Light & Health
Research
Foundation

Proceedings

Symposium Healthy Lighting...
at work and at home,
for increasing well being,
comfort and performance

November 20, 2002
Eindhoven University of Technology
The Netherlands
Welcome and introduction to the SOLG symposium:

"Why Light offers an opportunity to cope with the problems of a modern, 24 hour society"

For this second symposium of the Foundation for Research on Light & Health (Stichting Onderzoek Licht en Gezondheid, SOLG), we have been able to put together a program with outstanding international and national speakers. Their presentations give an up to date overview of current understanding of the non-visual effects of ocular light on people and the (potential) possibilities for a wide variety of practical applications.

We are rapidly discovering what constitutes “healthy” lighting. This in turn will also enable the identification of “unhealthy” lighting exposure and allow for corrective (lighting) measures and thus enhance preventive applications.

Healthy Lighting at work and at home is not only a research topic in medical sciences anymore. It has entered the professional lighting field. The Dutch Lighting Society (NSvV) is working on a draft guideline for Healthy Lighting at work and the Knowledge Center for Buildings & Systems (KCBS) at the University of Eindhoven has a major R&D program to measure health and productivity effects in offices and to develop healthy office lighting systems. A KCBS-program to develop healthy lighting systems for the elderly at home has started.

All over the world we see a strong increase in medical and application research related to healthy lighting. Both are necessary to fully develop Healthy Lighting for preventive and therapeutic applications.

New business opportunities as well as enormous benefits for people and society at large are becoming insight. The non-visible effects of the light that we see are becoming visible.

Prof. Dr. Ir. S.H.A. Begemann
Chairman SOLG
Date: 20 November 2002
Venue: Technische Universiteit Eindhoven, Auditorium, Blauwe Zaal

Chair Ir. W.M. v. Bommel, president elect, Commission Internationale d’Eclairage CIE

09:30 Registration

10:00 Welcome and introduction: Why light offers an opportunity to cope with the problems of a 24 hr society

Prof.dr.ir. S.H.A. Begemann, Eindhoven University of Technology, KCBS, chairman of the Light & Health Research Foundation

“24 hr society, biological rhythms and light”

10:15 The physiology of the non-imaging system: the eye and the brain

Prof.dr. S. Daan, University of Groningen, Laboratory for Zoology

10:50 Biological effects of ocular light
Dr. D-J. Dijk, Centre for Chronobiology, School of Biological Sciences, University of Surrey, Guildford, UK

11:25 Biological effects and the administration of ocular light
Dr. G.C. Brainard, Jefferson Medical College, Philadelphia USA

12:00 Healthy lighting. Recommendations for workers,
Ir. G.J. van den Beld, NSVV, comm. Light & Health, Arnhem

12:15 Lunch

“Key applications for healthy lighting"

Light and the working environment

13.30 At daytime, performance and well being,
Dr. M. Fontoynon, Lyon France

13.50 During the night, performance and well being,
Prof. dr. G. Kerkhof, University of Amsterdam

14:10 Applications of healthy lighting in the working place,
Drs. L. Zonneveldt, KCBS, Eindhoven

Light at home

14.30 Light and the elderly
Prof. Dr. D.F. Swaab, Netherlands Institute for Brain Research, Amsterdam

15:10 Tea break

15:30 The future of healthy lighting
Dr. M.S. Rea, Lighting Research Centre Rensselaer Polytechnic Institute, Troy, New York USA

16:00 Panel Discussion, recommendations for search topics, follow up & closing

16.30 - 18:00 Optional: visit new KCBS facilities and drinks
Introduction:
In November 1999 the Foundation for Research on Light and Health (in Dutch SOLG) organized the first national symposium on Light and Health in the Netherlands. This symposium was important for creating awareness that Light can have an influence on Health. It focussed on what light that enters our eyes (oculair light) does with our biological clock and some of its practical implications such as for nightshiftwork and sleepregulation. It also covered well established therapeutic applications such as the treatment of SAD (winterdepression), sub-SAD as well as ongoing experiments with Alzheimer patients. However it also concluded that a lot more had still to be discovered in order to define the parameters for Healthy Lighting. Once we are beginning to understand what constitutes Healthy Lighting it becomes possible to establish how "unhealthy" existing lighting conditions are for certain groups of people in specific applications. This in turn will enable us to take corrective measures. Of extreme importance are large scale applications both at work and at home because the majority of our population spends the day inside a built environment. If we live and work in Healthy Light environments we can expect a beneficial effect on human performance, health and well-being.

Healthy Lighting:
The title of this symposium is ambitious and reflects the enormous progress that we have seen in the last 3 years following our first symposium. Eminent international speakers from 4 different countries will present the latest findings and reflect on the future. What do we know today that justifies the claims incorporated in the title of this symposium.

Breakthrough:
The most significant breakthrough is undoubtedly the discovery of a separate non-visual, biological "detection" system in the eye. Although the exact details are not yet firmly established, we now know that it has a spectral sensitivity that differs from our visual spectral sensitivity in that it is shifted more to the green-blue part of the spectrum. This may not come as a big surprise since the evolutionary development of all primates happened in an outdoor environment lit by day-light with significant green-blue components. With a better understanding of the spectral sensitivity of the bio-stimulation system it will become possible to optimise the administration of oculair light. We can expect both large scale, general applications as well as small scale, case specific applications. It is not unrealistic to expect that ultimately it will be possible to define and administer healthy lighting even on a person specific basis both preventive as well as curative.

Curative applications.
Some well established curative applications already exist such as the treatment of:
- Winterdepression (SAD) and winterblues (sub-SAD)
- Sleepdisorders
Less well established but promising is e.g. lighttreatment for other forms of depression, Alzheimer disease.

Present day life differs from that of our primate ancestors in Africa in many different ways, but most important is the fact that most people are inside a building during day-time where lighting levels correspond more to biological darkness or twi-light while in the evening or night they live in artificially lit environments that are significantly "brighter" than even the moon-lit outdoor environment in Africa. Or to say it differently: oculair biological light stimulation in our present 24-hour society appears in many cases considerably different and often even out of phase from the fundamental requirements of the complex "human" system as it developed as part of primate evolution. It therefore can be expected that in the coming decade "unhealthy" lighting will increasingly be identified as a contributing factor to many different "diseases", some serious and others less serious, and health and well-being "problems of modern society". For the lamp and lighting industry above breakthrough is a clear sign that new business opportunities become visible at the horizon. The big challenge will be to prove the benefits of Healthy Lighting in large scale clinical trials, because so far most of the experiments have been conducted in laboratory environments. Although some fieldexperiments for certain applications have been conducted, they were limited in scope and time.

