen lamps	*2 000 - 4 000*	*10 – 24*	*Warm white*	*Very good*
Low pressure mercury-vapour lamps (fluorescent lamps)				
Tubular lamps (TL)	*12 000 -20 000*	*45 –105*	*Warm white to cool white*	*Good to very good*
Compact lamps (CFL)	*10 000 - 12 500*	*40-80*	*Warm white to cool white*	*Good to very good*
High pressure lamps				
High pressure mercury-vapour lamps	*12 000*	*30-60*	*Warm white to cool white*	*Moderate*
High pressure sodium lamps	*25 000*	*46 – 150*	*Yellow white*	*Bad to good*
Metal Halide	*12 000-18 000*	*72-110*	*Warm white to cool white*	*Good to very good*
Induction lamps	*60 000*	*50 – 80*	*Warm white to neutral white*	*good*
Low pressure sodium lamps	*18000*	*100 – 200*	*Monochromatic orange*	*none*

Table 2 – characteristics of different types of lamps

Lamps can be divided into 4 main categories: incandescent, gas discharge, induction and solid state. Gas discharge lamps generally contain mercury or sodium gas. This gas can be applied in high or low pressure conditions. Figure 3 shows in which category different types of lamps belong.

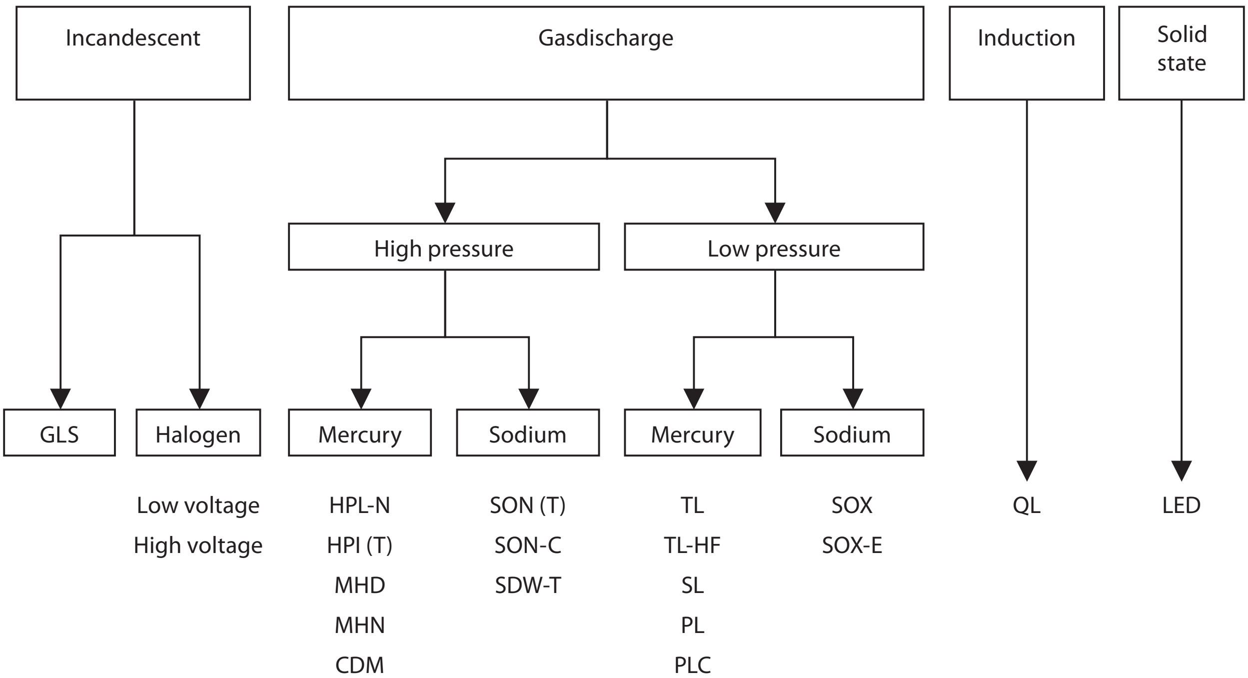

Figure 3 – Categories of light sources

There are many differences in efficiency. Over the years the light produce of the different lamps has evolved. This is shown in figure 4.

