Objectives and Approach

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1.1 Objectives

1.1.1 The Total Project

The project “Light and Health” is conceived as a four-phase study with the objective of finding the most favorable conception for the illumination of future office workplaces. A considerable number of these new working spaces will consist of VDU workplaces, the number of which will vary between 20% and 100%, depending on the individual company. Indeed, the figure of 100% has already been reached in many companies and, during the course of the next few years, it is likely to become a reality in the majority of all administrations.

In the extensive literature on this subject, there is neither a lack of expert judgements, nor is there any lack of normative and other suggestions for new conceptions. By contrast, this project intends to concentrate on the opinions of the users of work areas; the objective of the entire project consists in determining the standards for lighting techniques which are optimal from their point of view. The survey and the evaluation also take into account the existing space design and its possible development since the authors believe that lighting cannot be assessed without considering these issues.

During the first phase of the project, described in Chapters 9 and 10, more than 2,000 individuals were interviewed at their workplaces over the course of several years; questions concerning lighting were always an essential part of these surveys. On the basis of these surveys, we then formulated the hypotheses for the second phase of the project, which have now been verified by means of a representative survey of office workers. The subsequent, third phase of the project will be concerned specifically with investigating workplaces with particular lighting characteristics which proved to be especially favorable or unfavorable in phase two of the project. At the end of the third phase of the project, a final comparative study of a variety of artificial lighting systems was performed, the results of which will be used to specify which different lighting models will be studied under laboratory conditions in part 4. In addition to this, the reliability of the method was tested in a further investigation.

Since the results of the first three phases of the project are unambiguous, the last phase will be of interest primarily for manufacturers who want to optimize a product.

1.1.2 Phase 1: Field studies at different workplaces

The subject of the first phase of the project was ergonomic field studies in a large number of companies with the aim of finding relevant stress factors for office workers. Lighting is considered as one of the environmental factors with a significant impact on humans, however, most people tend to assume that its influence is positive. This means, in their opinion “good lighting” would reduce the workload in a given situation. This way of thinking may be true without any doubt if one considers that without artificial lighting, we would not be able to work at all, and lighting enables us to organize work independently from the rhythm of natural light.

However, the field studies demonstrated that the users at their workplaces do not share such an opinion. E.g., the acceptance of the artificial lighting was not 70% or more as was expected, but just between 0% and 20%. Since the field studies have been performed in offices where almost all available and financially realistic types of lighting were represented, we decided to perform a systematic search for the root causes for the lack of acceptance. For this task, six hypothesis have been formulated and were tested in the phases 2 and 3 of the project.

It should be noted, however, that studies on acceptance of an object (in this case lighting) can only yield results on the assessment of that object under given conditions (e.g. certain types of office rooms), and thus, give hints of other possible factors of influence which must be considered while determining the true impact of the object of interest. To accomplish the task of finding the essential factors, it is necessary to isolate those factors stemming from the object from other factors of possible influence present at the workplace. Concerning the acceptance of lighting, the most relevant factors to be considered are the work task, the personal qualities of the subjects and the design of work rooms.

1.1.3 Phase 2

The main emphasis of this report lies on the second and third phases of the “Light and Health” project. The results of the investigations of these two phases can be used independently, and are supposed to provide interested companies with scientifically based options for their choice of lighting installation.

As already mentioned, the object of phase 2 of the project is to verify the following hypotheses, and to suggest recommendations for the design of work areas and their lighting. These hypotheses were drawn from the results obtained in phase 1 of the project and from the norms and objectives which have already been established in the Federal Republic of Germany for the lighting of workplaces.

- Hypothesis 1
  The lighting of work-areas has a positive effect on the health and well-being of those who work there.
- Hypothesis 2
  The lighting of work-areas has a diminishing effect on human fatigue.
- Hypothesis 3
  The effects of artificial lighting on health and well-being are determined by the type of artificial lighting of work-areas.
- Hypothesis 4
  Daylight has a more favorable effect on human health and well-being than artificial lighting.
- Hypothesis 5
  In the vicinity of a window, daylight has an unfavorable effect on work with a VDT.
- Hypothesis 6
  Users of VDTs are not affected more negatively by artificial lighting than those working at conventional office workplaces.

The derivation of these hypotheses will be explained in more detail in Chapter 2.

The statements of this investigation are only valid for workplaces illuminated by fluorescent lamps, since this is currently the most common form of office lighting and fundamental changes in the foreseeable future are unlikely. The closely connected and decades old question of an alleged health hazard from florescent lamps was not investigated in this project. This does not mean that the question was considered irrelevant. There were two reasons for not studying the impact of the lamp: the limited likelihood of finding a sufficient number of office workplaces equipped with other types of lamps on the one hand and conclusions from some of the results described in Chapter 11 on the other.

1.1.4 Phase 3

In phase 3 of the project, various types of lighting were installed in workrooms with normal design features (size, windows, height etc.) to test hypothesis 3 under practical conditions. The main difference to phase 1 of the project was that in phase 3 new lighting systems could be considered which did not exist during phase 1 or were of an inferior technical quality. For example, modern lamps, now widely used for task lighting and overhead lighting, would have been rejected in the middle of the 80´s after a laboratory test because they tended to flicker. In addition, the technical quality of the “VDT-luminaires” has been improved to such a substantial extent, that a new study seemed sensible. Due to these and other reasons, at least in theory, a lighting system with poor acceptance in the first two phases of the project may be assessed very differently today.

In the course of this phase, there was the opportunity to realize 13 different lighting installations in similar rooms of a company with all of them planned following the same specification: The vendors have been asked to fulfil all relevant quality criteria of the relevant lighting standards (DIN 5035, parts 1,2 and 7). This study enabled us to check the practicability of these standards under carefully controlled conditions.

Another study under controlled conditions was performed in the rooms of a company in which five different systems for general lighting were installed and used with and without task lighting.

The last study of the project was performed to check the reliability of the questionnaire. In this investigation, an earlier study from 1976 was replicated in office rooms with virtually the same characteristics and lighting system. Such a study can help to demonstrate the reliability of the methods used in this project. In addition, it can also help to show that the results of the project are not biased by the personal preferences of the subjects but represent the response on the characteristics of the relevant object, the lighting.

Until today, about 800 persons have participated in this part of the study who had been working under the lighting in question for at least two months before the survey. The subjects’ average experience of the lighting was about six months or more.

1.2 General Description of the Problem

The problem of artificial and natural lighting of workplaces has been a subject of discussion for several decades; it took on a fundamentally new form with the invention of the fluorescent lamp in 1936 and its subsequent introduction over the course of the following decades.

For the first time in history, the introduction of fluorescent light offered the opportunity of illuminating workplaces with illuminance levels high enough that the work could be performed entirely independent of daylight. It now became possible to design work-areas which were relatively deep in relation to their height (so-called open-plan offices), since fluorescent lamps now helped to provide the complete illumination of such rooms under economically acceptable conditions. The amount of daylight provided for such areas, which can be calculated, for example, by the amount of window space per workplace, has steadily decreased throughout the years. The loss of importance of daylight as a means for illuminating the workplace formed one of the most important reasons for this development. In the seventies, there was even some discussion concerning the benefits of windowless offices and schools. Indeed, some were actually built, after the architects had received support from experts in their belief that lighting of workrooms and visual comfort could be improved if there were no windows. These experts - of occupational medicine - even claimed that artificial lighting was superior to daylight (Deutsche Gesellschaft fur Arbeitsmedizin, 1965). When speaking of “windowless workrooms”, one must include the majority of those workplaces in open-plan offices that receive little or no daylight as the result of the installation of dividing walls, etc.

In recent years, daylight has regained some of its importance as lighting, this time for energy saving reasons. There are new concepts for either trying to transport daylight into the depth of the workrooms or coupling the technical elements utilized for this purpose with a daylight-dependent control of artificial lighting. In both cases, the focus lies on energy saving.

Even though people working in areas with little or no daylight complained about the poor quality of the workplaces and their lighting (Sieverts, 1980), their complaints have only been reluctantly accepted. Although in recent years, the design of office buildings has taken into account the desires of those affected, through artificially enlarged facades, for example, lighting technicians have continued to insist on blaming all irrefutable complaints on the poor design of the lighting installations and have persisted in rejecting the existence of conceptual faults. In view of the fact that many lighting installations genuinely do contain some defects in their construction, this argument should be proved through representative investigations. However, it was never planned to check whether it is true that the complaints about lighting are caused by other relevant factors in the work environment since we believe such arguments stem from the fairy tails people tell if the part of technology for which they are responsible does not work. Similar stories have been told by supporters of open-plan offices who have failed with their approach, as well as by vendors for air-conditioning systems who have maneuvered their technology to the brink of complete unimportance.

In the Federal Republic of Germany, federal regulations *("Arbeitsstättenverordnung")* ensure the provision of a minimum amount of daylight for each workplace by requiring that the worker must have a view to the outside of the building (§7 (1)). Accordingly, a given workplace is in compliance with this regulation, independent of the actually available amount of daylight, as long as the person working at that place can see a window. Despite such minimum objectives, this regulation does provide one of the most important design criteria for both work-areas and office buildings, which is why German office buildings differ favorably from their American counterparts, for example. *"Letting the sunshine in"*, an ultimate goal for inhabitants of German cities who fought for healthy living spaces at the beginning of this century, found its way into legislation and has remained there almost unchanged until today. Although the relevant regulation is on "lighting", illuminating the workplace does not constitute the main reason for it. Reasons named in the commentaries are avoiding the feeling of enclosedness on the one hand and the positive impact of the communication with the outer world on the other.

Unfortunately, as technology has made its inroads into the office, a number of workplaces have evolved in which these lighting regulations are met - the rooms do have windows -, but where the view to the outside must constantly be blocked because the equipment being used is extremely sensitive to light. Today, almost all CAD workplaces are still operated under the virtual exclusion of daylight. Even lighting experts recommend the partial or total exclusion of daylight (Stolzenberg, Marx, 1987). Not only natural, but also artificial lighting must sometimes be "removed" from such workplaces, i.e. the lighting must either be dimmed or even turned off altogether. The operators work in semidarkness. It is at least probable that this will have an effect on both their performance and, above all, their health. They do, after all, belong to a species which, from the point of view of evolutionary history, is dependent on daylight. The question arises, therefore: Are the health and well-being of humans working in darkened rooms affected negatively as a result of the fact that they no longer have any contact to the outside world, as stipulated in the regulations?

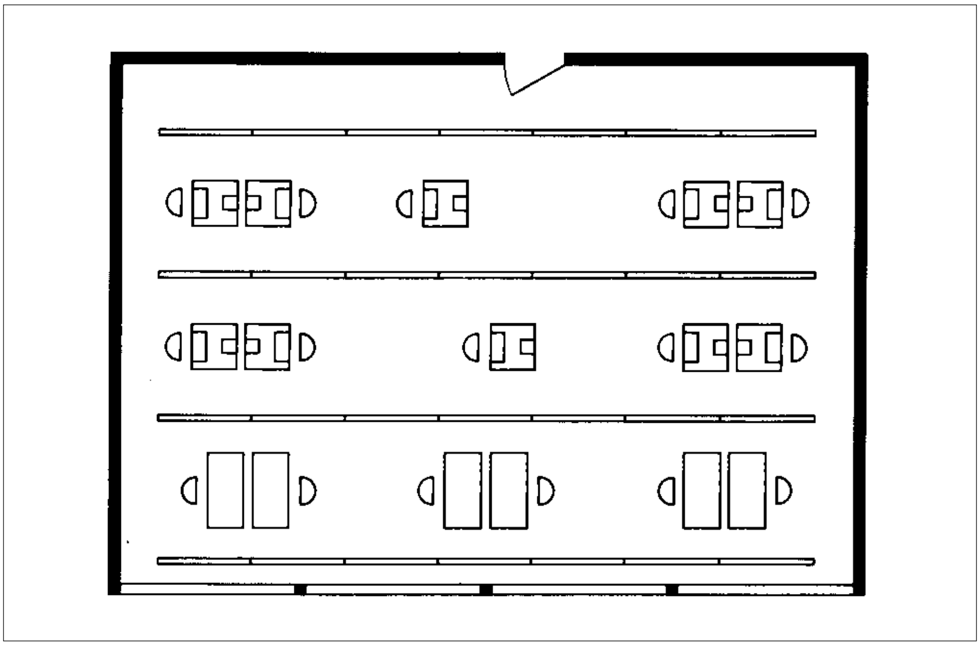
Another important question concerns the predominantly technical views on natural and artificial lighting: with respect to most of the criteria for evaluation, lighting technology treats natural and artificial lighting of workplaces according to the same basic principles. For example, measurements of the illuminance on a particular object or of the luminance of this object are made with the same measuring instruments, regardless of the type of lighting. Insofar that one is concerned only with purely physical properties, this method is undoubtedly correct. But is this method still valid when considering the factors which influence our well-being? Some problems that arise in connection with this question are given below by way of example:

- Natural light entering offices that are oriented towards the north is “colder” than any artificially created light used for the illumination of office space. Do people working in such offices sense this?
- Not only those people unfamiliar with lighting technology find light from an incandescent lamp to be “natural”, even though genuinely natural daylight seldom possesses similar properties as light from a lightbulb. Judged by physical standards - such as the color temperature - almost any artificial source of light that is used in offices appears to be “warmer” than daylight.In this respect, incandescent light from a lightbulb shows the greatest deviation from daylight.
- It is a known fact that there is no single type of artificial lighting which is equally acceptable to everyone. People living in southern countries, for example, tend to prefer a “cold” artificial illumination, whereas the Scandinavians prefer an even warmer light than Central Europeans.

The debate on VDT workplaces introduced new impulses in the field of lighting technology. An attempt was made to solve the problems, both real and presumed, which arose with the introduction of such workplaces. The most important of these are:

- Avoidance of the reflection of the light source by the screen through the use of innovative lighting (so-called “VDT-luminaires” or “BAP-luminaires”);
- Reduction of illuminance in order to obtain an acceptable contrast on screens of insufficient quality;
- Reduction of the degree of reflection from surfaces in the room;
- Reduction of daylight interference through the removal of VDT workstations from daylight areas (see Fig. 1.1).

