**Ergonomics of Light**

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**Summary**

In the modern world a storm of new lighting possibilities exist, but at the beginning or at the very end, this should be adequate to human needs and environment protection. Modern technology, when used carefully, could provide both functional illumination and appropriate atmosphere. Psychological needs of a man are really simple, clear and well defined lighting during the day and subtle, charming and intimate illumination, during the period of relaxation and rest, which comes at evening. Avoiding of stroboscopic effect is crucial, because of the psychomotorious system of a man, which is kept alert if some rhythmical phenomena occurs or exists in the peripheral view.

Article will consist on several parts, important to explain final conclusions. After we remind an audience on ergonomy, and its extremes, we will continue with eye anatomy, and through psychology of picture perception we will explain basic natural needs of a human being. We will demonstrate and remind on different colors of interior and their effects on human emotions. Also, different stages of the day have their extremes that have not to be forgotten when planning interior lighting. We will remind on usually forgotten particularities of light pollution, and situations that often are not considered as light pollution at all.

1. **Introduction**

Most of us learn early on that if something is good for us (think spinach), we may not enjoy it. But when it comes to ergonomics, comfort and health are synonymous. The concept of ergonomics is not commonly associated in general awareness with lighting. Since lighting is usually a prime source of complaint in relation to offices and other working and living places, this lack of awareness is surprising. In fact much study has gone into workplace lighting conditions. It seems to take a long period before academic research affects day-to-day lighting practice.

This paper raises certain ideas on the ergonomics of light that flow from the study of many researchers over the past 20 years. The central suggestion is that we do have to understand our anatomy and our possibilities before we start to create artificial spaces for people. Although the most appropriate light is a natural one, we are here to create artificial lighting scenery that will comply to human needs and possibilities.
2. Human Visual Needs and Possibilities

Everything starts with anatomy of human eye and perception of the visual signals. Our eye although a complex organ, is far from perfect sensorial tool. In the nature we know much better optical systems (such as hawk's eye, owl's eye and so on). However, this is only thing we can use so, we have to understand its bonuses and maluses. Of crucial importance is that we understand how a human eye functions and how the picture is perceived.

Our eye has a complex structure, where the most important part is weighted to our retina, a complicated network of cells. This network is not homogenous, because it is built from light intensity preceptors and color preceptors, which together build a picture we understand. For light intensity perception our eye has rod sensors, while for color perception we use cones in our retina. We have to say that we do have about 7 million of cones and about 130 millions of rods in our retina. Cones are concentrated around the macula, while rods disperse all around, although with reduced concentration when we go from macula onwards. This allows us to understand accurate colored picture during the day, when our pupil is tight, and shades of gray, during the nighttime, when our pupil is dilated. Rods are much more sensitive to shorter (blue) wavelengths. The corollary is that blue light is more effective at stimulating the brain and increasing alertness.

Our sensory cells, rods and cones, function differently, so while during the day, when we do have a lot of natural light, and our pupil is tight, visual data are collected by cones. This we call photopic vision. From the other hand, during the night, we speak about scotopic vision, when rods are the main sensory element of our eye. Above diagram shows approximations of the different types of vision. During the twilight, a combination of both types of cells is active, and we speak about mesopic vision.

The eye is a paired organ, and this helps us to understand volumes and distances, but at the same time, every eye sends its own picture to our brain, where this picture (in the form of electrical signals) is analyzed and interpreted.