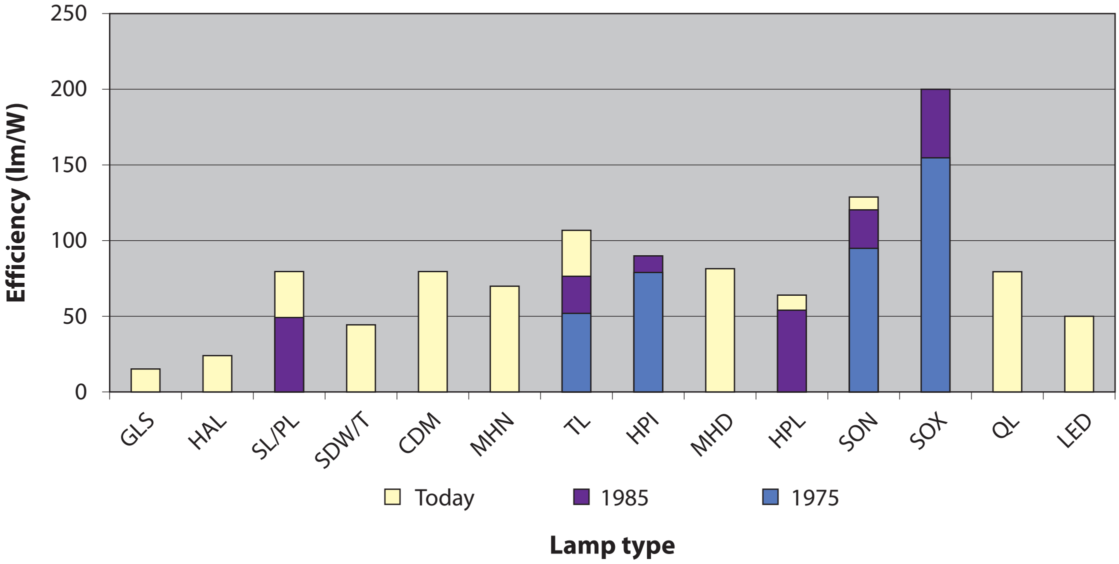

Figure 4 – Lamp efficiency evolution

With regard to the lamp efficiency, colour rendering and light colour of the various types of lamps, there are big differences.

Incandescent lamps have the lowest efficiency: 95% of the power taken up is lost as heat, only 5% is converted into light. On the other hand, incandescent lamps have an excellent colour rendering, which implies that in the radiated light all frequencies and also all colours are represented. Moreover, their purchase price is low.

Incandescent lamps can be used in applications with less burning hours or applications which demand high colour rendering.

High pressure mercury gas discharge lamps produce almost white light and are used in applications where a high power lamp is needed with good efficiency (30-60 lm/W) and good colour rendering (80). High power versions are used at sports fields and sports halls where the lamp is mounted at great height. Mercury vapour lighting is the oldest HID technology and can be considered obsolete.

High pressure sodium gas discharge lamps produce yellow-white light and are often used in street lighting applications in populated areas such as cities or villages. The efficiency is about 100-150 lm/W. Colour rendering is low at about 25.

Metal halide lamps are among the most energy efficient sources of white light available today (up to 100lm/W). Like fluorescent and high-pressure sodium lamps, metal halide lamps produce light by passing an electric arc through a mixture of gases. In a metal halide lamp, a compact arc tube contains a high-pressure mixture of argon, mercury, and a variety of metal halides. Colour rendering is very good, up to 96.

Low pressure mercury gas discharge lamps produce white light. Fluorescent lamps (TL, PL etc.) are the most common gas discharge lamps.

Fluorescent lamps are used in applications where good colour rendering (80-90) and good efficiency (up to 105 lm/W) are essential. They are used in offices, shops, schools, factories, etc.

In 1995 the TL5 was introduced. The TL5 is characterised by a diameter of only 16mm. Also the TL5 is a little bit shorter than its predecessors. This allows the armatures to be smaller, which has economical and esthetical advantages.