Preventive applications.
The general hypothesis is that long term exposure to unhealthy lighting may be an important inducing or contributing factor to the development of "health problems" (defined in a broad sense). A recent comprehensive study in the Netherlands for offices (Begemann 2002) concluded that, based on the results of a wide variety of relevant laboratory- and field-experiments related to offices and office work:
- Present day offices are from a biological point of view too dark for sufficient biological stimulation.
- Administering Healthy Lighting could be expected to reduce absenteeism due to illness by more than 10% and increase productivity by more than 1%, resulting in an economic benefit for the office sector of 2 billion Euro/year.
This does not take into account economic benefits for the National Health System and the non-economic benefits such as well-being at work. The study also concludes that in order to prove these economic benefits a large 2-year clinical trial will be necessary.

People at work during the day inside buildings are a major target. In the Netherlands some 2 million people work in offices and another 2 million in factories, hospitals, schools etc. It can be expected that all 4 million will benefit from healthy lighting at work during daytime.

Similarly the elderly form a large group that could benefit from Healthy Lighting. In the Netherlands we have at present more than 2 million people over 65 years of age. This will increase to more than 3 million in 2020. Most of these people spent most of their time inside their home. We have just started to investigate the actual lighting conditions that are typical for their living environment and living habits. In view of the fact that many have sleep-disorders of which a considerable percentage appears related to a disturbed circadian rhythm and with Alzheimer on the increase it can be expected that Healthy Lighting for the elderly at home has significant potential benefits. Also here clinical trials should be conducted.

The list of potential applications will be much longer but people at work in buildings and the elderly at home are in terms of numbers and potential benefits clearly the top priority. This is the reason why the Foundation for Research on Light and Health has earmarked these as the prime applications to focus on.

Conclusions:

Light and Health has become a major new field of science and can soon be expected to enter application engineering. The lighting profession, including the Dutch Lighting Society (NSV) is beginning to develop new Healthy Lighting standards. The Lighting Industry is looking at new lamps and systems that can meet these standards. Creating awareness among businesses, governments and special interests groups is important to educate society about the benefits of Healthy Lighting. In the mean time scientists will continue their efforts to better understand the influence of ocular light on health and well-being, including some of the negative effects of unhealthy lighting.

Reference:

Environmental light is a potent regulator of physiology. Specifically, light is the primary stimulus for regulating circadian rhythms, seasonal cycles, and neuroendocrine responses in many mammalian species including humans [1-3]. Given this regulatory capacity, many investigators have tested light as a therapeutic intervention. Controlled studies have confirmed that light therapy is effective for treating winter depression and selected circadian sleep disorders as well as re-entraining circadian physiology relative to the challenges of shift work or intercontinental air travel [3-4]. In addition, light has been shown to have an alerting effect in studies on healthy human subjects [5-8].

In the art and science of illuminating building interiors, the four major objectives have been to provide light that: 1) is optimum for visual performance; 2) is visually comfortable; 3) permits aesthetic appreciation of the space and 4) conserves energy [9].

There are a number of components of ocular physiology that mediate the photic regulation of nonvisual physiology in humans. These ocular elements include: 1) gaze behavior, 2) ocular lens age, 3) pupillary dilation, 4) photopigment and photoreceptor sensitivity, 5) photoreceptor location within the retina, 6) photoreceptor adaptation and 7) the ability of the circadian system to integrate photic stimuli spatially and temporally [10]. Recent findings suggest that a novel, nonvisual photopigment located in the ganglion cell layer of the retina is the primary regulator of neuroendocrine and circadian physiology [11-14].

The physiological and molecular identity of the ocular photoreceptors in humans which support circadian regulation and contribute to the therapeutic benefits of light therapy are in the early stages of being characterized. Since the early 1970's through the mid 1990's, different laboratories published both polychromatic and analytic action spectra for circadian and neuroendocrine responses in various mammalian species. Together, these action spectra were reasonably consistent in indicating that the spectral region between 450-550 nm provides the strongest stimulation of circadian and neuroendocrine responses in mammals [15]. Initial work on the action spectrum for melatonin regulation in humans confirmed that the secretion of melatonin by the pineal gland is not principally mediated by the three cone photopic visual system [16]. Two recent action spectra on melatonin suppression in healthy human subjects identified 446-477 nm as the most potent wavelength region for regulating melatonin [17,18].

The data from these studies suggested that a novel vitamin A1 retinaldehyde-based photopigment is primarily responsible for melatonin suppression in humans. Figure 1 illustrates one of these action spectra that tested nine monochromatic wavelengths [17]. As shown in Figure 2, the fitted template for melatonin regulation appears to be distinct from the classical photopigments of rod and cone visual photoreceptors [17,19]. This presentation will review the ongoing work on circadian and neuroendocrine phototransduction. Such studies open the door for innovation in architectural lighting.

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Figure 1: The data in this graph demonstrate that wavelengths in the blue portion of the visible spectrum are most potent for regulating melatonin in humans. Specifically, the action spectrum for melatonin suppression from over 600 night time studies involving 72 healthy male and female subjects is illustrated [17]. The line in the graph depicts the best-fit template for a vitamin A1 retinaldehyde-based photopigment and has a high coefficient of correlation ($R^2 = 0.91$). This figure is reprinted from [17, Copyright 2001 by the Society for Neuroscience].
Figure 2: This graph illustrates a comparison of the melatonin suppression and the classical visual photoreceptor action spectra [17]. The maximal spectral response and long wavelength limb of the melatonin suppression template is plotted along with the maximal spectral response and long wavelength limbs of the human rods and cones that support vision [19]. The shaded area around the 464 nm template represents ± SD from the data described above. This figure is reprinted from [17, Copyright 2001 by the Society for Neuroscience].