To ensure our survival, the signal firstly passes through Thalamus, an ancient mental organ, which has a function of shunter and it canalize visual signal to Amygdala and to Neocortex. Amygdala is a survival tool of our brain, whose function is to alert us about something that is coming to us from the peripheral visual field. This mechanism is instantaneous (microseconds) and with very simple analytical process. In this moment, the only importance is to avoid this object, and we don’t care about its form, color or texture. Neocortex is much more modern and sophisticated organ that serves for accurate analysis of a signal, and making decisions about it. Of course, this type of analysis takes time, but it happened when we are calm, so we do have time (we are talking about milliseconds here!). For example, that's how we distinguish a glass of wine from a glass with water in it.
Now we can understand what’s so annoying about neon flashing signals or with some rhythmical repetitions from our peripheral visual field (such as fluorescent luminaire driven by electromagnetic ballast, which makes fluorescent tube to switch on and off 50 times per second, and by doing so, creates subtle stroboscopic effect in our peripheral visual field). This disturbance makes amygdala alerted all the time and inhibits our brain in concentration and thinking.

Circadian rhythms are important in determining the sleeping and feeding patterns of all animals, including human beings. There are clear patterns of brain wave activity, hormone production, cell regeneration and other biological activities linked to this daily cycle. Here we do have to mention one more particularity of our eye and visual signal that goes to our brain. A picture, in the form of electrical signal starts its journey towards center of the vision in our brain. Visual nerve that conducts this signal is passing by the gland called pineal gland. This neural organ produces an important hormone for our resting process, Melatonin, in our bloodstream. As optical nerve interests the pineal gland, this small gland “knows” exactly what part of the day we are experiencing at the moment, and it does its own calculations. The circadian (daily) cycle of hormones within the bloodstream is controlled in the hypothalamic region of the brain. Melatonin prepares the body for sleep, which is a vital function in a healthy daily cycle, but only if it occurs at the correct time of day. Pineal gland starts the secretion of melatonin at about 21 hours, and it stops with it at about 7 in the morning, but only if we are not disturbed during the night. If, however, we sleep in illuminated space, this secretion will be reduced or inhibited completely. And why is it important? It’s important because among other functions, melatonin is a sleeping hormone that instructs cells to rest. Without his impulse, our cells don’t rest and they work as it is a day. The entire cell metabolism is rushed so they’ll die sooner. But, the negative aspect is that malicious cells will profit out of it, and they will propagate faster. At the diagram a side, we explained the rhythm of our day, based on main hormones regarding this topic (melatonin, serotonin).

In general, we can say that our physical repair lasts from 10 PM until 02 AM, and our psychological repair lasts from 02 AM until 06 AM, so it is strongly suggested to sleep in this period, to get full recovery.

3. Factors that are important in creating 'better workplace lighting'

Factors that are important in creating 'better workplace lighting' can be divided into two groups. The first group consists of vision factors, affecting the ability to see effectively. The
second represents comfort factors, determining satisfaction with the visual environment. Although some factors are common, the two groups are quite distinct from each other.

**Vision factors**

- Contrast - or reflectance difference - between a task and its background
- Intensity range and control of light source
- Spectrum of light source and resulting color rendering effect
- Direction of light source

**Comfort factors**

- Contrast between the task area and the general room view
- Control of glare in either task or general view
- The lightness of the space
- The luminous texture of the space
- Spectrum of the light sources
- Direction of the light sources
- The perception of controlling intensity - through dimming or switching.

The first three vision factors are interlinked, because contrasting luminance between a task and its background is the key to visual acuity. Differing reflectance, adequate intensity and sufficient spectral content create this luminous contrast, which the eyes then process as an image. The final vision factor also affects contrast, in that most tasks are best lit from the side. This is because surface reflection, which reduces contrast, is minimized from this direction.

Many of these factors are application specific and the final ergonomic quality of any particular space will often therefore depend on detailed design. This is not an attempt to cover the whole subject, nor attempting to improve the CIBSE Code for Interior Lighting or the lighting guide (LG7) for offices, both of which provide guidance on many of these ergonomic issues.

The clear conclusion from many other studies is that:

- Lighting can affect productivity
- Lighting does influence a sense of well being
- Lighting does impact on morale and motivation

Most people would have found these conclusions to be no more than confirmation of an intuitive belief that lighting conditions are important.