Another example of fluorescent lamps is the compact lamp (SL). Power efficiency is good (50lm/W) with good colour rendering (80-90). Compact fluorescent lamps have the same size and fitting as normal incandescent lamps. This means that for example a 75W incandescent lamp can easily be replaced by an 18W SL lamp. The life span is about 8 times longer than the incandescent lamp. Compact fluorescent lamps are most commonly used in domestic applications.

Low pressure sodium gas discharge lamps produce monochromatic yellow light. The efficiency is very good (200 lm/W) but they have very poor colour rendering. Because of the poor colour rendering these lamps are only used in applications where colour rendering is less important. Most commonly these lamps are used for security lighting and street lighting in non populated areas.

Induction lamps produce white light. They were introduced in the early 90's and have good efficiency (80lm/W) and colour rendering (80-90). However, the most important advantage is the life span of over 60.000 hours. Therefore induction lamps can be used in applications where a long life span is required.

Solid state lighting (SSL): The next revolution in lighting technologies has begun with the developments of the Solid-state lighting in the form of light-emitting diodes (LEDs) and recently organic light-emitting diodes (OLEDs). LEDs are made of semiconductor material and emit light when a current passes through them. Power efficiency is fairly good (45lm/W) and is expected to become even better in the near future. LEDs are available in a wide variety of color and power.

3.2 Ballasts

A ballast has to be used together with a fluorescent lamp to operate it. In relation to energy efficiency the power consumption of the ballast should be considered. A considerable difference in efficiency exists between the various ballasts found in the industry. Very inefficient ballasts can use up to 20% of the total energy consumption. Remark that, with an energy-efficient ballast, not only the ballasts will consume less, but also the lamps will consume less. The total energy saving can run up to 40% of total consumption.

There are 2 main categories of ballasts, electronic and conventional electromagnetic ballasts. Also the starters, which are used in combination with the ballasts, can be conventional or electronic. Several aspects have to be taken into account when choosing a ballast and starter. The characteristics do not only depend on the type of system, but also on the manufacturer. Important aspects are:

- Investment cost
- Energy efficiency of the total lighting system
- Lifetime of the ballast
- Lifetime of the lamp (which is influenced by the ballast)
- Possibility of flickering and/or stroboscopic effect when starting the lamp
- Heat development of the ballast and lamp
- Possibility of dimming
- Influence on the power quality of the power supply line
- Possibility of stroboscopic effect
- Size and weight of starter and ballast
- Durability against environmental influences, mainly the ambient temperature
- Influence on light production during life span

3.3 Armatures

Light bulbs are mounted in an armature. The type of armature has a great effect on the energy efficiency. Not all light that is produced by the lamp leaves the armature. This is, among other things, because of the shape and the material of the mirror and the shield at the bottom of the armature.

The main function of the armature is to reflect the light towards its designated area. A light bulb produces light at 360 degrees. The armature will guide and reflect the light to make it a useful beam.

The efficiency of an armature is the ratio between the amount of light produced by the light bulb and the amount of light, which leaves the armature.

In the following table 3 the armature efficiency for some types of armature is given.

Type of lighting device	Armature efficiency	Luminance limitation
Opal diffusers	30 to 40%	Hardly any
Mirror reflectors and shielding at 50°	50 to 65%	Excellent
Mirror reflectors and shielding at 60°	60 to 75%	Very good
Industrial armatures and linear assembly	70 tot 90%	Little to good

Table 3 – Armature efficiency for a few types of armatures

The luminance limitation should always be considered. For example, in an office building with a lot of computer screens, an armature with less luminance limitation will cause a lot of reflections in the computer screens. The efficiency of the lighting will be good, but the lighting will not be functional.

In general, the more attention is paid to shielding the stream of light from the lighting device to avoid blinding, the lower the efficiency of the device becomes.

3.4 Lighting control

Energy consumption of lighting systems is directly linked to the number of burning hours. It is obvious that reducing the number of burning hours will reduce the amount of energy that is used.

Another way to save energy is to dim the artificial light when there is enough daylight present.

In this chapter a number of techniques are explained.

3.4.1 Presence of people

In many buildings it is common that the lights are still switched on, without anyone being present. Not everybody switches the light off when he or she leaves the room. There are many ways to address this problem.