Healthy Lighting, Recommendations for workers

Gerrit van den Beld  
NSVV Committee Light and Health, Arnhem, The Netherlands  
Philips Lighting, Eindhoven, The Netherlands

Introduction

In the daily practice regularly requests for ‘better’ lighting are usually the result of complaints on the existing lighting installations. These complaints vary from problems in vision of e.g. details of the visual task to eyestrain and headache, to unsafe situations and to reduced productivity and increased absenteeism. In short adaptations of the lighting systems are in most cases carried out to overcome the existing problems. It is ‘problem solving’ instead of ‘problem prevention’.

However there are today coming in more and more requests for what could be called natural lighting or healthy lighting or lighting enhancing well-being. Such simple questions are difficult to address and in many cases the lighting design is based upon examples of buildings with lighting systems considered as healthy lighting solutions. It is too early to give complete recommendations but important elements of ‘better’ lighting can be given on basis of what is known as per today. This goes beyond the present standards as it is evident that non-image forming (NIF) effects of ocular light are at least as important as light needed to carry out the visual task. The NIF effects are equally important to both employee and employer, as it will have also a positive effect on productivity and reduction in absenteeism. So in principle there is a win-win situation as all parties benefit from better healthy lighting. However the awareness is of these aspects is still very low and we see many poor quality lighting installations especially in the industry.

1. The human lighting needs

1.1. Visual needs/aspects

The lighting requirements for all usual visual tasks are laid down in standards e.g. the new European standard EN 12464. The scope of this standard states that ‘the requirements meet the needs for visual comfort and performance but it does not specify the requirements with respect to safety and health of workers at work’.

So even the lighting needs for vision go beyond this standard, take e.g. safety lighting requirements.

Some aspects that could or should be considered are:

- Lighting conform the standard (? E.g. influence of age is not considered)
- Productivity
- Accidents, safety
- Absenteeism

1.2. Non-visual needs/aspects

- Light and biological clock (e.g. at nightshifts, experience in control rooms)
- Direct stimulation /effect (research on EEG changes, suppression melatonin, increase in alertness, cortisol levels, etc.)
- Light and mood (tests with ‘bright light’ at the work station, winter blues, increase vitality)
- And again productivity, accidents, safety and absenteeism

As an example the influence of lighting level and productivity (table 1) based upon data as given in the German ‘Handbuch für Beleuchtung’ in the case of metal industry. It shows a substantial increase in productivity in case the lighting level is raised from 300 to 2000 lx, being a lighting level where surely NIF effects can be expected to play a role.

Table 1: Relative increase in productivity by increasing the lighting level from 300 lx to 500 lx to 2000 lx in metal industry

<table>
<thead>
<tr>
<th>Metal Industry</th>
<th>Increased lighting level from 300 to 2000 lx</th>
<th>Increased lighting level from 300 to 500 lx</th>
<th>Relative increase in productivity (300 to 2000 lx)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Increase in task performance (%)</td>
<td>+16</td>
<td>+5 ± 2</td>
<td>+1.16</td>
</tr>
<tr>
<td>Reduction in number of rejects (%)</td>
<td>±29</td>
<td>±8 ± 3</td>
<td>+1.03</td>
</tr>
<tr>
<td>Accident reduction (%)</td>
<td>±52</td>
<td>±14 ± 5*</td>
<td>+1.03</td>
</tr>
<tr>
<td>Total relative increase in productivity</td>
<td></td>
<td></td>
<td>+1.23</td>
</tr>
</tbody>
</table>

* Accidents will lead in an estimated 2-10% of the cases to actual absence of work and thus to loss of productivity. (In above table, 5% has been used in the calculations)

2. Requirements and Recommendations for workers

2.1. Visual requirements and recommendations

In EN 12464 required values are given for illuminance, unified glare rating and colour rendering for the most usual visual tasks. The minimum level for occupied spaces is 200
For normal office work and a variety of industrial tasks the level is 500lx with colour rendering of 80. These levels should be achieved by daylight, electric light or a combination of both. Flicker and stroboscopic effects should be avoided. Further it is stated, "The choice of colour appearance is matter of psychology, aesthetics and of what is considered natural". In addition a number of recommendations/requirements are included which should of course be met, but those are less interesting in the context of this paper. The standard does not make any differentiation on personal needs, age or working time e.g. during the day or the night.

2.2. Non-visual lighting options and recommendations.
It is evident that time of day is an important factor with respect to the human needs for lighting or darkness. In normal daytime work a natural 24 hrs light-dark cycle should be followed. However this means that on the working place, including environments where no daylight contributions are entering or absent in e.g. wintertime, the NIF lighting needs should be fulfilled.

Working in nightshift requires lighting to keep you alert on one hand and offers good sleep quality after work, thus in the daytime. Therefore also in this case a 24hrs light-dark cycle should be followed. Working in the evening requires lighting that ensures good sleep quality afterwards, so again a 24hrs light-dark cycle is preferable.

This leads to the following elements in 'better' lighting:
- 24hrs light-dark cycle
- Sufficient light to control (synchronise or phase shift) the bio-clock
- Cope with the seasons (winter blues, dull days, short days)
- Cope with all weekdays (Monday morning, post lunch dips, evening and night shift)
- Maintain alertness (nightshifts in electric light or in darkness e.g. security personnel, drivers)
- Increase well-being, productivity and reduce absenteeism

2.3. Daylight and electric light.
Daylight and electric light have per today a number of different features:

Daylight

- High level (> 50 klx)
- Dynamic
- Continuous spectrum
- Colour rendering 100

Electric light

- Low level
- Legally min. 200 lx, EN 12464
- Recommended 500 lx (office)
- Mostly static
- Continuous spectrum + line spectrum
- Colour rendering 80

Spectral distributions of daylight, standard electric light and sun tanning lamps are given in fig.1:

2.4. Lighting levels for NIF effects.
A large number of publications give indications what lighting levels are required to achieve NIF effects e.g. with respect to synchronize the bio-clock, to phase shift the bio-clock and to cope with winter blues.

2.5. Action spectrum NIF effects and related light sources.
The recent published action spectrum is shown in fig.2 (Thapan, Brainard). Also recent results of research on possible new photoreceptors in the retina point towards such an action spectrum. These recently found photosensitive ganglion cells contain melanopsin with absorption characteristics in the same wavelength region (ref. Berson, Hattar). From this (fig.2) a graph can be derived to show the luminous efficacy as well as NIF efficiency for various light sources (fig 3).