Fig. 1.1 Recommendation of DIN 5035 Part 7 for the orientation of VDT workplaces in areas away from the windows



These measures were taken for the worst state of the technology of the working tools, and they are aimed at eliminating visible impairments to the recognition of information displayed on the screens, specular reflections. However, these measures - even if unintentionally - also affect the entire lighting situation and the impression of the room. Before such measures can be recommended as a form of protection for those concerned, it is therefore necessary to verify whether, in their entirety, they lead to a reduction of stress / strain for the users.

It was also a concern to take special protective precautions for people working at VDTs. This also includes the stipulation that such people generally may not use any additional illumination for their workplace - in the form of task lighting (table lamps), for example -, since this could increase eye strain (ZH 1/618, Sicherheitsregeln für Bildschirm-Arbeitsplätze im Bürobereich). Given current conditions, it must be questioned whether the presuppositions behind this well-intentioned regulation are still valid today.

This is not the only question of relevance for today 's office lighting; rather, one must also take into account the consequences of human actions such as turning off of artificial lighting, the removal of lamps or the screening of one's own workplace against daylight when certain screens with insufficient contrast are used. This leads to the question: what are the reasons behind such actions, and what are their consequences?

Only rarely does ergonomic research deal with questions of this sort. Generally, one is content with referring to the fact that a set of norms exists, the observance of which will facilitate good lighting conditions. Given the fact that the workplaces observed can often, if not generally, be proved to be inadequately illuminated, such an attitude is hardly surprising. In such a situation, the application of given norms will arguably bring about noticeable improvements. The question, however, whether these norms are indeed sufficient with regard to the importance of light for humans, is very seldom asked. It is somewhat surprising that safety engineers and company doctors often experience problems with the users if they insist on the company installing lighting systems which comply with the standards.

Even more rarely does anyone pose the question, whether the quality criteria for the design of artificial lighting remain appropriate in practice for current demands. These criteria were established decades ago to describe basic principles of lighting, e.g. freedom from glare, and they should represent basic demands placed on lighting technology by working people. In practice, however, these criteria have undergone considerable changes over the years. It is rarely asked whether the observed changes were related to a transition in people´s needs or motivated otherwise, e.g., to fit new equipment. Some people might have found it a brilliant idea to form the criteria for evaluating their product according to its features.

Generally speaking, it can be said that the underlying problematic of this project essentially stems from a way of dealing with light which does not do justice to the latter's existential importance. In this respect, the fact that the Federal Republic of Germany considers the small number of university lighting institutes, which train only a few lighting engineers, as sufficient, should provide food for thought. It seems that even these institutions do not put much emphasis on practical problems related to lighting engineering.

1.3 On the Effect of Light on Humans

1.3.1 On the Effect of Artificial Lighting

In the modern workplace, the human sense of vision is confronted with ever stronger demands. Meanwhile, in most fields of work, visual tasks have undergone considerable changes, as have the corresponding demands on lighting.

In 1960, Helmar Frank said that the *"temporary superiority of humans in the field of shape and pattern recognition"* in respect to the machine; in the course of the anticipated - and now, to an unexpected extent, realized - development of information processing technology, this superiority would be lost. Machines have indeed been developed (Optical Character Readers) which are far superior to humans as far as speed is concerned. However, they require a high degree of standardization of the material to be read. The execution of certain routine tasks by computers thus did not lead to a reduction in the visual tasks of the individual, but rather to a temporal intensification and reorientation (Çakir, 1979). The superiority of humans in recognizing patterns which was characterized as "temporary" by Frank 35 years ago, is still a fact, even in comparison with highly sophisticated hard- and software. Proof of this fact is the sudden decline of advanced technical equipment, machinery with sensory abilities, to the level of insignificance within some years of a promising start.

Most people cannot understand why reading machines for handwriting, even the most advanced species among them, are relatively unsuccessful. What could be learned from the short history of products with abilities in pattern recognition is that we do not even know how human shape and pattern recognition works. This means, exploiting the visual capabilities of humans will indispensable in working life for the next decades. It also means that lighting will remain an important environmental factor at least for the next decade.

A number of modern clerical tasks consists mainly in acquiring visual information from one medium and transferring it to another medium by visually controlled motor actions (e.g. typing, data processing). Thus, the sense of vision is the most important working "tool" for millions of people in the field of office work, since they receive 90% of their information from the environment by visual means. In this respect, modern people do not differ very much from their forefathers. In contrast to our ancestors, we have to perform more intensive visual tasks due to intensified work. Later developments in technology, e.g., the ability of computers to allow processing of graphics and retouching photographs on VDUs, constitute a greater visual load compared with "conventional" data and text processing.

The intensification of visual tasks with the attendant consequence of increased strain on the visual organs is not limited to the field of office employment; rather, it is characteristic of the development of all labor in industrialized society, in which humans increasingly exercise controlling functions. The information which is required in this regard is no longer obtained mainly through tactile or auditive, but rather through visual processes. As an example, one might mention the development from the lathe to the Computer Numerically Controlled (CNC) machines with a screen and a keyboard, which, among other things, replace tactile obtaining of information from the hand-wheel. Other examples can be found in the assembly of electronic boards, the adjustment of miniature components by means of a manipulator, micro-surgery by means of a microscope, etc.

In the course of only a few decades, the workload profile for the working person has changed from hard physical work to an increased load on the visual system and the motor-sensory functions. Whereas in the case of hard physical work, the sensation of fatigue provides the organism with a relatively effective protection against damage, the visual apparatus is characterized by a number of elements which are not subject to (measurable) fatigue. According to current scientific knowledge, the retina is free from fatigue, and hardly any investigations exist which have demonstrated a purely visually motivated fatigue of the accommodation process under normal working conditions, as the demonstrated increase in accommodation time also occurs in other forms of fatigue. The only symptom of fatigue which has been proved beyond a doubt is the inferior convergence of the visual axes so that a shift of the nearest focal point can be measured for an extended period of strain. However, this symptom, too, can occur as the result of general fatigue without visual strain, so that it is not possible to establish a significant relationship between a measured effect of fatigue and visual workload. Thus, attempts to establish a physiological measurement of visual strain have not yet been successful.

In spite of these difficulties, visual strain can be established by means of physiological methods. For in the case of increased stress on the visual apparatus, or in disturbances of its interaction with the visual environment, specific impairments will occur: “asthenopia” or eyestrain. These impairments are usually associated with headaches, burning eyes, irritation of the eyes, “floating” images, and increased tear production. These complications have the same protective function as muscular fatigue, i.e. they warn the human being. However, they can also be ignored more easily, and their effect is therefore less strong. The appearance of asthenopic complaints under certain visual conditions always indicates an inadequate adaptation of the properties of the visual apparatus to the visual task and the surrounding conditions; the reason for this inadequacy to adapt can lie in lighting conditions, though this must not necessarily be the case. According to current expert opinion, the cause for these complications lies not so much in the characteristics of the lamps and in the concepts for artificial lighting; rather, they can be traced to an inappropriate installation of the lighting systems and to the inadequate correction of eyesight problems, and to visual demands which cannot be met by the workers even under the best conceivable type of eye correction (Hartmann, Müller-Limmroth, 1981).

In practice, the ignoring of asthenopic complaints, such as continued work in spite of headaches and eye strain, requires an increased biological “effort” for the completion of work tasks; for the worker this can result in stronger fatigue of the entire organism. This has decisive effects on work performance and on the office environment, and, in extreme cases, it can lead to virtual work psychoses (Hartmann,1977).

Moreover, research at the Institute for Ergonomics at the Technical University of Berlin (Çakir, 1979) has shown that increased stress on the visual apparatus, due to more unfavorable visual tasks or increased glare, results in an increase of inner tension (increase in general central activation - *allgemeine zentrale Aktiviertheit* (AZA) -, according to Bartenwerfer). That is to say, an increase in visual strain leads to a measurable increase in perceived fatigue. Subjectively experienced glare thus makes a measurable contribution to fatigue.

According to investigations by (Çakir and Klingenberg, the subjective evaluation of the effect of lighting on well-being can be measured in at least two dimensions - *“sensation of disturbance”* and *“pleasantness”* (level of comfort). Both dimensions can be influenced by lighting parameters which can affect both visibility (e.g. contrast) and glare (e.g. direct glare) (Çakir, 1975).

In laboratory experiments, Östberg has shown that for a visual task of constant quality, an increase in glare leads to an increased subjective rating of the difficulty of the visual task (Östberg, 1979). In the inverted experiment, increasing the difficulty of the visual task while keeping glare constant leads to a higher subjective rating of glare (Östberg, 1979; Çakir, 1975).

The fatigue of the entire organism in turn can affect both the professional and the extra-professional parts of social life. In the professional field, one should pay particular attention to the increased risk of accidents and to a decrease in work efficiency. In extra-professional social life, both family and other relationships are adversely affected. In particular, it should be noted that the majority of working womens’ load consists of monotonous motor-sensory elements of activity. At the end of the working day it is only their “professional” work which is over, whereas they then carry out substantial work as housewives and mothers.

One method for the reduction of asthenopic complaints which is frequently used by those concerned is the reduction of eye strain by shifting into an unfavorable working posture. One indication of this fact is provided by the significantly different frequency in the treatment of back pains for people with correct eyesight and people with incorrectly adapted glasses at VDTs (Çakir, 1979). Thus, the latter would wear glasses adapted for 300-330 mm, even though the viewing distance in a normal, unforced working posture was 500-600 mm. The result of the survey showed that to date of those workers with normal eyesight 31% had undergone treatment for back pains, whereas the figure for those wearing glasses was 50%. The most recent literature shows that such problems are far from losing their significance. On the contrary, today, more and more people in the professional world experience them.

If artificial lighting is designed in a manner that occasions the same reactions as a wrong set of glasses (e.g. constrained postures, faulty postures for avoiding glare), it will cause the same increase in physical complications. Workers who adopt constrained postures in order to relieve their eyes reduce some asthenopic complaints at the expense of other parts of their body the stress on which seems less noticeable. The extent of the impact of visual problems on general somatic problems can be demonstrated by the correlation of “visual problems” and “postural problems”: According to field studies by Çakir (Çakir, 1981) the correlation is 0.59, a correlation which seldom occurs in field studies.

The effects of visual tasks which have been dealt with so far concern the completion of the work task itself. The so-called *limbic system* provides the anatomical structure for the psychological effect of a lighting which is not only responsible for the degree of vigilance and awareness, but which also determines the performance of short-term memory, for example. Due to this mechanism, the effects of a work-specific strain (e.g. the strain on awareness) and a non-work-specific strain (e.g. diminished well-being due to psychological glare) seem to appear in combination.

It must be noted, however, that natural light, too, can induce or influence the same processes. Therefore, in an investigation which is supposed to extrapolate the effects of artificial lighting, one must also consider workplaces which are illuminated mainly by natural daylight; in the Federal Republic of Germany, according to Workplace Directive 7/1 (Arbeitsstättenrichtlinie 7/1) and DIN 5034 (Clauses on Interior Lighting with Daylight), this includes all usual office workplaces. The only workplaces excluded from the study are those operated without daylight during daytime. Due to German regulations, such workplaces are, however, rather exceptional. (*Note: In other countries, e.g. USA, Australia or UK, workplaces without daylight are very common. In some other countries, e.g. Denmark, workers are entitled to have natural light at their workplace, however, not necessarily visual contact to the outside world.*)

The preceding remarks show that in addition to a variety of positive effects, artificial lighting also creates a substantial number of problems. The deliberations also show, however, that these problems are not necessarily connected to the technical properties of the lighting installations themselves. The objection which is frequently raised in connection with lighting technology, in which it is accused of disregarding the human being, can most certainly be refuted, since the entire literature on lighting technology of the last 40 years contains a host of examples from investigations which show how human needs were integrated into the development of a technology. Nonetheless, a number of problems exist in today's working world which are connected directly or indirectly to artificial lighting and vision at the workplace. The following list represents some of these problems:

Direct consequences:

- *Glare, reduced comfort*
- *Activation (or de-activation)*
- *Sensation of disturbance (from impairment of vision)*
- *Asthenopic complaints*

Indirect consequences:

- *Fatigue resulting from incorrect posture*
- *Fatigue resulting from an increase in central activation*
- *Fatigue resulting from the effort to ignore asthenopic complaints (e.g. the effort to concentrate in spite of a headache, eye complications, and reduced performance of short-term memory)*

The existence of these problems is proof for the fact that the consideration of human problems in technical development cannot be considered as sufficient. One of the major goals of this project is to investigate whether more could be done to satisfy human needs.

1.3.2 On the Effect of Daylight

Daylight has a number of known physiological effects such as skin tanning and the like. Inasmuch as they can be easily established by experimentation, these effects have been investigated with adequate precision, and the spectral areas of light and energy distribution relevant to the respective effect have been established. As we now know, daylight has not just been a source of unmixed pleasure for those who worked in nature without further protection; sailors from the days of big sailing ships and the farmers of the millennia owe their skin cancers to daylight. No wonder, then, that the peoples have protected themselves from daylight according to the degree of its effect. Thus, traditional living structures are built differently in North Africa and Southern Europe than those in Central or Northern Europe - whereas the former are supposed to provide optimal protection from the sun, the latter are designed to let in as much sunshine as possible.