More detailed explanation will ask for a separate voluminous text, so we will not go any further here.
4. Colors affect emotions

When we talk about colors, we have to be aware of basic principle of color. Color is something that can exist only if light exists. Color doesn’t make a form or defines the sense of the body, but can give us a clue. In the lighting praxis we consider light as a color, luminaire as a brush and the space as a painter’s canvas. Therefore, light design is something very complex and yet far from electrical planning. Light designer is a person who is very close to architect, having ingrown child very active inside his mind. To be a good and imaginative light designer, one can find his thoughts inside Light Design Triangle, shown aside. If he can iterate within yellow space, he can consider himself a good one!

Talking about colors and emotions, we do have to emphasize that here we are going to talk only about western culture, because a discussion about worldwide color meanings, would take us far from the scope of this article. If we agreed about first premise of this section, that color is related to the light, we have to accept a fact that we can affect emotions with both, color and light. Even more, we can change color of the space by changing the light in the space. Synergy of light and color will produce a resultant color of the space that at the end, will define emotions.

Basically we can explain color impact to human emotions by the data from the next table:

<table>
<thead>
<tr>
<th>COLOR</th>
<th>PSYCHOLOGICAL RESPONSE</th>
</tr>
</thead>
<tbody>
<tr>
<td>RED</td>
<td>Power, energy, warmth, passions, love, aggression, danger, courage, fast action, vibrancy; Energy and passion it can be a source of inspirational strength, happiness, love and total joy</td>
</tr>
<tr>
<td>BLUE</td>
<td>Trust, conservative, security, technology, cleanliness, order, professionalism, depth, calmness, freedom, loyalty; Coolness, inner peace and harmony, hope and calmness are associated with blue</td>
</tr>
<tr>
<td>GREEN</td>
<td>Nature, healthy, good luck, jealousy (“green with envy”), renewal, safety, growth; This is considered the color of nature. It is a healing color. Any physical, mental or emotional disturbances can be overcome when the green vibrations are released.</td>
</tr>
<tr>
<td>YELLOW</td>
<td>Optimism, philosophy, dishonesty, cowardice (coward=yellow), betrayal, light, intelligence, happiness, clarity, hope; Left brain activities such as creative thinking and reasoning are stimulated by this color. Considered as a color of joyousness. Peace, rest and spiritual excellence are identified with the color yellow, but very intensive yellow is irritating.</td>
</tr>
<tr>
<td>PURPLE</td>
<td>Spirituality, mystery, royalty, transformation, cruelty, arrogance, luxury, dignity, dreams, sexuality, free mind</td>
</tr>
<tr>
<td>VIOLET</td>
<td>Helps you to mingle with the higher consciousness. It is also associated high spiritual thinking and aspirations. Productivity, prosperity and wealth generation are connected to this color. It helps you to achieve self-actualization and exceptional creativity</td>
</tr>
<tr>
<td>ORANGE</td>
<td>Energy, balance, warmth, enthusiasm, youthfulness, excitement, creativity, joy</td>
</tr>
<tr>
<td>BROWN</td>
<td>Earth, reliability, comfort, endurance, nature, home, longevity</td>
</tr>
<tr>
<td>GRAY</td>
<td>Intellect, futurism, modesty, sadness, decay, industrial, traditionalism, seriousness, conservative, practical</td>
</tr>
<tr>
<td>WHITE</td>
<td>Purity, cleanliness, precision, innocence, sterility, death, cleanliness, peace, union</td>
</tr>
<tr>
<td>BLACK</td>
<td>Sexuality, sophistication, death, mystery, fear, unhappiness, elegance, power, sophistication, depth, dramatic, seriousness, domination, force</td>
</tr>
</tbody>
</table>

Certainly, here we nominated typical and extreme significance of the basic colors, while real perception depends on various circumstances, such as season, psychical type of the day, people around us, fatigue we experienced before, during the day and so on. However, in the
process of decoration, when we do have to think about furniture and illumination, those directions should be considered and hopefully, followed.