The areas in this graph relate to the elements as indicated above for better lighting:
- Area A: High effectivity in NIF effects, low luminous efficacy, for night work with little visible light
- Area B: High effectivity in NIF effects, high luminous efficacy, for night work with visible light
2.6. Concept Lighting Algorithms.

2.6.1. Dayshifts

In fig. 4 an option is shown for daytime activities, which starts with a high lighting level in the morning, compensation for the so-called lunch dip and again an increasing level at the end of the working day to cope with increased fatigue. The lighting levels for achieving boosting effects are in the order of 1000-1500 lx and can be provided by daylight, if available, or by electric light either from the general lighting or localized lighting e.g. desk lights. The color temperature of the light is preferably high, e.g. more than 10000 K. Suitable light sources are found in the B area of Fig. 3. These boosting effects seem to be most efficient if the increase is offered as a step function. A gradual increase gives a lower effect (ref. Cooper).

The timing of additional boost can be offered to the worker giving him a personal control to meet his individual lighting needs.

The lower illuminance levels (minimum meeting the ‘visual standards) are achieved by gradual dimming and changing color temperature to values of 4000-6000 K, depending on preference and matching with daylight contributions.

In addition dynamic effects can be added to achieve a natural effect as can be experienced on a mixed sunny/cloudy day. Care should be taken that this does not interfere with the visual task to be carried out.

2.6.2. Working in the evening

An option is to start with a boost of 1000 lx as in fig. 4 and gradually reduce to the required standard level. At the start the color temperature should preferably be high and gradually reduce to very low values. The spectral distribution changes from the B to the A area in fig. 3. In this way a better sleep quality can be expected after finishing the evening work.

In case of working at home even the lighting level can be lowered in the course of the evening.
2.6.3. Working in the night shift.

Already in the seventeenth century it was pointed out that ‘work at night’, particularly referred to bakers, is harmful: “When during the dark others sleep they stay awake and they try to sleep during the day like animals who escape the light”.

Shift workers are confronted with shifting of sleeping/working hours and the internal body clock. The major stress sources are related to unfavorable working, organizational and environmental conditions. Others problems are related to family and social life. Stress influences general well-being as well as affect both physical and mental health. Direct effects are disturbances in sleep quality, both in overall duration and fragmentation. On longer term a number of disturbances, disorders and diseases are frequently found. Gastrointestinal disorder is one of the most frequent (prevalence in various sources ranges from 20-70%, compared to non-nightshifts 10-25%). The symptoms vary from less appetite, constipation, and heartburn to chronic gastritis and peptic ulcer. Another category is psychoneurotic disorders, manifesting in anxiety, chronic fatigue, depression, nervousness etc. These aspects increase the risk for other diseases e.g. cardiovascular disorders, disturbances in blood pressure, heart rate, irregular cortisol secretion etc.

These characteristics lead to less productivity, increased risk of accidents and a higher level in absenteeism due to illness. Without going into specific types of shift work and tasks an overview will be given of the general findings and trends in the three fore mentioned elements.

In a number of studies alertness and performance clearly show a daily pattern (see fig.5). Examples are e.g. drivers missing signals, risk on car accidents, number of failures and rejects in industry etc.

The biological clock regulates the circadian rhythms e.g. of body temperature and melatonin. The temperature rhythm is well in line with the circadian component in the degree of alertness and performance. Some other factors are important as is shown in the so-called three-process model (Akerstedt et al). Following the black curve in fig.6. The first period of 8 hours represents sleep, followed by wake-up and stay awake until midnight. The black curve is continued if sleep follows, however the black dotted curve is followed in case of staying awake e.g. in case of nightshift. In latter case the red curve represents the resulting subjective alertness rating over about 36 hours, including the first nightshift, and shows a dip around 4 o’clock in the morning (Derived from Folkard/Akerstedt).

Without sleep shortly before going in the nightshift the subjective alertness rating is at minimum values, as the red curve shows. Taking sleep before the night shift will give improvement as some increase in rating will occur (black dotted curve starts at higher level). Circadian adjustment is also very effective as it will increase instead of decrease the exogenous component (maximum of the C component, blue curve, is shifted to the night period). Combining both options can, at least in theory, result in equal alertness ratings for evening and night shift and can be even close to day shift.

The trends over the 24-hour day in productivity and accident risks, reproduced/derived from various field and laboratory studies, are shown in fig.7. The differences between night and morning shifts are significant for many types of tasks both in performance and accidents. Some studies show 20% more incidents at night compared to morning shift and even 80% in serious incidents. Differences are also substantial in e.g. failure rates can increase by up to 50% and performance with 10-20% compared to morning shifts.

The figure 7 shows two dips in productivity that are at the same time for a variety of activities, and are moreover strongly correlated with the ‘peaks’ in driver- and other accident risk. The mayor dip of both is between midnight and 06.00 hrs, similar to the timing of the dip in alertness as shown in the model of fig.6. Although to a much lesser extend in depth, the second dip from is between noon and 16.00 hrs. This dip is often referred to as ‘post lunch dip’ (note: without ‘lunch’ there is still a dip).
There are many studies on absenteeism carried out, however the methods used differ largely, making it complicated to draw general conclusions. Many studies show for shift workers a higher rate in complaints and illnesses, however the absence rates vary from lower to higher compared to day workers. One of the reasons could be that e.g. visits to family doctors, dentists, etc normally take place in daytime.

The nightshift worker has to cope with the night dip in this natural rhythm and stay alert, work safe and perform on acceptable level. Secondly he has to cope with the sleeping problems or reduced sleep quality after the night shift that aggravates the problems for the next days' nightshift.

In the context of this article question will be addressed to what extent light-bright light-offer options to cope with nightshift activity and can ameliorate the negative effects on well-being and health.

Bright light studies are carried out both in the field and under laboratory conditions. Bright light, with illuminance levels in the order of a few thousand lx, can be used to adapt the circadian clock to nightshift work resulting in improvements in sleep quality and duration as well as in alertness (see fig.8). Some studies show that with lower levels and avoiding daylight when commuting home (e.g. by wearing dark goggles) also support this. To speed up adaptation a well-controlled 24 hours light/dark cycle is important, thus the timing of the bright light period in the nightshift and timing of the dark/sleep period should be planned carefully.