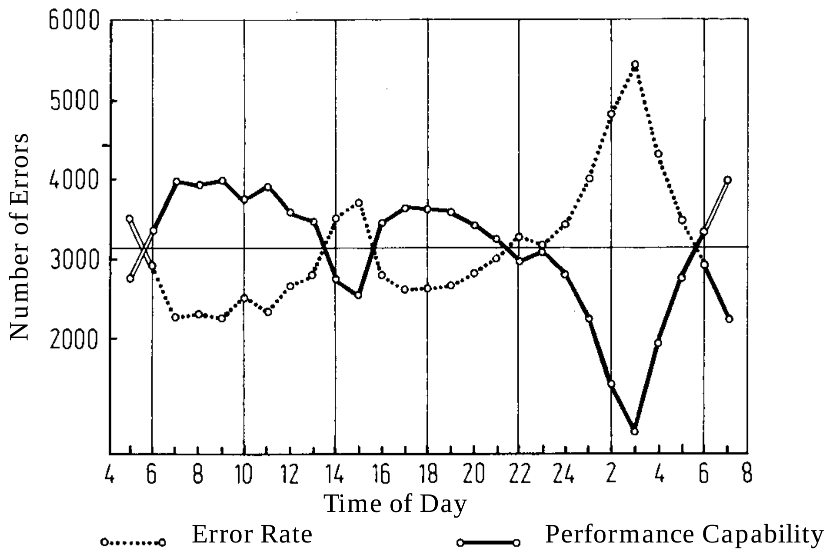
The increasing global communication which has developed during this century has led, among other things, to building design which often disregard traditional aspects. Thus, many office buildings in Iceland and in tropical countries are constructed in very similar ways. As a result, one either had to accept the disadvantages relative to the respective local climate factors, or one had to develop adequate mechanisms for protection. Consequently, architecture increasingly treated daylight as an influencing factor against which protection was required. The benefits were simply ignored by most lighting experts. This leads to a particularly difficult situation for Central Europeans, whose habitat temporarily provides an abundance of daylight, while at other times daylight remains sparse. As a result of a rather narrow minded approach, the idea of eliminating daylight entirely was born, and so began the construction of windowless rooms on the basis of the notion that artificial lighting represented a fully adequate replacement for daylight. Moreover, the relevant experts did not consider artificial lighting "ersatz" or replacement, but a requirement for modern work organization: "*The introduction of fluorescent lamps has made it possible to realize two dreams of technology, namely working in windowless and precisely air-conditioned rooms on the one hand and daytime-independent machine operation on the other.*" (Schober, 1961)

This citation from the "Manual of the Entire Occupational Medicine" was not the only blessing artificial lighting has received from occupational medicine. During the 6. Congress of the German Society of Occupational Medicine 1965, dedicated to the "windowless workspace", it was questioned whether one could investigate all aspects of windowless work environments, however it was stated: "*Humans in windowless work rooms do not have to fear health impairing impacts of the environment as long as that environment is optimal from the point of view of work hygiene.*" (from Batzel, 1989). Obviously, the experts of occupational medicine did not consider that natural light could be a factor of work hygiene. Heavily armed with this blessing from the doctors of occupational medicine, the lighting engineers dared a step forward: The major statement of one paper presented on the congress of LiTG (German Society of Lighting Technology) in 1971 on "Vision-Lighting-Work" reads: "*Lateral windows cannot satisfy high lighting requirements as artificial lighting does…*". The statement is true but irrelevant: Lighting requirements have been formulated by lighting engineers under consideration of artificial lighting. Why should natural lighting satisfy them? During the zenith of belief in the power of technology, people tended to have faith in the controllability of work environment through technical means.

However, it soon became obvious that the illusion of complete control over problems of lighting and climate was limited to the technical criteria on which the respective deliberations had been based. The satisfaction of the actual occupants of such rooms could not be achieved. This short-lived experiment did, however, reveal new knowledge concerning the influence of daylight. Not only did one recognize that communication with the outside world has a significant influence on the well-being of humans (Roessler, 1978), but it also became evident that daylight has other effects than simply facilitating the visual recognition of objects in the work task. The former insight resulted, for example, in the stipulation that every workplace has to have a view to the outside world. (*Note: The notion that also the artificial lighting is not just a means to make visual work objects easily recognizable was already formulated in the year 1962 when Bodmann had justified certain levels of illuminance with subjective factors concerning the room impression. This notion was readily "forgotten" since subjective factors are not highly estimated by technicians.*)

The second finding, daylight is more than just a means for making objects recognizable, is even more difficult to interpret than the first, for it mixes both psychological and physical effects in a way which makes it rather difficult to establish knowledge that is applicable in practice. And where such knowledge is found, the classification of any existing investigations between the poles of serious science, occultism, and profit interests becomes rather difficult.

Fig. 1.2 Daily biological rhythm and performance capacity (adapted from Graf, based on measurements from Bjerner, Holm and Swenson)



The insights on the dependence of the human organism on daylight, however, can be considered as proved beyond a doubt and are widely accepted. In the field of artificial lighting they are used in ways to be described below. Ergonomic investigations (Graf et al., 1961) have shown that human performance will follow a typical curve which depends on daytime (see Fig. 1.2). This curve remains unaltered even when the subjects become used to a sleeping/waking pattern that differs from its usual form, such as when they work different shifts, for example. For various reasons, this working rhythm is detrimental to health, since the person must act against her/his own physiological rhythm.

The phenomenon which lies behind Graf's insight, namely the temporal coincidence of the functioning of the human organism on the one hand with the movements of the earth on the other, had already been the subject of intensive research since the 1930s; the most important result of this research was the isolation of the light-dark-rhythm of the sunlight as the most important “zeitgeber” (“zeitgeber”; Aschoff et al., 1982). The “zeitgeber” is a “clock” which provides the organism with the most important impulses. It triggers a mechanism synchronizing vital functions of the organism with the external event(s).

In both the professional and in the public world an additional, so-called “social *zeitgeber”*, also exists, the effect of which overlaps with, may indeed “mask” the effect of the natural *zeitgeber.*

It is perhaps trivial to state that human work organization has created artificial conditions which also transgress well-known insights into human physiology, as is the case in the abolishment of the “siesta” as an extended midday break. As an antidote against the now well-known phenomenon of the “midday low”, background music has been introduced and features of artificial lighting have been designed. Background music has been employed to avoid variations in performance, whereas lighting has been implemented with the explicit aim of creating a bright and stimulating atmosphere in the room, which can counterbalance the performance low. In both cases, the impact of lighting and that of music as stimulation, the subject is an environmental factor that is welcomed and is likely to induce a positive influence if humans wish to have it. If introduced against the will of users, such environmental factors are considered stressors.

Küller (Küller, 1987) has shown that the balance of hormones is influenced by the total amount of light and that the quality of the artificial light is also of some importance. He concludes that *“daylight entering the eye controls or affects many of the highly complex endocrine and autonomic processes that take place in the human body.”* Light and the visual environment also affect the daily and yearly rhythm of vital functions.

In summary, it can be said that in windowless rooms, or in rooms with excessive depth, daylight is eliminated in its role as a zeitgeber. Simultaneously, the body is raised to an artificial level of performance by means of another influencing factor - artificial lighting. Since both processes occur simultaneously, it was not possible to isolate one of the two factors as the ultimate cause for changes in performance levels. In any case, the control of vital functions of the human body by light is an established fact; the question which remains is, which properties are to be held responsible for the effects.

During recent years, it was demonstrated that at least one impact of daylight, the triggering of sleep-wake-rhythm by the light-dark-rhythm, can also be induced by artificial light if the level is sufficiently high (about 10,000 lx) through its impact on the melatonin production of the human body. The alleged effects of luminaires used for “light therapy” against SAD (Seasonal Affective Disorder) are based on this impact of light. “SAD” is understood as a disorder which takes effect in fall and reaches its peak during winter. It has become known in specific areas of the world where the intensity of daylight is low during the winter period.

Above and beyond the communication with the outside world and the control of the daily and yearly rhythm which have already been mentioned, no further influences of daylight can be deduced from the existing literature.

On the other hand, the existing literature, gives no indication supporting the assumption of experts of occupational medicine that working in an environment with completely artificial lighting would not impair the state of health. During the three decades since that assumption was documented, not a single paper supporting it was published. Obviously, it lacks any scientific basis.

Working Hypotheses and their Justifications

2 Working Hypotheses and their Justifications

This chapter serves the purpose of explaining and commenting on the working hypotheses which where used to investigate the problem of lighting. Some of them have been formulated on the basis of arguments repeatedly put forward by lighting engineers for decades. However, nobody seems to have asked whether such arguments correspond to the real situation.

2.1 Hypothesis 1 and its Justification

The first working hypothesis is:

> *"The lighting of work-areas has a positive effect on the health and well-being of those who work there."*

This hypothesis is derived from the general objectives of lighting technology, which have been fixed as follows in DIN 5035, part 1:

> *" 3 Goals of lighting*
>
> *3.1 General Statements -*
>
> *By its quality, lighting has an effect on human visual performance, activation, work safety, and well-being.*
>
> *Lighting should therefore be designed in a manner as to fulfill its respective goals and to integrate harmoniously into the given room.* "

Given that these general objectives were not developed recently, but have been in existence for several decades, and in view of the fact that efficient mechanisms exist within the Federal Republic of Germany for the implementation of norms in practice (e.g. health and safety organizations, worker participation in companies, etc.), one should expect that existing lighting installations satisfy the established objectives.

While this fact is presumed as given, its verification becomes necessary for two reasons:

- In the subsequent paragraph, the norm places restrictions on the objectives for the design of lighting of work-areas: "*The lighting of work-areas must facilitate an effortless recognition of visual objects. It should contribute to the promotion of attentiveness and activation, counteract premature fatigue, and render dangerous situations clearly recognizable.*" There is no longer any mention here of well-being; rather, the question of visual performance becomes the central concern for the lighting of work-areas. The dimension of work safety is limited to the recognizability of dangerous situations and to the counteracting of premature fatigue.

- Phase one of the project (cf. Chapter 9) has shown beyond a doubt that at least half of all the persons surveyed in more than 80 companies felt the lighting to be both a strain and a disturbance. Depending on the respective design of the lighting installation, only 0% to 20% of the employees were satisfied (Çakir, 1988). These figures would seem to provide reason to assume that the goals set for lighting technology have in fact not been met. Yet, this assumption is not legitimate before further verification, since the evaluation of lighting is not determined by the properties of the artificial lighting installation alone, but rather by a number of other factors, such as the optical properties of the visual objects or the optical properties of the furniture (degree of reflectance, glare of desk surfaces, etc.). Additionally, since phase one comprises a period of approximately one decade, during which these factors have changed for the better due to the influence of the "Safety Regulations for VDT-Workplaces in the Office" and the "Safety Regulations for Office Workplaces", it seems worthwhile to seek a representative verification of the current state of affairs.

2.2 Hypothesis 2 and its Justification

This hypothesis, too, is derived from the general objectives of the above-mentioned DIN-Norm 5035; which claims that:

"*The lighting of work-areas has a diminishing effect on human fatigue.*"

The reason for the verification of this hypothesis consists not so much in questioning the effect as such - as without light, almost nobody would be able to perform any office work -, but rather in the endeavor to determine whether the statement is valid for all workplaces. For in phase 1 of the project, it was established that the quality of lighting can vary significantly from one workplace to another within the same workroom, even when the lighting installation was carried out in compliance with the norms. These differences consist not only in the quality of the artificial lighting, but essentially in the provision of daylight, which, in turn, has both positive and negative aspects. For example, the quantity of light can appear here as a positive aspect: during most times of the year, workplaces in the vicinity of windows, for instance, receive more light than is produced by artificial lighting. The negative aspect of the provision of daylight consists in temporal irregularity, in the temporary oversupply (glare), and in the side effects (heat radiation).

The differences in the quality of artificial and natural lighting can be established even for small rooms with reference to the example of the common double offices, where desks are usually placed opposite of each other in blocks of two: one of the two workplaces offers a better angle of incoming daylight, and, consequently, better working conditions. In practice, it is precisely this workplace which is generally preferred.

For all companies, one can note that in larger work-areas, employees prefer window workplaces even when there are no protective measures against heat radiation and glare. Indeed, one user characterized his “career” as a civil servant as a *“struggle from the darkest place to the corner where two windows meet.”* Although the reasons for this may differ, the tendency consistently remains the same. We can only speculate whether the reason for the preference of window workplaces lies in the quality of the lighting alone. In any case it should be noted, however that the negative aspects of daylight do not play a decisive role in the employees' evaluations of their work environment.

2.3 Hypothesis 3 and its Justification

This hypothesis derives from DIN-Norm 5035 as well as from the experiences gained in phase 1 of the project. Its claim is as follows:

> “*The effects of artificial lighting on health and well-being are determined by the type of artificial lighting of work-areas.*”

The norm gives preference to the general lighting of the workplaces, i.e. *an even lighting, which creates approximately the same visual conditions at all points of the work area.* As a rule, general lighting is to be implemented. As an exception to this recommendation, a *workplace-oriented* form of general lighting is considered appropriate in those cases where different areas of the room are reserved for performing tasks which differ significantly in their demands as far as the respective visual tasks are concerned. The third form of lighting is the *lighting of the individual workplace (task lighting),* which is considered permissible only in conjunction with general lighting. In this respect, the norm includes so many restrictions on the permissibility of task lighting (cf. DIN 5035, part 1, § 5.2.3) that it can be assumed that this form of lighting is generally not considered to be acceptable for offices. The conditions which are attached to the quality of task lighting are kept relatively strict, so that they cannot be met by the use of a table lamp, for example.

The Safety Regulations for VDT-Workplaces formulate a similar recommendation:

> *“In general, task lighting of VDT-workplaces (use of table lamps) should be avoided” (§* 4.10.2).

This recommendation is explained as follows:

> *"Due to the constantly shifting adaptation to light and dark, the unbalanced distribution of luminance in the work-area, and a potentially increased thermal stress at the workplace, all of which are connected with task lighting, this form of lighting causes greater stress to the employees."*

This recommendation is essentially based on the results obtained from the author's own research in connection with the "VDT-Workplaces"- project of the Federal Ministry for Labor and Social Affairs (Çakir, 1978). As far as the reasons which were given in the explanation do indeed exist, the validity of the recommendation remains unchanged even today.