Colors that induct certain emotions are usually planned for specific areas, where this is of fundamental value, like wellness, MR room, hospital wings (oncology, pediatric …). Besides colors of the walls, lighting plays important role here, to emphasize the final scope.

5. Ergonomic parameters of illumination

What should light do for us to consider it ergonomic? We shall understand basic elements of light, to be able to answer this question. First of all we expect out of light to fulfill our basic needs, such as security, comfort, orientation, functionality …

When we mention principal elements of lighting, such as direction, brightness, glare, and so on, we might construct a diagram, shown at the left. By organizing those elements, we define main groups, which are Visual comfort, Visual performance and Visual Environment. Here we speak of main and basic elements, which influence our life in private and professional dimensions. Hence, this is not all we can say about this matter.

Usually, we think about light and lighting mainly in our private and professional environment, but there are a lot of other situations when we depend on light. Traffic is the first to be mentioned (if we are not talking about professional drivers). Surely, one can imagine a road tunnel and think about it as a specific part of the road, where driving is to be performed more carefully. It seems very natural that the tunnel has to be illuminated, but our colleagues, lighting planners and other traffic engineers still perform a wrong approach here.

On the pictures we can agree that the tunnel is illuminated, but do we feel comfortable? Left picture shows illumination during the day, where very intensive artificial light should be
performed for the adaptation zone (entrance), because of the disability of an eye to adapt to the darkness fast. Diagram below shows exactly this defect of our eye. From the other hand, during the night, we don’t really need such an illumination that is visible on the right picture, and is also a standard for traffic tunnels. We would feel more comfortable with much lower light intensity, but continuous and uniform all way long, through the tunnel, during the night, and much higher intensity, during the day.

Diagram shows that adaptation time, from sunshine to light level such as office interior, lasts for about 5 minutes, while adaptation to moonlight level lasts for more than 15 minutes! We are far from being secure when entering dark areas. For this reason, good planned tunnels have street lighting after exiting the tunnel, which helps us to adapt to the dark road again. Hence, adaptation from dark area to high illuminated areas is measured in milliseconds, so here we don’t need any particular adaptation lighting, what so ever.

This is an extreme situation, but we might think about similar situations on the workplace. Let us mention dentist, for example. A special luminaire that dentist uses while performing an intervention, guarantees him more than 25.000 lux in the mouth of a patient! Now, it is easy to imagine when a dentist turns his head to pick up something from the closet besides, where standard illuminance of working plane is about 500 lux, he must feel kind of blind! He experiences dark blindness because of the significant difference in lighting level and our poor eye adaptation possibilities.

When we talk about task lighting, the effects of poor light can include the following:

- low productivity
- high human error rates
- inability to match or select correct colors
- eyestrain
- headache
- a reduction in mental alertness
- general malaise
- low employee morale
From the other side, we discovered that good planned lighting might increase efficacy (for example) in the educational institutions. On the following diagram we show how much of benefit, a higher lighting level, combined with dynamic lighting, can achieve. By the term Dynamic Lighting, we think of active lighting systems that change light color (CCT) during the day, so natural light is accurately simulated in the interior spaces, where daylight is not present in sufficient quantity.

To avoid problems from the beginning of this section, illumination societies around the world, have agreed about defining lighting recommendations, which if followed can guarantee appropriate illumination quality for most people.

6. Lighting recommendations

All principal Lighting associations and Societies of the world agreed about optimal lighting conditions for various areas, so finally international standards have been made. Standards that are reachable from our location are collected within European norms, which can be purchased from National Standardization Institutes or from the central European Institution for Standardization.