Research recently published (August 2001) on melatonin suppression show that the wavelength region from 430 to 460 nm is most effective. The maximum sensitivity is at a shorter wavelength than either photopic or scotopic vision. It is hypothesized that also the effectiveness in phase shifting the biological clock is following the same action spectrum, which would offer lighting options to follow either a natural cycle or an effective phase shifting at relative lower lighting levels by means of lamps with specific spectral distributions

The large individual variations in phase shifts in the field studies lead to the fact that the present standard lighting applied in the night shift working environment is not optimal for the worker. A more individually controlled lighting on the individual workplace instead of an overall general lighting system seems to be more favorable. Anyhow more attention should be paid to the lighting for the nightshift instead of using the same lighting for daytime, evening and nightshifts. Considering the biological effects of light especially with respect to circadian adjustment and spectral sensitivity different lighting strategies can be distinguished e.g.:

a. Lighting resulting in no or minimal circadian adjustment and phase shifting. Area A lamps
b. Lighting resulting in partial circadian adjustment and moderate phase shifting. Area B-A lamps
c. Lighting resulting in maximal circadian adjustment and large phase shifting. Area B lamps
d. Deep blue lighting to increase e.g. driver alertness. Area C lamps.

The lighting levels and timing differ from first to last night of the night shift period and depend also on personal sensitivity. As for the daytime work boost of light can be applied to increase alertness at particular times. This can take place at the workplace or during breaks.

For control rooms circadian lighting systems with high lighting levels (type c) have been tested on basis of 'Harvard' protocols in e.g. 6 nights shift schedule. Type a and b can e.g. be applied for fast rotating shifts.
Lighting will have to meet both visual and non-visual human needs and will become:

- Work/task dependent
- Work shift dependent
- Work day dependent
- Work hour dependent
- Weather dependent
- Season dependent
- Person dependent
- And

- Light level controllable
- Light color controllable
- Flicker free
- Good color rendering

REFERENCES


Abstract:
At daytime, daylight is certainly the main economical light source able to offer illuminances above 2000 lx indoor, with an ideal spectral distribution. Such high illuminance values can be obtained near windows or under rooflights. They also can be obtained deeper inside buildings with daylight guidance systems. Beyond the fact that daylight contains some Ultra Violet radiation, its spectral distribution varies according to the climatic conditions, the type of outdoor environment near the building, and over time. The variability of daylight availability is certainly its major character, making daylighting design more difficult, but enhancing its interest over electric light. This papers reviews the economical challenge related to bringing daylight at work place: the cost of the systems, their performance, the comparison with salary costs. We propose to express benefits of daylighting in terms of measurable quantities.

Daylight, the preferred light at work.
It is often stated that daylight is the preferred light source at work places. In fact, surveys clearly demonstrate that occupants prefer to work near windows, but the reason seems to be related to the importance of maintaining a view toward the outside, more than the actual quality of light.

The healthy aspect of daylight is certainly not fully understood by the general public, except for a possible reduction of stress or fatigue at the end of the day. The benefit of daylight on health seems to be a rather subtle phenomenon, involving a rather long duration of exposure.

It seems however important to assess the impact on health of our evolution in urban life, with daily exposure to daylight as low as few thousands lux.hours on the plane of the eyes, and with little contribution from daylight in winter.

Daylight, for human health more than energy savings
Lighting electricity consumption in offices and factories is related to the electric power density (W/m²) and its duration of use (hours per year). Taking an average power density of 15W/m² and a typical duration of 2,000 hours of use this leads to an annual electricity consumption of 30KWh/m², or a cost of 3 Euros/m².yr. Turning off or dimming lights when daylight is available can reduce this value to 2 Euro/m².yr. Combination of efficient lighting strategies and daylighting can reduce this value down to 1 Euro/m².yr.

If we assume a worker to use 10m² of space, then the financial challenge of lighting electricity saving with daylighting per worker is of the order or 10 to 20 Euro per year, which is of the same order of the cost of one hour of salary for the employer (29 Euro/hour average).
As a result, we can conclude that the access to daylight, perceived by occupants for more than 1000 hours per year at workplaces has a minor energetic cost in comparison with the salary costs.

However, it appears legitimate to study the role of the levels of exposure to light as well as the impact on health associated to its spectrum since lighting is used during about the 1600 hours of work per year (estimation), with a potential of about 1000 of them being supplied by daylight (500 lx for a daylight factor of 5%), 400 hours leading to high illuminances (above 1000 lx) and 150 of them to values above 2000 lx. These values do not take into account the extra light from sunlight. And it should be noted that, unfortunately, most of this extra light is supplied in summer.

Looking only at costs, it appears that the challenge in lighting techniques stands more in user satisfaction than with the potential for energy conservation. The impact of poor lighting at workplaces should be assessed in comparison with salary costs (around 50,000 Euros/year and per worker, 1 Million Euro over 20 years).

**Daylight technology, a reasonable investment at workplaces.**

We propose below a comparison of figures between salaries, and various features of comfort at workplace, among them lighting and daylighting.

<table>
<thead>
<tr>
<th>Item</th>
<th>Operating costs (€/yr)</th>
<th>Hourly working cost (€/hr)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Office space rental per worker</td>
<td>1500</td>
<td>53</td>
</tr>
<tr>
<td>Energy (heating, cooling, lighting)</td>
<td>150</td>
<td>5.5</td>
</tr>
<tr>
<td>Lighting Electricity</td>
<td>30</td>
<td>1</td>
</tr>
</tbody>
</table>

Operating costs of an office workplace in € per year, and expressed in hours of staff costs (hypothesis: 1600 hours / year at 29€/hour).

In other words, an office worker works 53 hours a year to pay for the space rental, 5.5 hours a year to pay for the energy, and 1 hour per year to pay for the lighting electricity.

We have also computed the amortized costs of various equipments in an office, taking into account the various durations of those equipments. Our hypothesis: building life: 60 yrs, windows: 30 yrs, exterior shading system: 10 yrs, interior shading system: 15 yrs, shading motors and controls: 15 yrs, furniture: 15 yrs, computer: 4 yrs, lighting equipment: 15 yrs.

Below is the expression of the costs of these equipments in hours of salary for the employer. This gives an idea of how much working time is devoted to reimburse these investments.