The normative recommendations are in opposition to the desires expressed by the users, who clearly prefer task lighting. The reasons which they give for this preference are the "comfortable" appearance of the work-area, or "better lighting", whatever that may mean. However, as earlier investigations by the authors have shown simply accepting the wishes of the users unchecked, cannot be recommended, as there is a well grounded suspicion that the preference for "table lamps" as task lighting is usually referred to, does not necessarily lie in their special qualities but comes more from inadequate general lighting. In other words, users may prefer task lighting possibly because they dislike general lighting. If this was true, one had to improve general lighting instead of introducing task lighting. (Note: The quality problem of table lamp has in the meantime been addressed by a new standard on individual lighting, DIN 5035-8.)

The hypothesis can be verified by referring to workplaces where the respective lighting concepts show fundamental differences: general lighting on the one hand, and only task lighting on the other. The combined use of general and task lighting is available as a further variant between these two extremes, and it is this third form of lighting which is in fact discussed in DIN 5035, Section 1. In recent literature this type of lighting is named "combined lighting". *(Note: According to German norms, the exclusive use of task lighting is not permissible, yet in practice it occurs in a small number of cases).*

The following three types of lighting were therefore used for the verification of the hypothesis in phase 2 of the project:

- Purely task lighting with "table lamps"
- Purely general lighting with overhead ceiling-mounted luminaires
- Lighting comprising two components (ceiling luminaires and table lamps), so-called "2C" or "twin component" lighting.

In the case of phase 2 of the study, the type of lighting was specified by the subjects and could therefore not be further differentiated to yield a more specific grouping. Thus, only two concepts, where the user has only one choice (namely to switch the artificial light on or off), were tested against a third, where the user can choose between the use of zero, one, or two parts of the artificial lighting.

In phase 3, on the other hand, we were able to describe all lighting installations involved in the investigation and, in addition, measure their technical quality according to lighting engineering criteria. All planners were asked to design the lighting installation following relevant standards (DIN 5035-1, DIN 5035-2, DIN 5035-7). They were also informed about the way how their product was to be measured (DIN 5035-6). The room geometry of the test objects guaranteed adequate glare limitation according to DIN 5035-1 irrespective of the quality of the planning process.

In this phase of the study, the following lighting concepts could be used for the verification of the hypothesis:

- General lighting from ceiling-mounted luminaires with cut-off angles at 50 with a maximum luminance limited to 200 cd / m^2 ("VDT-lighting")
- Same as 1., with an additional indirect component *("semi-direct lighting")*
- Workplace-oriented lighting with features for the avoidance of reflected glare and for the maximization of the "***c**ontrast **r**endering **f**actor*", so-called "CRF-luminaires" *("semi-indirect lighting")*
- Totally indirect lighting
- Indirect lighting with task lighting - a concept with an indirect component in the form of general lighting and a direct component in the form of task lighting.

In this case, the type of lighting could be correlated with the specific type of luminaires used, and all its relevant features were known. The selection of the types of lighting corresponds with the state-of-the-art in luminaire design during the years 1992 / 1993. More information on these aspects is given in Chapter 11.

This selection did not include lighting with incandescent lamps and fluorescent lamps with the so-called "full spectrum" (e.g. "true light"). The reason for excluding incandescent lamps is the difficulty of realizing general lighting with levels of illuminance required in the standards without causing annoying side-effects like heat, infrared radiation and glare. The authors did not want to suppose in advance that the illuminance or even the whole concept of general lighting were unimportant. Furthermore "full spectrum" lamps are frequently installed in companies where the employer or the users are convinced of their advantages. The survey method employed did not seem suitable for use on people who had already chosen a certain kind of lighting installation and were enthusiastic about it.

2.4 Hypothesis 4 and its Justification

Given the importance of natural light for humans, this hypothesis appears to state the obvious:

> *"Daylight has a more favorable effect on human health and well-being than artificial lighting."*

However, this statement is not quite as self-evident as it may seem, since it was assumed that for the lighting of workplaces, artificial lighting represents a fully adequate replacement for daylight. Moreover, the statements in section "1.3 On the Effect of Light on Humans" show that lighting engineers as well as doctors of occupational medicine believed that better lighting conditions could be achieved in windowless rooms.

The verification of this hypothesis has a decisive relevance for the question whether the legal requirements offer sufficient protection by simply prescribing "visual contact with the outside world" without specifying the amount of daylight for the illumination of the workplace.

It is not the purpose of this hypothesis to examine whether workplaces without any daylight at all do or do not make sense. In Germany at least, this question has already been answered unequivocally: Workplaces without daylight are only permissible in situations where the work-task cannot be completed otherwise, such as in mines, photographic laboratories, etc. There will presumably be no more serious attempts to construct schools or offices without daylight; not only because nobody really likes such environments but possibly for the reason that one argument in favour of windowless workspace has been proven wrong: Saving energy by compact building layouts. Siegel and Wonneberg (Siegel and Wonneberg, 1979) have demonstrated that office buildings with compact layouts did not have the smallest energy consumption per unit office space, as was believed for long time, but the highest! (*Note: The results of these authors are only valid for Germany. They may be applicable to countries or geographic areas with similar climatic conditions.)*

In other countries, however, people still tend to believe that artificial light is a satisfactory replacement for natural light. Thus, a considerable proportion of the offices in the USA or in countries with similar attitudes towards human behavior lack any influx of daylight; indeed, they are lit according to lighting concepts which date back by almost a century, stemming from the age when people believed that workers would accept anything that looks bright.

2.5 Hypothesis 5 and its Justification

Work with VDTs places certain demands on lighting which cannot be met, or can only be met with great difficulty, in the vicinity of windows. Since almost all commonly used screens not only present problems with disturbing reflections, but also produce only low contrasts at high illuminance due to their limited luminance, it is generally recommended not to place VDT-workplaces in the vicinity of windows; hence the hypothesis:

> *"In the vicinity of a window, daylight has an unfavorable effect on work with a VDT."*

The question at hand is of vital importance for office architecture. For the last 20 years, architects have been trying to increase the ratio of windows per workplace by adjusting the design of the facades or the size of the windows. However, if this hypothesis can be verified, these endeavors would tend to lead to negative results due to the increasing use of technology. Furthermore, by far the largest part of office workplaces in small-scale workrooms are oriented towards a window, and would thus prove to be unfavorable, should the hypothesis hold true. On the other hand, given the fact that lighting experts have tried to keep natural light out of office environments, attention to their efforts for creating a better working environment would have to be increased, should this hypothesis be verified. In this unlikely case, however, one would need an explanation why people tend to prefer workplaces near windows even in open-plan offices.

2.6 Hypothesis 6 and its Justification

This hypothesis is based on the fact that in Germany there exist not only one, but *two* norms governing the lighting of VDT-workplaces (DIN 5035-7 and DIN 66 234-7, which has since been abolished), both intended to guarantee special protection of VDT- workers:

> *"Users of VDTs are not affected more negatively by artificial lighting than those working at conventional office workplaces."*

The wording of this hypothesis does not implicate that the impact of lighting is necessarily negative. In both cases, at conventional workplaces and VDT workplaces, the users may be satisfied with the quality of lighting, however, to a different degree. The hypothesis expresses the belief that both types of office work can be supported by the same type of lighting. (*Note: Studies with the earlier versions of the questionnaire used here have demonstrated that particular types of lighting can achieve very positive assessments.*)

Should it be possible to verify this hypothesis, then it would not be necessary to base the lighting of VDT workplaces on different criteria than the lighting of conventional office workplaces.

This hypothesis was tested in phase 2 of the project on the basis of the lighting systems in Germany which were in existence by 1990 whereas in phase 3 we had the opportunity to test any feasible and reasonable lighting system.

2.7 Summary of the Hypotheses

This study and its hypotheses are designed to answer the following questions:

- Does artificial lighting meet the objectives of positively affecting the work, health, and well-being of office workers, if projected following the applicable sets of regulations? If so, which particular types of artificial lighting meet these objectives?
- Does artificial lighting represent a fully adequate replacement for natural light in rooms with windows where / if there is an insufficient amount of natural light?

We have not attempted to find an answer to the question whether a working environment without any daylight is acceptable in the long run, as it is impossible to test this in a real working environment in Germany. Nor have we attempted to test lighting systems with incandescent lamps, since it is impossible to fulfill German standards (especially the recommended levels of illuminance) with these light sources. In addition, not enough organizations with regular office work use incandescent lamps for lighting. This does not necessarily mean, however, that these light sources are completely unsuited for office lighting.

There is a growing amount of literature concerning the health effects of fluorescent lighting. No attempt was made here to falsify or to verify the findings of such research for the simple fact that there are no workrooms with incandescent lamps providing a lighting, which fulfill existing standards. However, one should note that the detrimental effects of fluorescent light have been the subject of reports since the earliest days of its application, and we expect anyone who would defend the harmlessness of this kind of lighting to proceed with the same caution with which we formulate our statements here. The results of our research, especially those reported in Chapter 11, suggest, that the major factor of influence is not the type of lamp used in an installation but the type of lighting selected for a particular environment.

Methodology

3 Methodology

3.1 Procedure in phase 1

In phase 1 of the project, the questionnaire FEA (Questionnaire for work related strain) was used to identify relevant stress factors (for a brief description of the questionnaire see chapter 10). Possible causes of these factors were determined by appropriate methods. In the case environmental factors, e.g. lighting, air-conditioning, acoustics, technical measurements were performed. The methods used have been published in their entirety in an earlier research report (Çakir et al, 1978).

One of the important results of the research work published in 1978 is the influence of some external factors such as air-conditioning or furniture design on visual workload which is relevant for the assessment of lighting. For example, a high visual load can be caused in individual cases by the air conditioning which leads to excessive dry air flow in workrooms which dries out the mucous membrane of the eye. Poor furniture design may increase the visual workload by not allowing adequate visual distances. Such results were considered while formulating the questionnaire of this project as well as for the selection of rooms for phase 3.

3.2 Procedure in phases 2 and 3

The survey in phase 2 of the project was carried out by means of a mailing. This method ensures that those questioned are not influenced by the investigating institution. In phase 1, on the other hand, such influence did exist, since employees were questioned in selected companies. This naturally means that they could be dominated by certain concerns relative to their position and therefore generally were not as free to respond as in a mail survey.

The survey was conducted anonymously, although those involved did have the opportunity to include their addresses if they wished to receive the results. Approximately 30% of those who returned the survey made use of this possibility. The interest of the subjects in the results of the study underlines the importance of lighting in their point of view. The extremely high return rate (see below) would also seem to confirm this.

No special incentives were provided for completing the questionnaire; nor did the necessity of sending out additional mailings arise, since the first batch resulted in a sufficient percentage of returns two weeks after the date of the mailing. In the following 8 weeks, returns increased to 16.4%.

In phase 3, subjects in selected organizations and locations were given the same questionnaire, as well as an additional questionnaire on “discomfort glare”. These locations were chosen with respect to the type of lighting installed. Both management and union representatives were asked in advance for their permission. Participation was always above 90% in each of the selected target groups.

In addition to the information obtained in the survey, relevant parameters for environmental factors, such as the characteristics of the respective lighting system, or the room furniture, could be measured.

In a survey of 242 subjects employed in an office building, we were able to investigate the behaviour of users with regard to the reasons of preference for general lighting and task lighting. They were asked if they preferred to use general lighting or task lighting (if provided) or both and if they altered their use of these according to the amount of available daylight or the current task at hand.

3.3 The Questionnaire

The questionnaire was designed so that the target group could answer the questions without further help. Thanks to some pretests, instructions could be reduced to a minimum. The questionnaire did not ask for technical details on the lighting of the work area, since experience has shown that they cannot be answered with any degree of reliability.

In response to the increasing concern for data protection, we included as few personal questions as possible. Most of the questions related to the person (e.g. stature, weight, abilities, education, job training) have proved irrelevant with regard to the assessment of lighting in the phase 1 of the projects. Thus, during the second and third phase they were not included in the questionnaire.

The questionnaire (cf. Appendix) consists of the following blocks:

- **Personal questions**
  Gender, age group, glasses
- **Questions concerning professional activities**
  Hours worked per week, hours worked per day, profession, main equipment, length of time worked in present room, size and type of company
- **Questions concerning the workroom**
  Number of persons in the room, type of lighting, number of windows, distance to closest window, glare control mechanisms for protection from daylight, orientation of the windows

- **Questions concerning the effects of the artificial lighting**
  Paired concepts inquiring about two factors which resulted from phase 1 of the project: “Pleasantness”, “Sensation of Disturbance”
- **Questions concerning the change in impression of the room as a result of artificial lighting**
  These questions are based on the same pairs of concepts as in the preceding block of questions, which were reformulated accordingly: more acceptable rather than acceptable, etc.
- **Questions concerning particularly impairing working conditions**
  These questions concern environmental conditions which, according to the results of phase 1, can make a particular contribution to stress factors: noise, room conditions, excessively hot or cold temperatures, dry air, lighting conditions, conversations, too much or too little daylight.
- **Questions concerning perceptible disturbances to health and well-being**
  Concentration weaknesses, rapid fatigue, grogginess, irritability, visual complications, headaches, dry eyes, burning eyes.

In formulating the questionnaire, particular care was taken not to evoke or induce any prejudices. The questions concerning lighting are formulated negatively as well as positively, and they suggest no single tendency; they are given in the form of a list of bipolar attributes (see Fig. 3.1). This list was extracted from a list of more than 100 attributes used on several research projects at the Institute for Lighting Technology at the Technical University of Berlin (Çakir, 1975; Richert, 1975; Klingenberg, 1973).

The rating scale consists of five steps. This construction of the scale leads to a relatively high number of answers centering around the third step which corresponds to a neutral attitude vis-a-vis the object of investigation. In earlier investigations on evaluation of lighting, the 5-step scale has proven preferable to scales with 9,7, or 6 steps.

The questions concerning impairing working conditions and disturbances of health and well-being were unipolar; following von Zerssen (v. Zerssen, 1975), a four-fold range of possible answers was provided (see Fig. 3.2 and Fig. 3.3).