- Central time-switch: This is a quite simple solution. At pre-programmed times (for example after working hours) all or some of the lights are switched off. This can be done by a short interruption pulse in the power supply. After the pulse the light can be switched on as usual. It is important to separate power supplies from other power supplies because of the short power interruptions. The switch off pulse can also be generated when for example a burglary alarm system is set active. This will ensure nobody is present when the lights are switched off.
- Presence detection: Can be used for rooms that are used rarely or intermittently. For example toilets, storage rooms, etc. The lights are switched on / off by sensors which detect the presence of persons in the room. It is important to use specific sensors for this purpose. Sensors based on infrared as well as ultrasonic techniques are capable to detect persons, even when they do not move. This will avoid that lights are switched off when someone is still present.
- Advanced control systems: In buildings which have a pattern of usage that is known in advance programmable controls can be used. For example, in schools lighting can be switched on /off according to the timetable.

3.4.2 Presence of day light

Energy in lighting systems can also be saved when daylight is used. Often lights remain switched on, although there is enough daylight present. Energy can be saved when the amount of artificial light is reduced, according to the amount of natural light (daylight). This can be done by on/off switching, automatic switching, central dimming systems or decentral dimming systems.

- Switching manually: Switching of the lighting system is done manually for each room, part of a room or even separate lights. When there is enough daylight present the area near the windows will have enough light, even when the lights are switched off. The lighting system should be designed in a way that the light can be switched in rows, parallel to the windows. The function of the switches should be obvious to the users. This type of switching is easy to install, but is dependent on its usage.

- Automatic switching: Lights or a group of lights are switched on/off according to a central light sensor that is located in a reference room. An important remark concerning this system is that the light is not switched on/off frequently during the day: it is preferred to set a delay for switching. Also the user should have the opportunity to switch the light back on manually.
- Central dimming systems: these systems use a light sensor that is located in a reference room. All the other rooms are controlled by this sensor. This system can be used for a number of rooms at the same side of a building. Depending on the amount of daylight present in the reference room the lights will be dimmed or even switched off. The main advantage of this system is that the intensity of light will be constant during the day. The transition from daylight to artificial light will be gradual.
- Decentral dimming systems: In the last years decentral dimming systems are becoming more popular. Big advantage is that the intensity of light in each room is no longer dependent on the amount of daylight in the reference room. Each armature has its own sensor to detect the amount of daylight. The quality of the light sensor (LDR) is important. Every armature should be calibrated so all the lights are dimmed the same amount.

The amount of energy savings is dependent on the amount of daylight in the office. The amount of daylight depends on the size of the windows, building design, size and colour of the room. In standard offices about 30% of energy can be saved.

In figure 6 a decision making table is given for lighting control systems.