<table>
<thead>
<tr>
<th>Item</th>
<th>Amortized costs in hours of salary</th>
</tr>
</thead>
<tbody>
<tr>
<td>Building (70% work spaces, 30% services)</td>
<td>10.3 hours</td>
</tr>
<tr>
<td>Window (for daylit space only, fraction of facade cost)</td>
<td>3.4 hours</td>
</tr>
<tr>
<td>Shading system (exterior)</td>
<td>1.4 hours</td>
</tr>
<tr>
<td>Shading system (interior)</td>
<td>0.6 hours</td>
</tr>
<tr>
<td>Motors and controls</td>
<td>0.4 hours</td>
</tr>
<tr>
<td>Armchair and desk</td>
<td>3.4 hours</td>
</tr>
<tr>
<td>Filing cabinets / miscellaneous</td>
<td>3.4 hours</td>
</tr>
<tr>
<td>Computer work station</td>
<td>10.3 hours</td>
</tr>
<tr>
<td>Lighting equipment</td>
<td>0.7 hours</td>
</tr>
</tbody>
</table>

Comparison of running costs expressed in salary cost related to the creation of a working environment in an office. Non exhaustive.

From the table above, we can see that the running cost of computer equipment is close from the running cost of the building itself, due to the short life on this investment. Again, costs related to the quality of the interior environment is quite low. Adding windows, shading, shading controls and lighting leads to a value below 5 hours/year.

**Conclusion: good lighting, healthy lighting is not expensive**

The discussion on healthy lighting requires scientific, technological, financial and cultural considerations.

**Scientific**: what are the doses of natural light, electric light and UV radiation that a human being requires for its health and well-being.

**Technological**: what are the lighting scenarios which are best suited to meet the human requirements: lighting quantities, duration of exposure, spectrum, etc.

**Financial**: since we have demonstrated that the costs associated to lighting remain low compared to other elements of the working environment, the next task is to assess the financial risks associated to poor lighting with respect to health, reduction of well being and productivity.

**Cultural**: our civilization has established a pattern of life which is getting away from our original environment. In cities, our exposure to daylight, sunlight and UV has been significantly reduced, and the situation is even more critical at high latitudes in winter. Should lighting technologies compensate for this trend or should we consider that we will be more reasonable in the future, increasing daylight at work places?
Light and Performance
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Field studies have shown that the quality of alertness and performance varies in the course of a working day and that it appears very difficult to maintain a stable level. Measurements of the number of warning signals missed by train drivers and of the number of deviations in the electrocardiogram incorrectly identified by ..., for instance, clearly indicate an increased risk for errors during the night period. Strictly controlled laboratory recordings have confirmed the existence of a circadian periodicity, driven by a biological clock mechanism located in the suprachiasmatic nucleus of the hypothalamus.

These consequences of night work may be explained by a physiological maladaptation to the inverted work/sleep schedule. Light regulates the circadian pacemaker in such a way that its effect is dependent on the timing of exposure relative to the nadir of the endogenous body temperature rhythm. Light exposure before the nadir induces a phase delay, whereas exposure after the nadir induces a phase advance. Thus, light exposure of the night worker on his way home after work will phase advance his circadian pacemaker and oppose the phase delay needed to adjust to night work. Therefore, a deliberate choice of the timing of (artificial) light and dark may accelerate the shift of the nadir of the endogenous body temperature rhythm. Also, concomitant phase shifts in melatonin and cortisol concentrations, increased alertness and performance, and better sleep have been reported.

In addition to its effect on the timing of circadian rhythms, light has been shown to exert direct effects on a number of physiological, subjective and behavioral variables. Light exposure can result in melatonin suppression, elevation of body temperature and also increases in alertness and improvements in performance. Thus, the timing as well as the level of light should be implicated in optimizing working conditions.

References

Bjorvatn, B. et al. (1999). Bright light treatment used for adaptation to night work and re-adaptation back to day life. A field study at an oil platform in the North Sea. Journal of Sleep Research, 8: 105-112.


The lighting is controlled through an infrared control that also can operate the external shading. The external shading consists of screens that are controlled automatically based on insolation for each façade. The individual users can overrule the automatic control. An extra internal glare protection by venetian blinds is operated manually. Ceiling mounted light sensors and occupancy (motion detector) sensors ensure that the selected level will be maintained and that the lighting will be switched off when the user leaves the room for more than 15 minutes. When the light is switched on again it will come back at the default level of 500 lux. In this way a lighting system is created which provides high levels but at the same time is very energy efficient.

An extensive evaluation [9] shows the users are happy with the system. At the same time there is a strong (25%) reduction on energy use compared to a standard office with a manually switched lighting system without controls. An interesting aspect of the evaluation is that although many people preferred high illuminances (daylight + 800 lux electric light), some chose to have much lower levels of 200 lux in total.

Evaluation of biological lighting at workstations: retinal exposure measurements

Lighting standards and practice in offices today are solely based on visual criteria. The "horizontal illuminance on the working plane" is used as the dominant lighting installation design parameter. Technical and user evaluations are mainly focusing on visual comfort and energy aspects. So new ways of evaluating lighting conditions with respect to health parameters have to be developed.

To measure the retinal illuminance a specially developed instrument called the Retinal Exposure Detector [5] will be used. This detector is a simulated eye and measures the light falling on the human retina with respect to anatomic restrictions and the spatial response function of the eye. The current experiments investigate retinal illuminance in relation to the commonly used visual comfort parameters.

For different working planes in a standard office room a person is simulated in an experimental set-up at eye-height (1.25m) sitting at a desk. During the measurements retinal, facial (at the face, vertical or 25° inclined [4]) and horizontal illuminance will be measured (Figure 1a). In test rooms or real office rooms the main desk- and sitting positions are indicated with a capital letter (A to E) In Figure 1b an example is given for positions in an office room with the accompanying viewing direction. The vertical position of the set-up is mentioned with number 1 (straight) or 2 (25° inclined).

The results of the first experiments show that there is very little relationship between horizontal illuminance and retinal exposure.
There is however a correlation of retinal exposure with the amount of daylight at the window. If the objective is to achieve a high retinal exposure then it is obvious to utilise daylight from windows as much as possible.

**The future: new tools and techniques for lighting spaces**

Many of the new insights about light and people presented at this conference will change the way we illuminate our working environment and our homes. The first implication is already mentioned: the need for an increased flexibility. We have to create options to adapt the lighting conditions to different tasks, periods of the day, ages, moods, etc.