For reasons of data protection, no questions were asked concerning previous medical treatment of the subjects. According to our experience, the researcher who wishes to receive reliable answers to such questions must have a relationship of trust with the subject and give the latter a credible explanation of her or his objectives. It was

Fig. 3.1 Scales for the evaluation of lighting installations

How do you judge the artificial lighting of your work room?

Please tick the number which represents your personal feeling about the lighting. If the word on the left is appropriate, tick "1", if the word on the right is appropriate, tick "5". If both are not accurate, please tick one of the numbers between "2" and "4".

pleasant	①	②	③	④	⑤	unpleasant
disturbing	①	②	③	④	⑤	not disturbing
friendly	①	②	③	④	⑤	unfriendly
cold	①	②	③	④	⑤	warm
glaring	①	②	③	④	⑤	not glaring
bright	①	②	③	④	⑤	dark
soft	①	②	③	④	⑤	dazzling

planned to do this in phase 3 of the project, but as this matter has become even more sensitive in the meantime we abstained from asking such questions.

3.4 Target Group and Sample Group

3.4.1 Target Group

In order to determine the health effects of lighting on humans in general, the target group would necessarily have to include the entire working population. In this case it would be very difficult, however, to separate the effects of light from the influences of other environmental factors and work specific stress, which can be greater than the influence of light. Visual stress, for example, can vary significantly under constant illumination due to the influence of the respective visual task or equipment. In addition, workplaces outside of the field of office work are not illuminated with only one, but rather with various different types of lamps and luminaires. Furthermore, according to our experience, the lighting of workplaces in the field of production is often deficient in ways which can be assumed to have negative effects on humans. However, it is not the object of this project to investigate the effects of inadequate lighting, a subject on which ample information can be found in the existing

Fig. 3.2 Questions concerning regular impairments by working conditions

Do you experience regular impairments by working conditions?

	strong	moder-ate	barely	not at all
Noise, sound	❑	❑	❑	❑
Room conditions	❑	❑	❑	❑
Too warm temperatures	❑	❑	❑	❑
Too low temperatures	❑	❑	❑	❑
Dry air	❑	❑	❑	❑
Lighting conditions	❑	❑	❑	❑
Conversations	❑	❑	❑	❑
Too much daylight	❑	❑	❑	❑
Too little daylight	❑	❑	❑	❑

literature. For this reason, we designated “workers in office environments” as our target group. This target group includes appr. 50% of the West German working population. We did not include employees in the state of Berlin, since here age distribution is different from other federal states. In addition, public service accounts for 25% of the job market, thus making it the biggest source of employment in Berlin. Given the age of the office buildings and the financial situation of this state, a substantial portion of the lighting installations are outdated; as a consequence the total picture that would emerge from an investigation would presumably be negative.

Men and women are represented almost equally in the target group, with a slight surplus of women. The questionnaires (phase 2) were sent to women and men in equal numbers. Responses divided into 50.19% from women and 49.81% from men.

In phase 3 of the project, female workers were represented with approximately 60% in most work areas. This figure corresponds with the gender distribution in German offices.

Since phase 2 took place shortly before the fall of the Berlin Wall, nobody from the former GDR was surveyed. This could have been done in phase 3, however, in the

Fig. 3.3 Questions concerning perceptible disturbances to well-being

Do you suffer from perceptible disturbances of your health and well-being?	**strong**	**moder-ate**	**barely**	**not at all**
Concentration weakness	❑	❑	❑	❑
Rapid fatigue	❑	❑	❑	❑
Grogginess	❑	❑	❑	❑
Irritability	❑	❑	❑	❑
Visual impairments	❑	❑	❑	❑
Headaches	❑	❑	❑	❑
Dry eyes	❑	❑	❑	❑
Burning eyes	❑	❑	❑	❑

light of the thorough and rapid changes in this part of Germany, it seemed wise not to include workers in the new German states.

3.4.2 Geographical Distribution

The questionnaires were sent out to employees in all of the federal states except for Berlin in direct proportion to their percentage of the total working population. The mailing did not differentiate by size of communities, since people living in small communities may work in cities and vice versa.

A record was kept of the postal codes of the responses in order to test for a potential distortion of the sample group. The verification yielded approximately the same distribution as in the actual mailing.

The targeted individuals were chosen at random, making sure that every German citizen working in the field of office employment had an equal chance of being represented in the sample group.

In phase 3 of the project, the number of objects was relatively small, thus, they could not be evenly distributed throughout Germany. This fact is unlikely to bias the results since problems related to lighting appear to be generic rather than being limited to Germany or to a specific geographic region in Germany. During the presentations of our research at international conferences findings from experts from other countries have confirmed the existence of similar problems in their environment.

3.4.3 Size of the Sample Group

5700 target persons were contacted for the first mailing. Since experience has shown that postal surveys yield a sample group of approximately 7% after one additional mailing, responses by appr. 400 subjects could be expected. Following the first batch of responses, potential distortions in age structure, geographical or gender distribution, were to be balanced subsequently by the deliberate selection of a new sample group. The goal was set at a total of 1000 responses.

Since this goal was already met with the first mailing - presumably because of the amount of interest by the recipients -, a second batch no longer appeared necessary.

The responses were subjected to preliminary evaluation upon receipt of the 50th, 150th, and 350th return respectively. The comparison of these results shows that it was already possible to examine the hypotheses after the receipt of 150 questionnaires, and that the evaluation of further questionnaires does not yield any new information. The objectives of the project could also have been reached with a relatively small sample.

In phase 3 of the project, 800 persons were surveyed. As in the second phase, obtaining the relevant results would not require such a big sample.

3.4.4 Evaluation of the Sample

833 fully completed questionnaires with a maximum of 2 missing answers were used for evaluation. From the basic pool of “workers in office environments”, we eliminated that subgroup which legally would be classified as employers, i.e. company owners and managerial staff from departmental managers upwards. With this subgroup one can assume a strong individual influence on working conditions and working hours, which could lead to a potential distortion of the project’s results. *(Note: however, it became apparent during the course of the evaluation that this elimination was not absolutely necessary, since the reactions of this group differed only marginally from those of the sample group that was selected for evaluation. Nevertheless, the former was not taken into account out of methodological considerations).* It was not necessary to make such a distinction in phase 3 as all the subjects belonged to the target group.

Some characteristics of the sample group of phase 2 are as follows:

- As has been mentioned above, the number of women and men is approximately equal. As far as age structure is concerned (Fig. 3.4), the distribution within the sample group roughly corresponds to the distribution established in phase 1.
- Fig. 3.5 represents the distribution according to the main site at which the respective work tasks are completed, indicating that 53% of the sample group work at a conventional desk, 33% work at a VDT workstation, 7% work at a typewriter, and another 7% work at other office workplaces.

The average number of hours worked per week is 38.15h. 85% of the subjects begin work between 7:30 am and 9 am, averaging out at 7:57 am. The majority finish work between 4 and 5:30 pm.

44% of those surveyed had been working in their current room for less than 4 years. As indicated by the distribution shown in Fig. 3.6, the maximum number of years anyone had been working in the same room was 40. Almost 100 persons had already been working in their respective rooms for 20 years or more.

Fig. 3.7 shows the number of workers employed by the subjects respective companies. Thus, 45% of those surveyed work in companies which employ more than 500 people, 25% work in companies of 100 to 500, 22% work in companies of 10 to 100, and the remaining 8% are employed in small businesses with no more than 10 workers.

The responses indicated an approximately even distribution among industrial administration, business administrations in the service sector, and public service administration. Only 3.5% checked the answer listed in the questionnaire as “pure administration”; apparently the term was poorly chosen. In the evaluation, those who checked this term were therefore included among the group of employees from businesses in the service sector.

Fig. 3.4 Age structure of the sample group

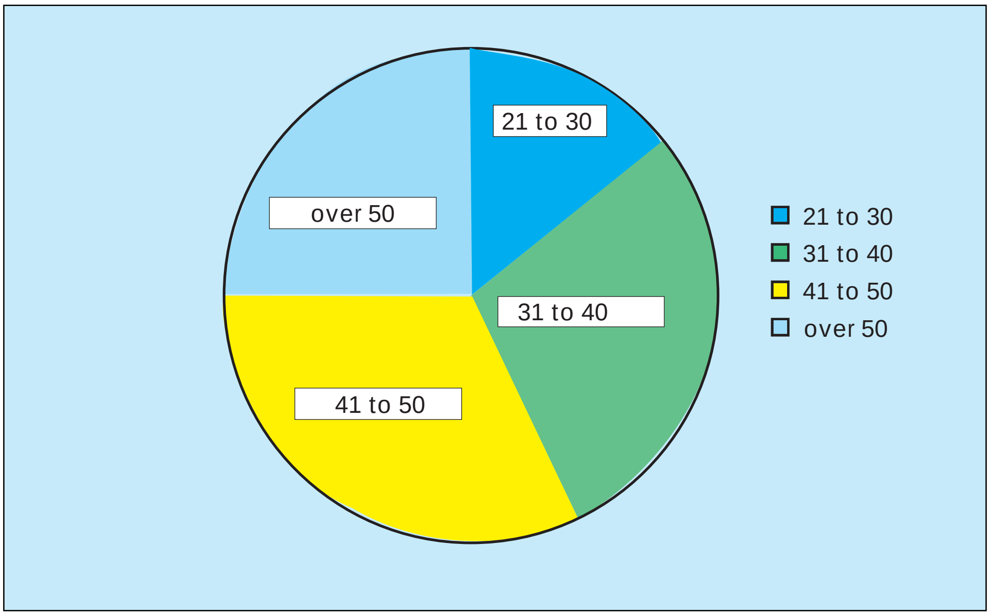


Fig. 3.5 Main workplace: site where the largest portion of the working day is spent

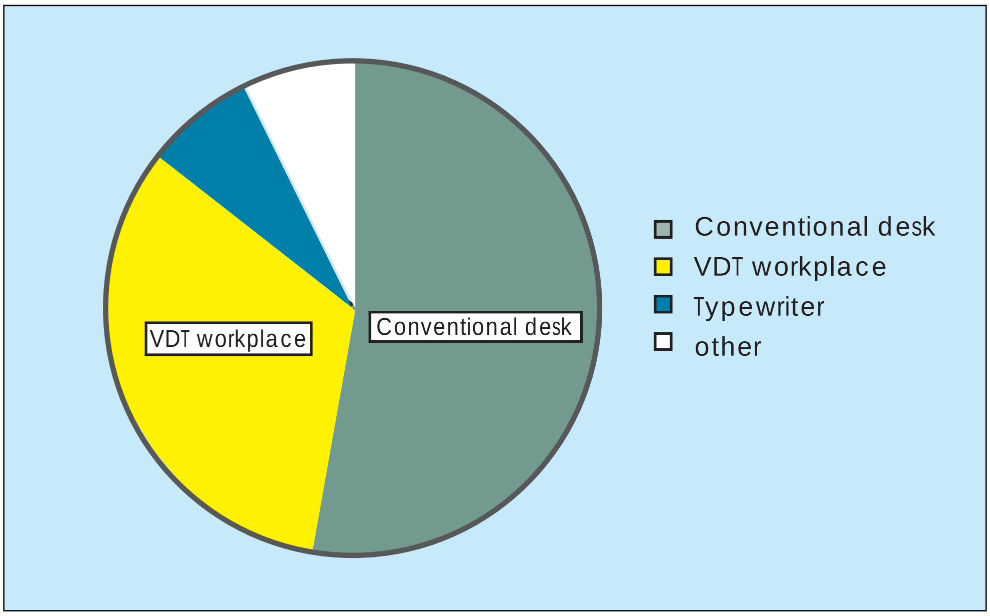


Fig. 3.6 Number of years worked in the current room

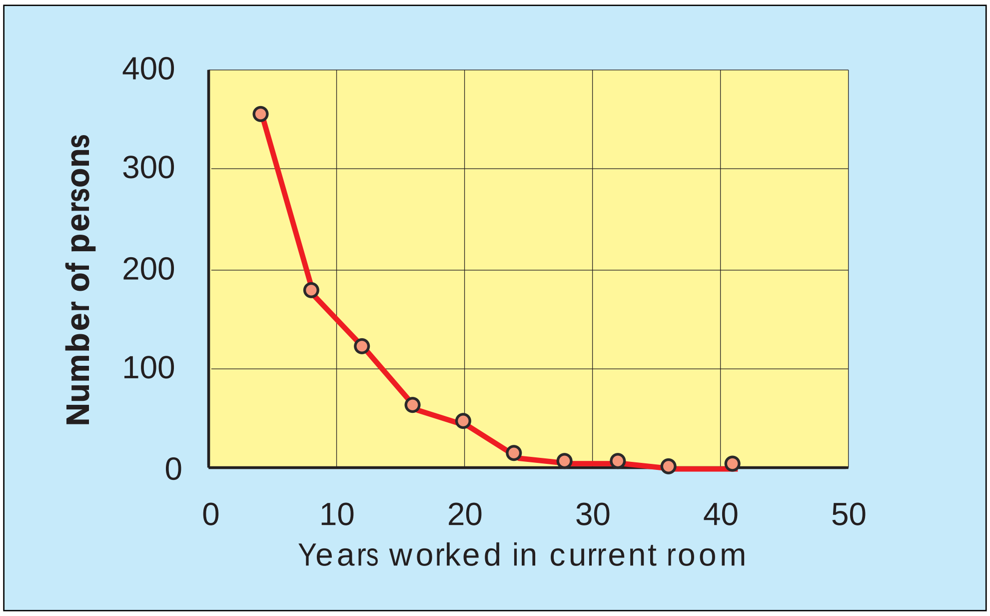
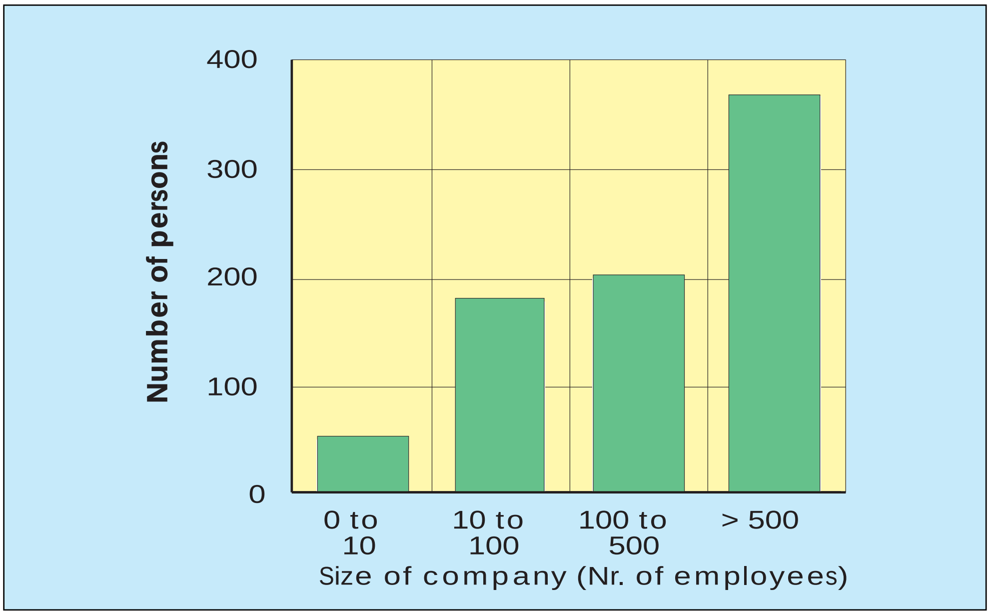


Fig. 3.7 Size of the companies (Nr. of employees)



Working Conditions

4 Working Conditions

This chapter describes the working conditions of the subjects surveyed in phase 2 of the project. The corresponding information for the other subjects is given in Chapter 10 (phase 1) and Chapter 11 (phase 3).