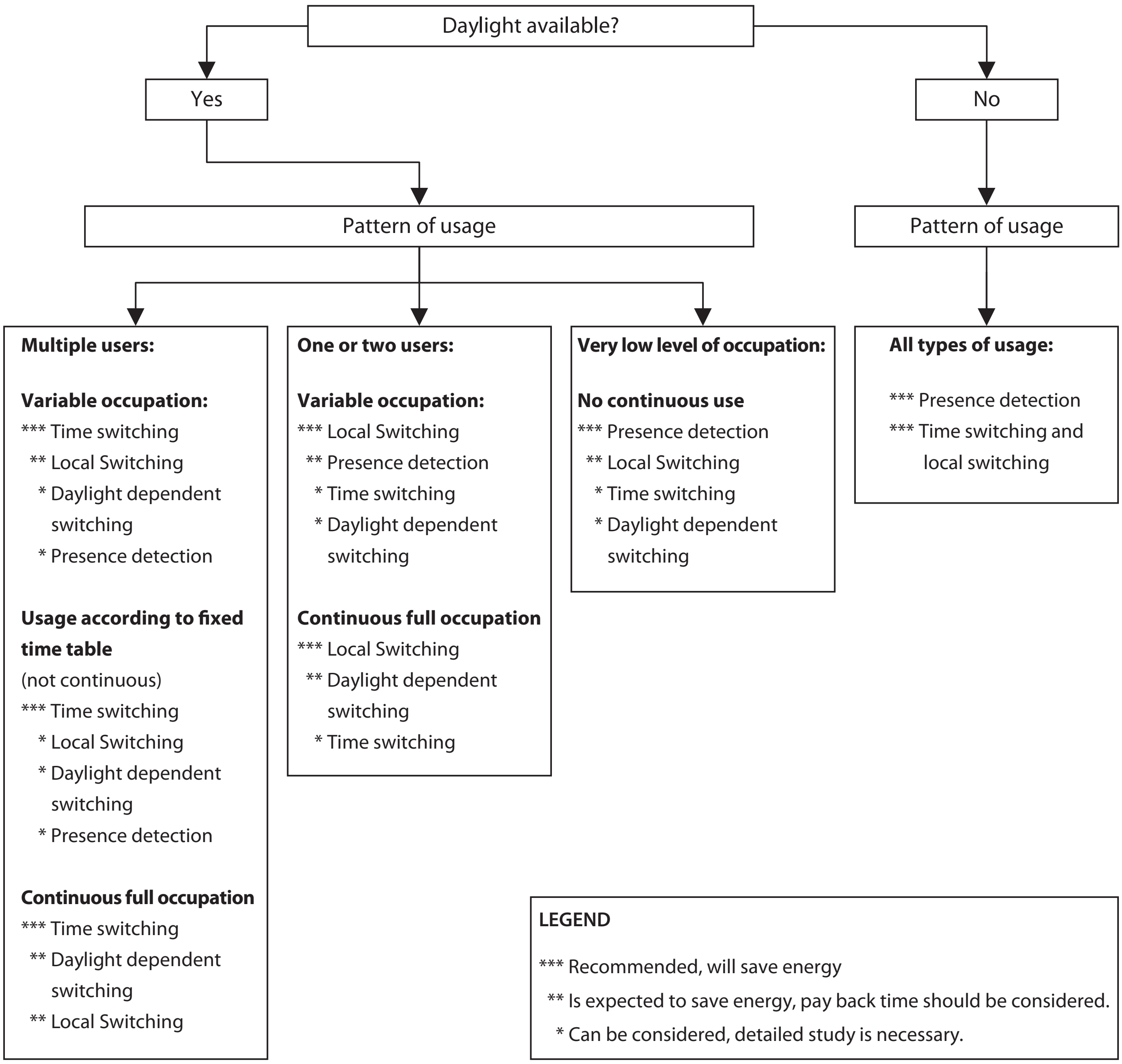

Figure 6 – Decision making in lighting control.

4. Human aspect

In all lighting designs the human aspect should be considered. Lighting has a big effect on the physical well being and productivity.

One of the aspects is visual comfort. The working environment in an office has a large effect on the human mood and productivity. In theory a very energy efficient lighting system would be a system which only brings light on the surface where it's needed, in general the working surface. In that case the walls and ceilings would remain unlit. In practice, the room will appear very unlit and uncomfortable. It will not be pleasant to work in such an environment. Savings in energy (if not done properly) can cause costs in productivity.

Colour rendering and colour temperature is also an aspect which has influence on the human mood. When the lighting system in a room has low colour rendering, not all colours will appear as they are. Incandescent lamps have very good colour rendering, but are energy inefficient. The colour rendering of fluorescent lamps varies from 30 to 90. In generally, colours will appear better when colour rendering is higher. For example an industrial white light (colour rendering 33) produces a lot of green and less red. Objects that are lit by this type of lamp will appear greenish. The human skin will appear a bit pale.

For office buildings a colour rendering of 80 is appropriate.

When working with computer screens or other reflecting surfaces glare or blinding should be avoided because it will have a negative effect on the productivity.

5. Conclusions

In lighting design energy can be saved. There are numerous types of lights and armatures. Every application has its own demands regarding the type of lighting that is used. The human factor should also be considered when designing a lighting system.

The approach in lighting design demands following action plan in order to improve overall energy efficiency:

- Determine the type of light bulb that is required for the application.
- Determine the right type of armature.
- Choose an energy efficient ballast.
- Check for opportunities in lighting control.
- Check for opportunities to use daylight.
- Take in mind the human aspect of lighting.

6. References

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