The basic principle to create a healthy lighting is to start from using as much daylight as possible. Daylight is in most buildings provided by vertical openings and so directly aimed at the eyes and at vertical surfaces in the room. Daylight is also a very variable and even unreliable source. The challenge here is to control the amount and distribution in such way that visual comfort and biological demands are both supported. See for example the ETAP system (figure 4). This system uses retroreflective venetian blinds to direct the daylight towards the ceiling. A ceiling mounted specially designed mirror system will spread the daylight towards the walls in the front of the room. These vertical illuminances will contribute to a pleasant bright environment in the front of the room. A special feature of the system is that it is relatively little dependent on the slat angle. Therefore at most sky conditions a view out remains.

![Figure 4. The ETAP daylight system [3].](image)

Artificial lighting should integrate with daylight and supplement or take over when too little or no daylight is available. The lighting installation has to be capable to provide psycho-biological stimulation lighting at all times. The direct consequence is a shift from general lighting to ambient lighting in combination with localised task and bio-lighting. Vallenduuk [8] shows that people prefer dynamic and variable lighting. So lighting has to become more flexible too.

**Conclusions**

Creating working and home environments with healthy lighting is a challenge to every one involved in lighting design. New criteria and standards are being developed.

This means that also new evaluation techniques are needed. Measurement of retinal illuminance might be one of the first. In the last years large scale evaluations of office environments with respect to lighting have been made. They provide ample info and are very well feasible. Most evaluations are still investigating energy efficiency and visual comfort. Now is the time for evaluation with respect to health and well-being. Apart from the technical evaluation shown here psychological and physiological measurements are being developed. The evaluation of the Palace of Justice shows that people like to have higher lighting levels. It also shows that this does not directly mean higher energy use. Obviously the challenge for industry is to develop new products providing people with a healthy and energy efficient illuminated environment. The future of indoor lighting will be less uniform, less constant in levels, colour temperature and with changing components. In short it will be far more interesting and stimulating.

**References**

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An age-related decrease in circadian modulation has, among other things, been observed in hormone levels, temperature, electroencephalographic (EEG) activity, alertness and sleep (Van Someren et al., 1993; Swaab, 1999; Van Someren, 2000). Elderly people start napping during the day and often complain of disturbed sleep during the night (reviewed by Van Someren et al., 2000). In Alzheimer’s disease this fragmentation of the sleep-wake pattern is even more pronounced. The suprachiasmatic nucleus (SCN), which is the biological clock of the brain, is of critical importance in the circadian modulation of behavior and physiology. In aging, and even more so in Alzheimer’s disease, a marked reduction in the number of vasopressin-expressing neurons is found in the SCN. The combined anatomical, physiological and behavioral findings suggest that a dysfunctional clock may underlie the sleep-wake pattern fragmentation (Hofman and Swaab, 1994; Swaab et al., 1985; Swaab, 1999; Liu et al., 2000), and we therefore tried a number of strategies designed to stimulate the circadian timing system in order to promote preservation of neuronal functioning of the circadian timing system, and thereby to enhance the functionality of the clock. Increased input to the circadian timing system can be effectuated by means of bright environmental light and peripheral nerve stimulation. Our studies in aged rats have demonstrated improvement of both functional and anatomical signs of degeneration of the circadian timing system after environmental stimulation. Witting et al. (1993) demonstrated that the decreased amplitude in the circadian distribution of sleep and wakefulness as it is present in very old rats, could be restored to the level of young rats by means of increasing the intensity of daytime environmental light. Lucassen et al. (1995) demonstrated that such increased light input counteracted the age-related decrease in the number of vasopressin-expressing neurons in the rat SCN.

In human, we have used the rest-activity rhythm as a marker of the functionality of the circadian timing system, because this variable can easily be assessed using actigraphy. An actigraph is a small wrist-worn solid state recorder that continuously assesses the activity level, resulting in a time-series from which the strength of the circadian rhythm can be calculated. In a correlational study, we first investigated which constitutional and environmental factors were related to the severity of rhythm disturbances in Alzheimer patients. Regression analyses showed the most severe rest-activity rhythm disturbances in patients with a sedentary rather than physically active life style, and in patients exposed to low levels of environmental light (Van Someren et al., 1996). Subsequently, we investigated the effect of additional bright light on rest-activity rhythm disturbances in demented patients. Additional bright light improved the coupling of rest-activity rhythms to stable environmental cues (so called Zeitgebers) in patients with intact vision, but not in patients with severely compromised sight (partial blindness, cataract) (Van Someren et al., 1997). These results agree with other studies showing improved circadian rhythms and decreased behavioral disorders in Alzheimer patients treated with bright light (Campbell et al., 1988; Hozumi et al., 1990; Okawa et al., 1989; 1991; Satlin et al., 1992). The observation that light therapy also increases the mini mental state scores in demented patients (Graf et al., 2001) makes light therapy of even greater interest for Alzheimer’s research. Recently it was shown that the age-related decrease in melatonin secretion, which is under the control of the SCN, is partly due to the poor illumination experienced by many elderly people and can be restored using bright light (Mishima et al., 2001).

References

There is no question that light regulates the timing of the human circadian system. One clear example is the ability of light of sufficient intensity to suppress melatonin concentration in the bloodstream. Our understanding of the timing, intensities and spectra of light required to impact the circadian system has progressed very rapidly over the past several years (e.g., Wurtman et al., 1985; Rea et al., 2002).

![Mean Melatonin Levels](image)

The science of circadian photobiology will continue to grow without reference to practical applications, although some practical applications of light for circadian regulation will certainly emerge. Except perhaps for military and quasi-military applications, such as space travel, light applications for circadian regulation probably will be limited to very specific sectors of the general population, such as Alzheimer’s disease patients (Van Someren et al., 1997; Figueiro et al., 2002a), premature infants (Miller et al., 1995; Bullough and Rea, 1996; Brandon et al., 2002), and seasonal affective disorder (Rosenthal et al., 1985). For wider applications such as shift work (Boyce et al., 1997; Figueiro et al., 2001) and jet lag (Wever, 1985), light treatment will probably play a very limited role. It is clear that despite the proven efficacy of light treatment for these two applications, shift workers and frequent international travelers are unlikely to “drop out” of our diurnal society with its normal rhythm of daytime activity and nighttime rest. It seems even more unlikely that still larger segments of the population will be willing to change their normal life routines as a result of the growing science of circadian photobiology. Recall that there are still many cigarette smokers despite fifty years of unambiguous research on its implications for ill health.
Since only a few segments of the general population are likely to obtain the benefits of our understanding of light for circadian regulation, it seems unlikely that the traditional, commodity-driven lighting industry will play a role in the development of systems and products to deliver light (and darkness) for the benefit of these groups. Rather, specialized companies will cultivate these "niche" markets. Ironically, this reluctance of major companies to engage in light treatment will further retard widespread applications of light for circadian regulation because the brand name recognition of large companies will not be used to increase consumer confidence.