4.1 Room Size

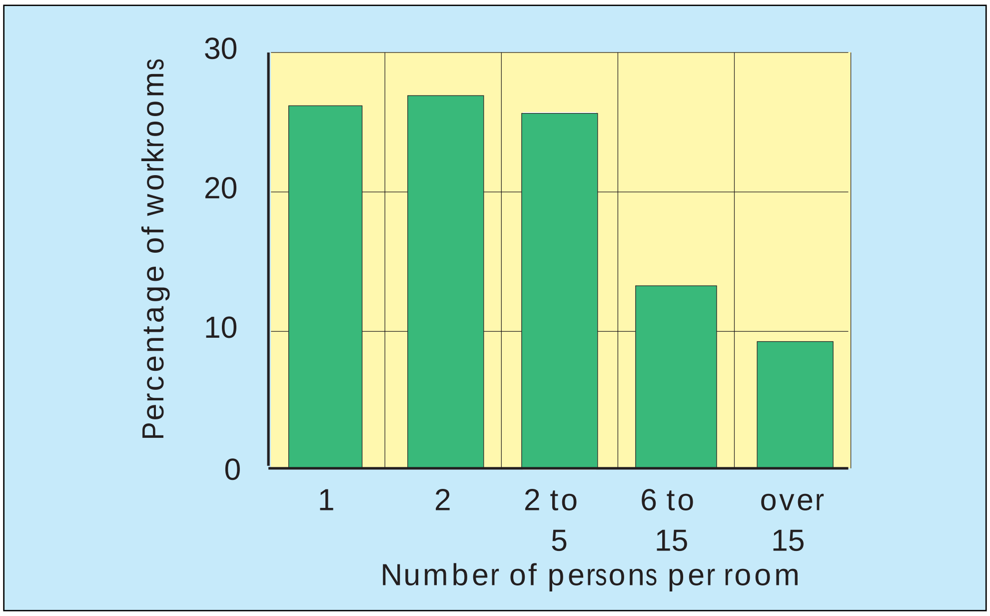
The size of the rooms, which in this project was approximated by means of the "number of colleagues per room", is one of the most important marginal parameters for normative recommendations related to the environmental factors in an office. It is important to know in what kind of rooms administrative work is performed, not only for the purpose of establishing lighting norms; the manufacturers of office furniture and office equipment, too, are concerned with this parameter.

In this respect, as can be seen in the case of DIN-Norm 5035, recommendations, standard dimensions, etc. are generally modeled on large rooms or open-plan offices. The majority of office furniture design series, too, are based on a type of room which corresponds not so much to the small, individual office, but rather to the group or open-plan type of office.

Given the evaluation of the answers relative to room size, this basic orientation towards large office spaces is by no means realistic. As can be seen in Fig. 4.1, only 9% of office employees work in rooms with more than 15 persons, whereas over 75% work in rooms with no more than 5 other workers. These 75% can be further divided into more or less equal thirds working in single, double, and 3 to 5 person rooms, respectively.

The possibilities for the positioning of work desks is relatively limited in the latter types of rooms, making it relatively easy to predict the distribution of the desks in these rooms with reasonable accuracy even without knowing the particular company in question. In this respect it suffices to be acquainted with office planning during the last 40 years, as it is sketched, for example, in "Office and Administration Buildings" (Sieverts, 1980).

Fig. 4.1 Room size in number of workers



4.2 Windows and Protection from Light

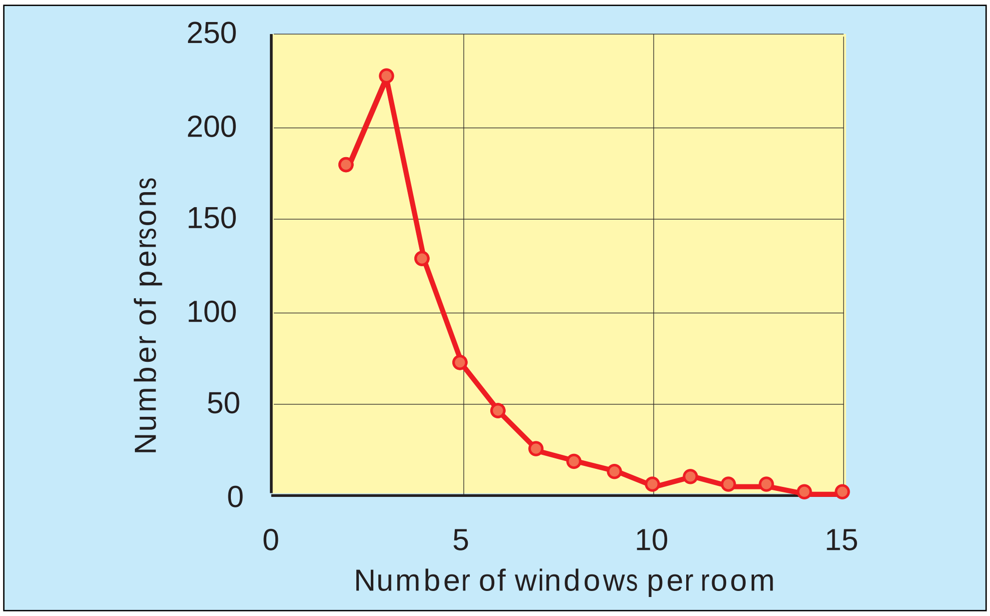
With few exceptions (1%), the rooms have windows, the number of which varies between 2 and more than 15. The overwhelming majority of the rooms has between 2 and 5 windows (see Fig. 4.2).

There seems to be no preferred orientation of the windows, which are distributed evenly over all directions of the compass. This result corresponds to previous expectations.

These expectations were thwarted, however, as far as the implementation of measures for protection from light, by means of blinds or curtains, for example, is concerned. A substantial portion (20.4%) of the rooms has no protection whatsoever, even though they are not all situated on the northern side of the respective buildings. Of those rooms oriented towards the South and the West, 10.6% have no light protection. Even on the southern and western sides of some buildings there exist VDT-workstations without measures for protection from light (5.5%).

The most common form of protection from light consists in the use of blinds (37%), followed by curtains (28%). The largest proportion of blinds can be found in rooms with VDT-workplaces on the southern and western fronts (63%), while the smallest amount (still 20%, however) is in rooms facing the North.

Fig. 4.2 Number of windows per room



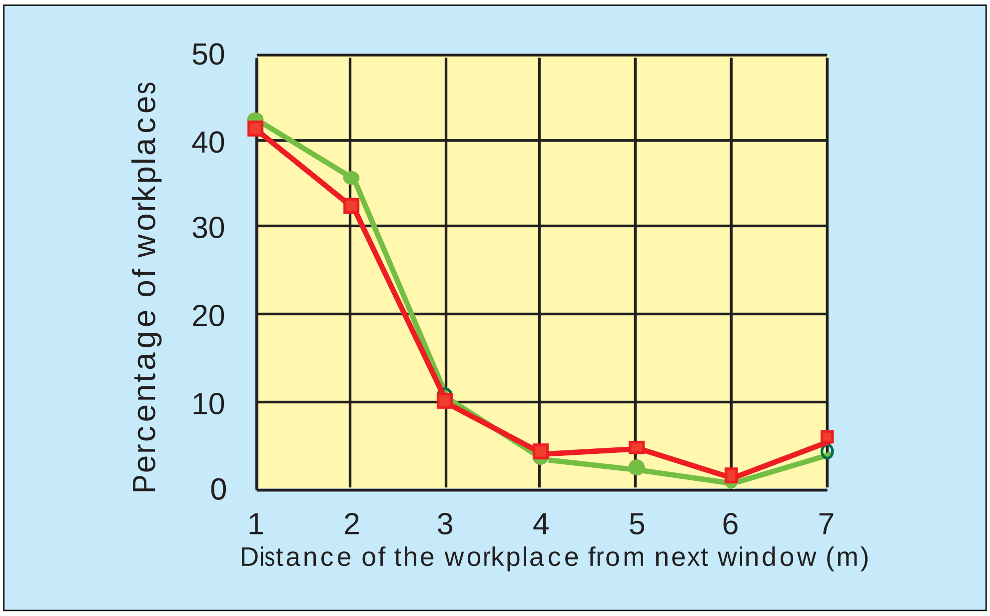
Apparently, curtains are used not so much for necessary protection from light, but rather for the purpose of embellishing the rooms; their use is distributed almost evenly regardless of room orientation.

4.3 Distances of Workplaces from Windows

Assuming that the majority of currently existing VDT workplaces were created in the eighties and nineties, i.e. after previous elaboration of ergonomic insights on correct setup, and their codification in DIN-Norms, one should expect that these workplaces have been positioned further into the rooms. From this point of view, the result represented in Fig. 4.3 is surprising: the positioning of VDT workplaces does not differ in the least from the positioning of other office workplaces. 41% of the workplaces are located at a distance of one meter or less from the closest window, and another 32% are situated at a distance of up to 2 m from the window.

Consequently the recommendations contained in DIN-norms (the now abolished 66 234 part 7 and the still current 5035 part 7) concerning the positioning of work desks are incongruous with practical requirements for at least 70% of existing workplaces. The question therefore arises, whether this discrepancy between theory and practice will have an unfavorable effect on the evaluation of the lighting situation and on the disturbances to well-being. It is part of the object of this study to pursue this question.

Fig. 4.3 Distance of workplaces from next window:
- **green** **all workplaces**
- **red** **VDT workplaces**



4.4 Types of Lighting

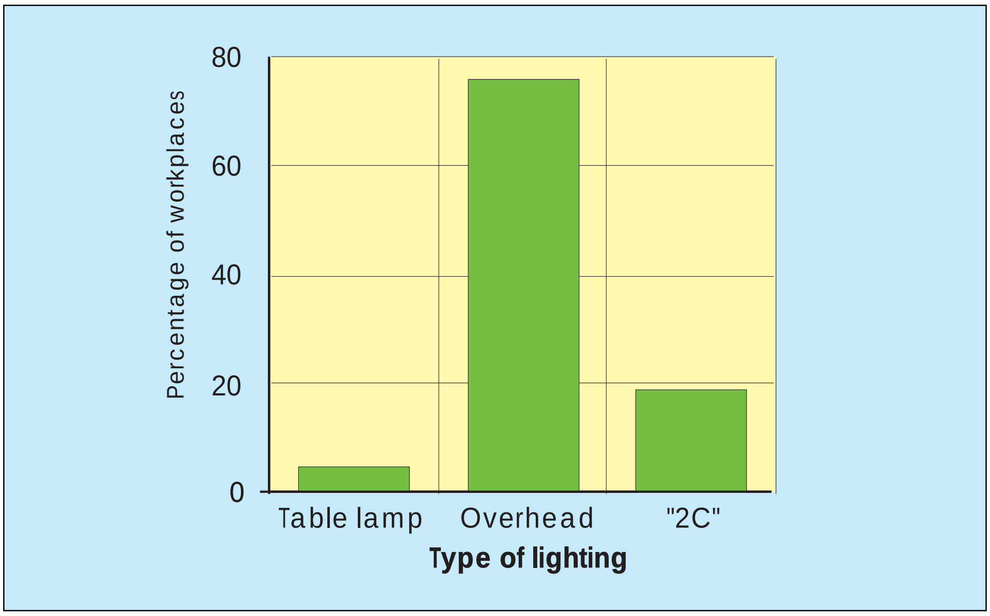
The types of lighting that are used also deviate from the recommendations contained in the norms (see Fig. 4.4). Almost 5% of the workplaces are lit by nothing but a table lamp, and 19.7% have both general lighting in the form of overhead and task lighting, i.e. a twin-component type of lighting. The proportion of VDT workplaces with desk lighting only, is somewhat greater even than for other workplaces, even though this in contradicts all existing norms and standards.

It can be noted, therefore, that a total of appr. one quarter of all workplaces are illuminated in ways that are not recommended by the relevant norms.

Based on this result, the effects of lighting can and must be evaluated separately for the various types of lighting.