Some of the standards collected in European Norms, are listed below:

<table>
<thead>
<tr>
<th>Standard Number</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>CEN/TR 13201-1:2004</td>
<td>Road lighting - Part 1: Selection of lighting classes</td>
</tr>
<tr>
<td>CR 14380:2003</td>
<td>Lighting applications - Tunnel lighting</td>
</tr>
<tr>
<td>EN 12193:2007</td>
<td>Light and lighting - Sports lighting</td>
</tr>
<tr>
<td>EN 12464-1:2002</td>
<td>Light and lighting - Lighting of work places - Part 1: Indoor work places</td>
</tr>
<tr>
<td>EN 12464-2:2007</td>
<td>Light and lighting - Lighting of work places - Part 2: Outdoor work places</td>
</tr>
<tr>
<td>EN 12665:2002</td>
<td>Light and lighting - Basic terms and criteria for specifying lighting requirements</td>
</tr>
<tr>
<td>EN 13032-1:2004</td>
<td>Light and lighting - Measurement and presentation of photometric data of lamps and luminaires - Part 1: Measurement and file format</td>
</tr>
<tr>
<td>EN 13032-2:2004</td>
<td>Light and lighting - Measurement and presentation of photometric data of lamps and luminaires - Part 2: Presentation of data for indoor and outdoor work places</td>
</tr>
<tr>
<td>EN 13032-</td>
<td>Light and lighting - Measurement and presentation of photometric data of</td>
</tr>
</tbody>
</table>
As data from European norms, which are considered as Lighting Recommendations could be found on the internet archives, we will not develop this topic any further.

7. Light pollution

Recently, we hear more and more about “Light Pollution”, a subtle enemy of the nature in general. When we say nature, we consider range from the most primitive life forms to the human, so this argument is not to be ignored. Usually, under term of “Light Pollution”, one thinks about outdoor lighting, but to be accurate, we can think of interior lighting that not only disturbs, but can have long term negative effects.

Basic explanation for outdoor light pollution is shown on the following picture:
Interpretation of the picture is simple. Nobody wants public lighting to enter into his home, and disturbs him during the night. Same goes for astronomers, who found upward light really disturbing, because of the increasing of the sky glow and therefore reduction of the possible notification of the stars. Light that travels horizontally, may reach far distances (several hundreds of kilometers), and on its way it veils the sky. Birds, that navigate by magnetic perceptors in their brains, when enter into illuminated sky, can't find their way out of it, so the stay or even worse, fly until drop from loss of energy.

As mentioned before, light pollution is sometimes noted in the interior spaces, too. One of the common examples is night light in children room. We usually leave a small table luminaire in the children room, sometimes even all night long. In big number of cases this might provoke myopia in the children. The reason is simple. The eye never really sleeps, so during the night, if the light enters into an eye, it tries to focus the picture. But, as the eyelid is closed, the picture can't be really focused. During the time, an eye shortens its focus length permanently, and the kid becomes myopic.

A lot of studies have been made on the people that work in the night shift and various disturbances have been noted. A very simple advice is that during the night sleep we don’t need any light at all. If one have to work in the night shift that certainly doesn’t have to be a rule. He has to change shifts, so at maximum one nocturnal week per month is really allowed. Everything that exceeds this rhythm puts the human health in jeopardy.

Not only for the mentioned reasons, but also because if not planned well, it might cause various disturbances and diseases, light pollution also falls under subject of the Ergonomics of Light.

**Conclusion**

Ergonomics is employed to fulfill the two goals of health and productivity. It is relevant in the design of such things as safe furniture and easy-to-use interfaces to machines and equipment. Proper ergonomic design is necessary to prevent repetitive strain injuries, which can develop over time and can lead to long-term disability. But not only furniture or devices we use have to respond to ergonomic attributes. Lighting is also of crucial importance, because 80% of all external stimuli came through our eyes. Furthermore, stroboscopic effects of the light influence our mental processes in a negative way. Knowledge of light pollution can help us to avoid negative consequences of improper lighting. This is most evident when we talk about kids, of age less than 4 years, because until that age the vision system is in developing stage.


Specification Sales Manager SEE

GE Lighting
References


3. "Daylighting in Schools" report from Heschong Mahone Group for PGE, 1999

4. "Skylighting and retail sales" report from Heschong Mahone Group for PGE, 1999