Possible exceptions may exist, however, for capitalizing on our evolving understanding of circadian photobiology to impact larger segments of the population. Preliminary evidence is mounting that lighting during the daytime, and in particular, exposure to bright light during the working day, can affect productivity (Figueiro et al., 2002b). If this evidence continues to mount, related areas of research, including psychology and work place ergonomics, will begin to take on new directions, leading to new lighting and architectural design practices. Architectural practice might change even more radically to incorporate more windows into workspaces (an efficient means of providing bright light to the worker), a feature that has receded from architectural practice in the latter half of the twentieth century (Lechner, 1987).

In this context, the design of schools may be the most affected in the near future. Melatonin levels in young children are very high, compared to those in adults (Waldhauser and Dietzel, 1985). The medical community is presently investigating the possibility of a link between chronic light exposure at night and the incidence of cancers such as breast cancer (Stevens and Rea, 2001). Although evidence for such a link is presently very tenuous, at best, it has been suggested that cancer in adults might be related to factors experienced in youth (Swerdlov et al., 2002). If children, with their higher melatonin levels, are somehow more susceptible to endocrine disruption by light, and if subsequent research bolsters the hypothesis about cancer as a childhood-originating disease, society's concern for its young could very well effect changes in the designs of schools and homes, providing bright, plentiful light during daytime and darkness at night.

Nonetheless, sweeping changes in architectural practice are probably years away. In the meantime, there will always be enthusiasts for "healthy living through light" who will be quite willing to talk about our emerging understanding of circadian photobiology, in much the same way as those in recent years who have promoted the use of vitamins and nutritional supplements to enhance general health. It was 1753 when James Lind of Scotland published his treatise on the treatment of scurvy with citrus foods, now known to contain Vitamin C. But widespread use of vitamins has only recently become a lucrative industry, growing during the 1990s from US$2.6 billion to more than US$6.1 billion!

Perhaps it will not take two centuries for light treatment to become a billion-dollar-per-year industry, but it will take several decades before we see widespread changes to mainstream lighting and architectural practice. Nevertheless, the rapidly growing science of circadian photobiology will undoubtedly be embraced by an ever-growing number of entrepreneurs who will attempt to derive their income from specialized applications of light.

References


Acute effects of light treatment on cerebral blood flow in healthy individuals and patients with seasonal affective disorder

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Objectives: Light treatment is an effective treatment for winter depression in seasonal affective disorder (SAD) and, according to several reports, for nonseasonal depression. Although it may take several weeks for a complete antidepressant effect of light, some degree of improvement in depressive symptoms occurs within the first hour of treatment and predicts response to light at two weeks (1). No previous functional neuroimaging study, to our knowledge, has focused on the acute effects of bright light on brain physiological activity. We hypothesized that after bright light treatment, changes in brain activity in healthy subjects and in patients with seasonal affective disorder will occur in areas where abnormalities in patients with recurrent depression have been previously reported (2).

Methods: Cerebral blood flow (CBF) was measured using 15O water and PET with arterial input functions in 15 SAD subjects (age 45.8±9.1, 10 females and 5 males) and 15 age and gender matched controls (age 45.7±9.1, 10 females and 5 males). Nine scans were performed at 12-minute interval. SAD patients were diagnosed using Rosenthal criteria for SAD (5) and had to be clinically depressed according to SIGH- SAD scores (typical score >13 independent of the total score, or, typical score >11 and total score >19). Three scans were performed at baseline (dim light). The subsequent 6 scans alternated between the “on-light” (three scans) and “post-light” (three scans off-light) conditions. Depression scores were documented on the NIMH mood scales and compared across conditions with ANCOVA with post-hoc t tests. Bright light was administered with a light device suspended above the scanner and delivering in average 8,200 lux at the level of the eye. The average cumulative duration of light treatment per “on-light” or “post-light” scan was 29.7 minutes. Global CBF was compared across conditions and between patients and controls using ANCOVAs. Effects of light on regional CBF in patients and controls were assessed by comparing normalized blood flow in the “on light” and “post-light” conditions relative to the baseline condition, using SPM 99.

Results: At baseline, in SAD subjects, increased rCBF was found in the ventrolateral prefrontal cortex bilaterally, right orbitofrontal cortex, left ventral striatum, right globus pallidus, in the vicinity of the right hypothalamus and posterior cingulate (p <0.001). There were no regions where rCBF was significantly decreased in SAD subjects vs controls.
Patients’ depression acutely but incompletely improved, with depression scores significantly (p<0.01) lower “on- light” and “post-light” as compared to baseline. In the “on light” vs. baseline conditions, in patients as well as controls, rCBF increased in the occipital lobes bilaterally and decreased in the cerebellum and medial frontal cortex bilaterally, and the right anterior cingulate, anterior insula, and temporal cortices (p<0.001). The “post-light” - “baseline” comparisons, in patients as well as controls, show that rCBF increased in the ventrolateral prefrontal cortex bilaterally and right lingual area (occipital lobe), and decreased in the cerebellum, bilaterally (p<0.001). In patients, additional changes were found in the vicinity of the infralimbic area (deactivation) and in the pontin raphe (activation). However, the “postlight”- “baseline” differences between patients and controls were not statistically significant.

**Discussion/ Conclusions:** In both patients and controls, post- light activation was found in the ventrolateral prefrontal cortex. In previous studies in major depression activity in this area appeared compensatory, insofar as showing an inverse relationship with depression severity (2). Thus, activation by bright light of brain regions involved in modulating the emotional experience and behavioral expression of depression could be an important mechanism of its antidepressant effect.

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**References:**