***Note**: Surveys from the 1996 demonstrate that the percentage of the rooms with overhead lighting did not change substantially. It was still 76%.*

Fig. 4.4 Types of lighting in the work rooms



4.5 Summary

The study shows that working conditions in German offices deviate substantially from the conditions which are assumed by the existing regulations on lighting and the positioning of workplaces. It should be noted in particular that

- **as a rule, German office rooms are relatively small,**
- **workplaces are normally positioned in close proximity to windows,**
- **approximately one fifth of the work rooms provide no protection from daylight, and**
- **approximately one quarter of the workplaces are illuminated in ways not recommended by the norms.**

Note: Surveys from 1996 show that percentage of rooms without any protection from daylight has hardly changed from the figure mentioned above.

Lighting Evaluation in Phase 2

5 Lighting Evaluation in Phase 2

5.1 General Evaluation

The evaluation of artificial lighting according to the scales for the rating of "pleasantness" *(comfortable -uncomfortable, friendly - unfriendly, soft - dazzling) is* consistently negative; i.e. in every case, more than 50% of those surveyed reject the positive attributes (Fig. 5.1). The mean values are always over 3, the majority feels the lighting to be uncomfortable, unfriendly, and dazzling.

The answers to questions concerning sensation of disturbance (scales: *disturbing - not disturbing, cold -warm, glaring - not glaring)* vary. Thus, 40% agree with the attribute "*disturbing*", 42% disagree, and 18% ticked a 3 (Fig. 5.2). The majority of those surveyed feel the lighting to be "*cold*", however, whereas only 20% disagreed with this characterization. This is the scale on which lighting received the most negative rating. The evaluation of "*glare*" is similar to that of "*disturbance*".

Overall, the results of phase 1 were confirmed in this investigation.

5.2 Comparison of Types of Lighting

There is a statistically significant difference between the ways in which the types of lighting were evaluated on the different scales (Fig. 5.3 and Fig. 5.4). As was to be expected, the evaluation of general lighting does not deviate from the total evaluation, since 80% of the sample group had overhead lighting. Desk lighting was tendentially felt to be comfortable and friendly, though "*dazzling*". 2C-lighting received a better rating than overhead lighting, even though it consisted of both desk and overhead lighting. Presumably, this apparent difference can be traced to specific forms of usage. Whoever has an additional lighting source will switch on the overhead lighting somewhat later. This results in a shorter use of the overhead lighting which is rated as more uncomfortable.

The subjects find desk lighting and 2C-lighting to be significantly less "*disturbing*" than overhead lighting, and they consider desk lighting to be significantly "*warmer*" than the other types of lighting. Apparently, existing desk lighting also has its problems, since this type is also judged to be "*glaring*" by the majority. 2C-lighting obtains the most favorable rating on the scale "*glaring - not glaring*". Since, according to the statements in chapter 1, glare must be counted among the factors that contribute to fatigue, one should expect the least fatigue for 2C-light-

Fig. 5.1 General evaluation of lighting (pleasantness)

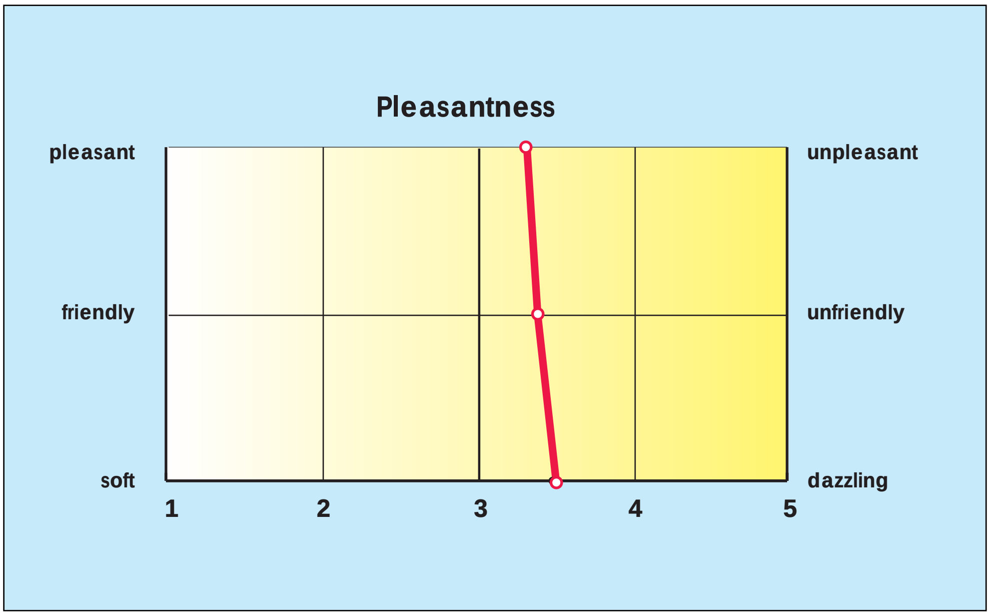
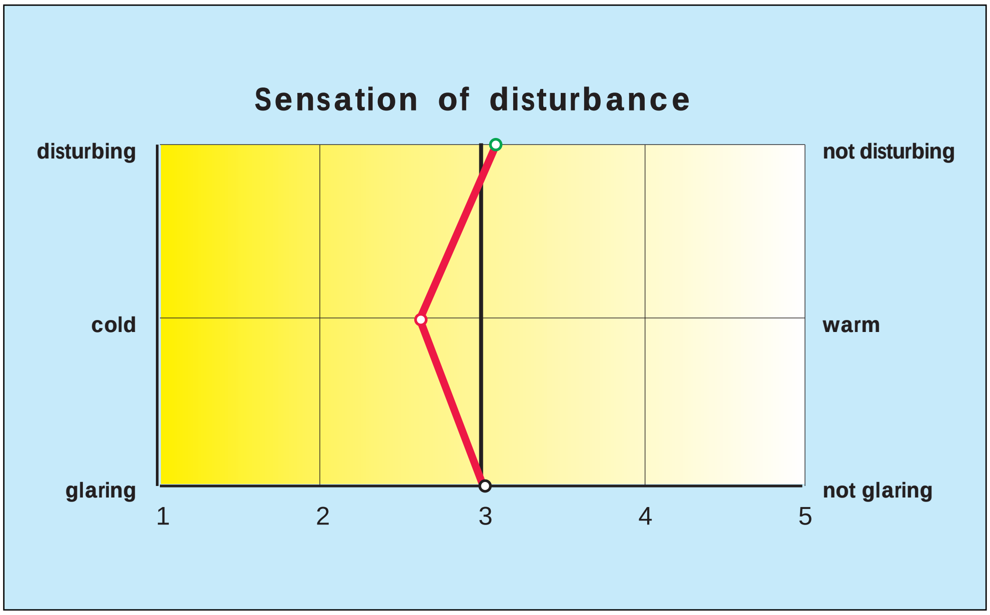


Fig. 5.2 General evaluation of lighting (sensation of disturbance)



ing. This finding yielded one of the questions to be investigated in phase 3 of this project.

Fig. 5.3 Evaluation of pleasantness of different types of lighting

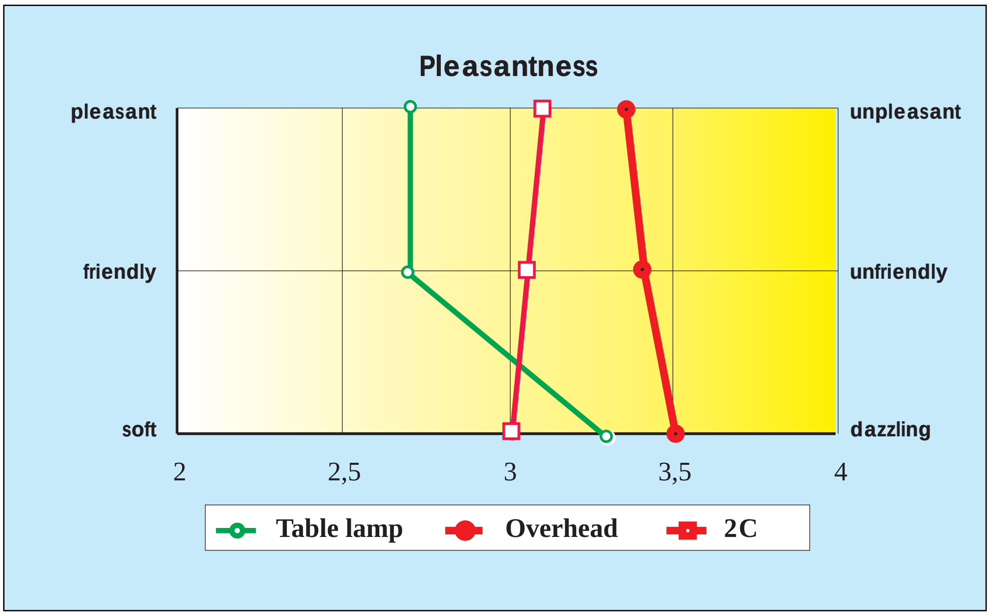
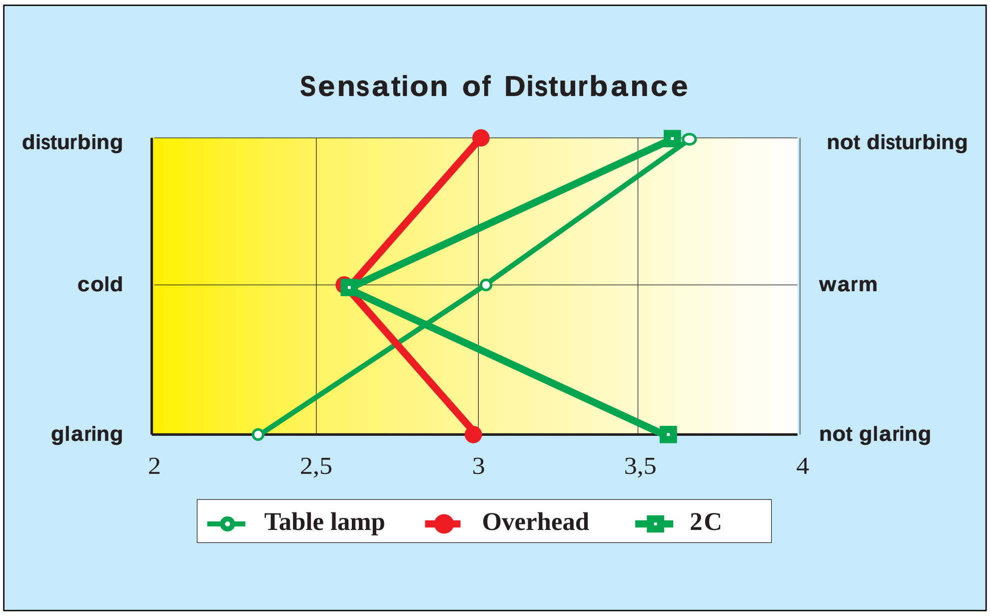


Fig. 5.4 Evaluation of disturbance caused by different types of lighting

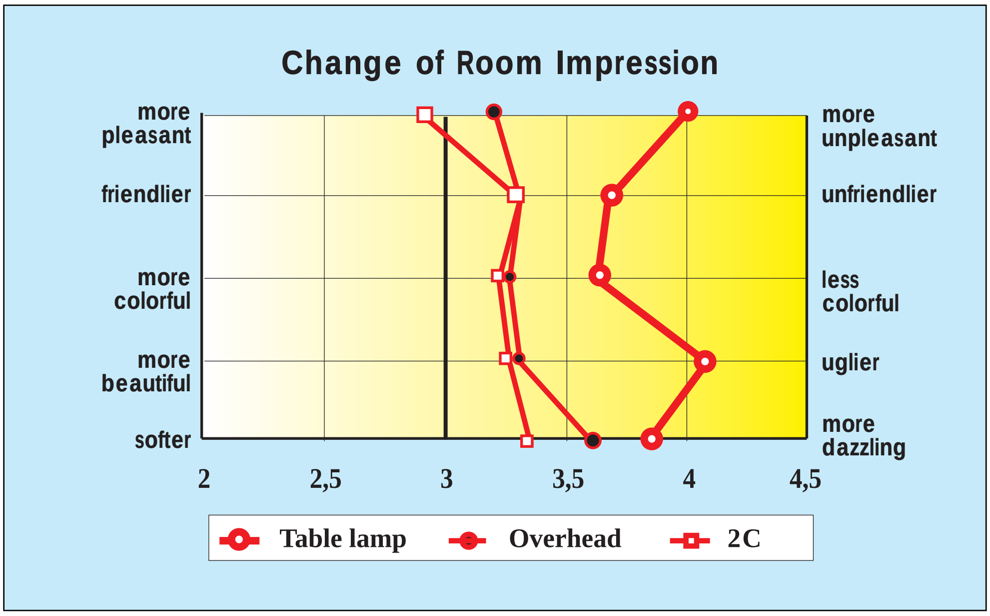


5.3 Modification of Room Impression by Artificial Lighting

This section of the questionnaire is meant to provide an overview of the modification of the room‘s impression registered by the subjects after the lighting has been switched on. Does the room become more friendly, more attractive, and more colorful, or does it tend to leave a colder, less colorful, and more glaring impression than before the light was turned on?

The result of this section of the questionnaire (Fig. 5.5) shows a somewhat disappointing picture. Relative to the impression of the room, desk lighting, which in the preceding section tended to be judged as comfortable and friendly, is now rated more unfavorably than the two other types of lighting on all scales. Where a table lamp provides the only source of light, the room appears more uncomfortable, more unfriendly, less colorful, uglier and glaring.

Fig. 5.5 Modification of room impression as a result of lighting having been switched on



This result confirms the opinion which is taken into consideration in existing regulations, namely that pure task lighting will have unfavourable effects on humans and is therefore not permissible. The importance of this finding is given by the fact that this negative vote was given by subjects who are in favor of task lighting.

The evaluation of 2C-lighting and overhead lighting is identical on 3 scales, while differing perceptibly on 2 other scales. These differences are not very great, however. In general, none of the three types of lighting seems acceptable from the viewpoint of room impression.

The scales that register disturbances *("more disturbing"* and *"colder")* lead to the same result. Only desk lighting is judged to be significantly less favorable than the two other types of lighting which again differ perceptibly though only slightly from one another. Here, too, 2C-lighting fares better.

5.4 Summary and Interpretation

This section of the questionnaire shows that artificial lighting of offices tends to receive a negative evaluation. Interestingly enough, pure desk lighting, which is felt to be more comfortable than the other types of lighting, is also judged most unfavorably with respect to its effects on the workspace.

In view of the fact that approximately three quarters of the rooms are small offices, the number of persons who rate their lighting as *"glaring"* is surprisingly high, for as a rule, the luminaires in such rooms are installed in such a way that they normally should not cause any glare problems according to the curves for glare limitation (see Chapter 9).

The negative evaluation is likely to be connected to the fact that artificial lighting is felt to be cold and colorless, even though as far as the color temperature of light is concerned, all lights currently in use in Germany are "warmer" than the daylight entering the rooms. The assessment concerning the modification of the room impression is independent of the room's orientation on all scales; this permits the conclusion that the physical (spectral) composition of light does not play a demonstrable role in the evaluation.

In theory, one would expect that the change of the room impression was different on the west side of building than on the north side. However, this was not the case. One of two possible explanations for this finding is based on the correlation between the assessment on the scale "colorful - not colorful" and the assessment of glare. The judgement that the artificial lighting was "cold" and "colorless" may be caused by the degree of glare. The more likely cause is that the luminous color of the lamps has a lesser effect than expected. This gives food for thought for the second explanation which is based on the actual situation with regard to use of color in German offices. The developments in the design of computers and office furniture has meant that both computers and furniture have turned gray.

How could artificial lighting render non-existing colors in such an environment? The actual situation in German offices displays mainly shades of gray as color experts would characterize them. Some computer magazines call it "computer grimy gray". There are many indicators which justify the assumption that the complaints of office users about their dull environment should be attributed to the lack of imagination of furniture designers and facility managers rather than to lighting.

The gruesome-gray look of some office rooms is not of temporary nature. Rather, it seems to be one of the inevitable outcomes of the globalizing of the markets which forces the manufacturer to develop products with features that should never collide with their environment. Applied to the shape of a technical product, this means preference for "neutral shapes", e.g. cube or cuboid and neutral colors i.e. gray.

The finding of this project concerning the relative insignificance of the luminous color of the lamps does not mean this factor was unimportant under any circumstances. The fact is that in the current state of offices (most visible surfaces in some shades of gray) and of lighting (luminous colors of lamps with small differences between "neutral white" and "warmwhite") the impact of lamps remains low.

On the basis of the results represented up to this point, it is not possible to conclude that artificial lighting constitutes an important stress factor at the workplace as some factors can be negligible even if they are rated as unpleasant. This is true for numerous factors of marginal importance. In some cases, unpleasant factors in working life can even be preferred by the users if in addition they offer some benefits. In order to be able to make a statement in this respect, we must consider the two final sections of the questionnaire.

Phase 3 of the project examines the dim picture of the state of office lighting 55 years after the first lighting standard was issued. Much emphasis is put on the question whether the assessment of lighting is based mainly on functions and characteristics of lamps and luminaires, or rather on other factors. The basic question is, however, whether the negative impact of artificial lighting is inherent to this type of lighting in general or a characteristic of some types of artificial lighting.

Lighting and Impairments by Working Conditions

6 Lighting and Impairments by Working Conditions

6.1 General Statements

During work in office rooms, the office environment produces both avoidable and unavoidable impairments to humans. Room temperature in shared work-areas, for example, numbers among the unavoidable impairments, partly because every individual prefers a slightly different temperature, thus making it impossible to strive for the most comfortable temperature for every single person; rather, one can only settle on an “optimal” temperature, i.e. the temperature which is comfortable for the majority of the workers. Since this optimal temperature is approximately 2°C higher for women than for men, there are constant conflicts in shared work-areas. Yet, given the fact that there are a number of good reasons for working in shared work-areas, one is forced to live with this impairment. Conversations among others in the same room, which form an integral part of working and living together, provide a similarly problematic source of impairment.

On the other hand, impairments due to machine or traffic noise for example, can be avoided, although it may not be possible to take the relevant measures in every case. An excessive influx of daylight at workplaces - especially VDT-workstations - in the proximity of a window, for instance, would also number among the avoidable sources of impairment. However, as the data concerning working conditions have shown, one is either forced or willing, to put up with these impairments.

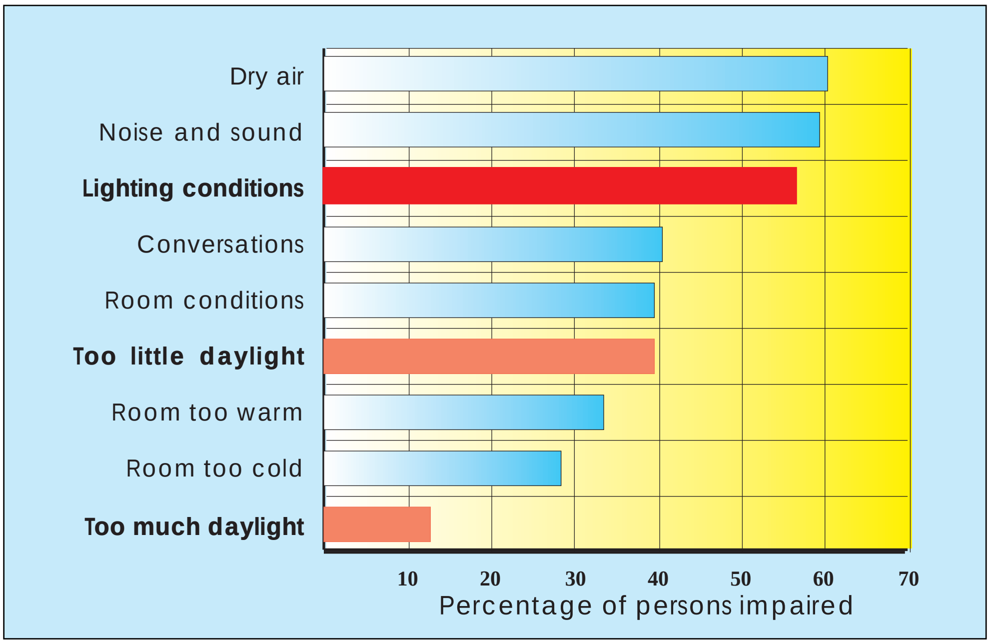
In the framework of this project, an effort was made to ask questions relevant to the most important avoidable and unavoidable stressors causing impairments to the subjects, and to compare them with potential impairments through lighting conditions. Fig. 6.1 shows the corresponding section of the questionnaire.

Fig. 6.1 Questions concerning regular impairments due to working conditions

Do you experience regular impairments by working conditions?

	strong	moderate	barely	not at all
Noise, sound	❏	❏	❏	❏
Room conditions	❏	❏	❏	❏
Too warm temperatures	❏	❏	❏	❏
Too low temperatures	❏	❏	❏	❏
Dry air	❏	❏	❏	❏
Lighting conditions	❏	❏	❏	❏
Conversations	❏	❏	❏	❏
Too much daylight	❏	❏	❏	❏
Too little daylight	❏	❏	❏	❏

Fig. 6.2 General evaluation of regular impairments in office work



Tab. 6. 1 Sources of regular impairments and percentages of persons who feel moderately to strongly impaired

Impairment	% of subjects
Dry air	61
Noise and sound	60
Lighting	**57**
Conversations	41
Too little daylight	40
Room conditions	40
Room too warm	34
Room too cold	29
Too much daylight	13

6.2 Comparison of Impairments Due to Lighting and to Other Stressors

6.2.1 General Assessment

Fig. 6.2 shows the result of this section of the questionnaire, Tab. 6.1 represents the percentage of persons who feel moderately to strongly impaired. It shows that lighting belongs to the strongest impairing factors in the office environment, along with noise and dry air; even such stressors as conversations, temperatures which are either too high or too low, or room conditions are not responsible for the same amount of stress as lighting conditions. By contrast, too much daylight represents the least important form of stress. What this means, however, is that the negative assessment of lighting is in fact based on regular human impairments due to artificial lighting. A stepwise regression calculated with the nine variables shown in Fig. 6.1 as independent variables, and with health data, show that the "lighting" variable is responsible for the biggest proportion of variance in almost all cases, e.g. for 50% of common variance for the variable "premature fatigue". Noise and conversations as impairing factors only affect variables such as "*poor concentration*" or "*irritability*". This finding corresponds well with the results of physical measurements in phases 1 and 3 of the project which show that the overall noise level in offices has declined during the last decade by almost 10 dB(A).

6.2.2 Influence of Equipment and Room

The above-mentioned influence of lighting conditions does not necessarily stem exclusively from the lighting installation itself. It is at least likely that it is also produced by the equipment used. If we assume such an influence, its source can lie in the office equipment, e.g. VDTs and typewriters. For example, under specific conditions one can demonstrate that it is not the lighting itself which causes dissatisfaction with the lighting, but rather glossy keyboards.

The analysis of the data established in this project has shown that the most important influence is constituted by the size, and specifically by the depth of the rooms: the larger and deeper a room, the greater the impairment. As shown in Fig. 6.3, the influence is a function of room depth; as the latter increases, so does the number of complications. The trend illustrated in Fig. 6.3 does not differ for users of desks on the one hand and for the users of VDTs on the other, i.e. the disturbance due to daylight in work with VDTs that is postulated in the standards is not experienced as such by the workers.

Fig. 6.3 Percentage of strongly impaired and moderately to strongly impaired persons in relation to the distance of the workplaces from the nearest window.

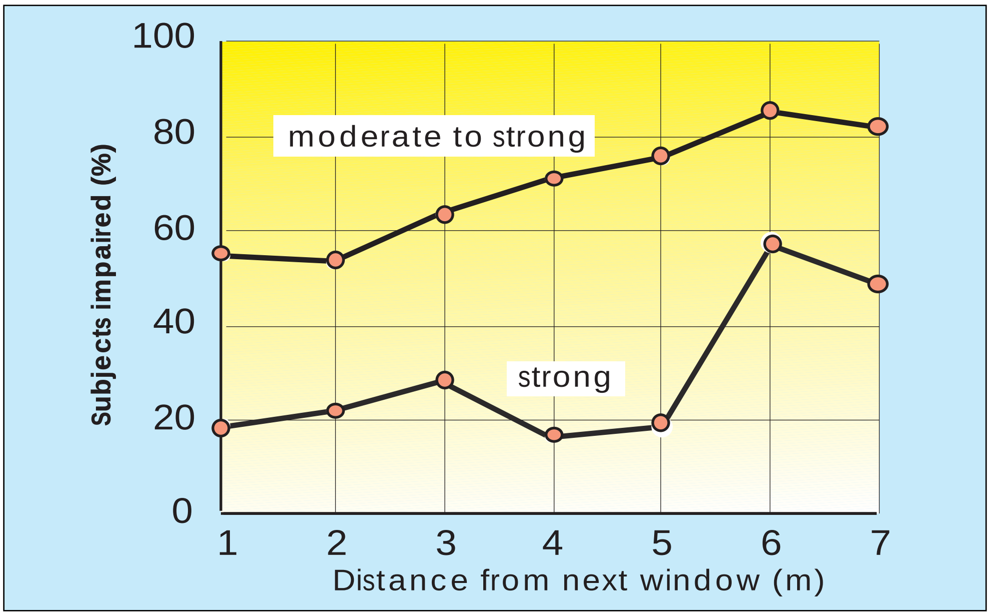
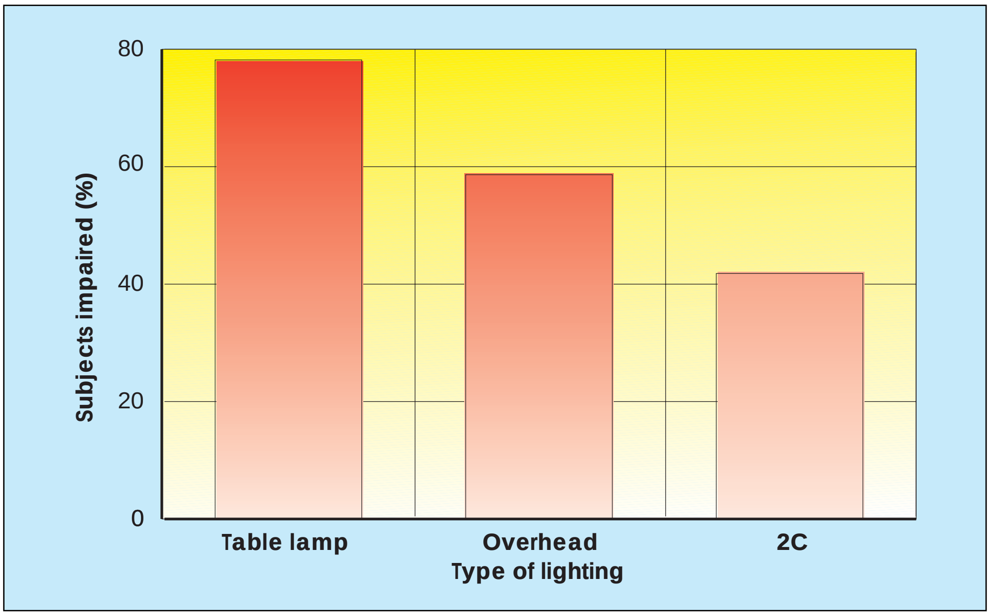


Fig. 6.4 Influence of the type of lighting on the percentage of moderately to strongly disturbed persons



Artificial lighting, which is intended to replace daylight in rooms of great depth, can at best produce the desired brightness, as can be seen in the affirmative answers to the corresponding question: 90% of those asked feel the lighting to be “bright”. Such lighting fails, however, as far as the promotion of well-being is concerned. Artificial lighting tends to be considered as an impairment.

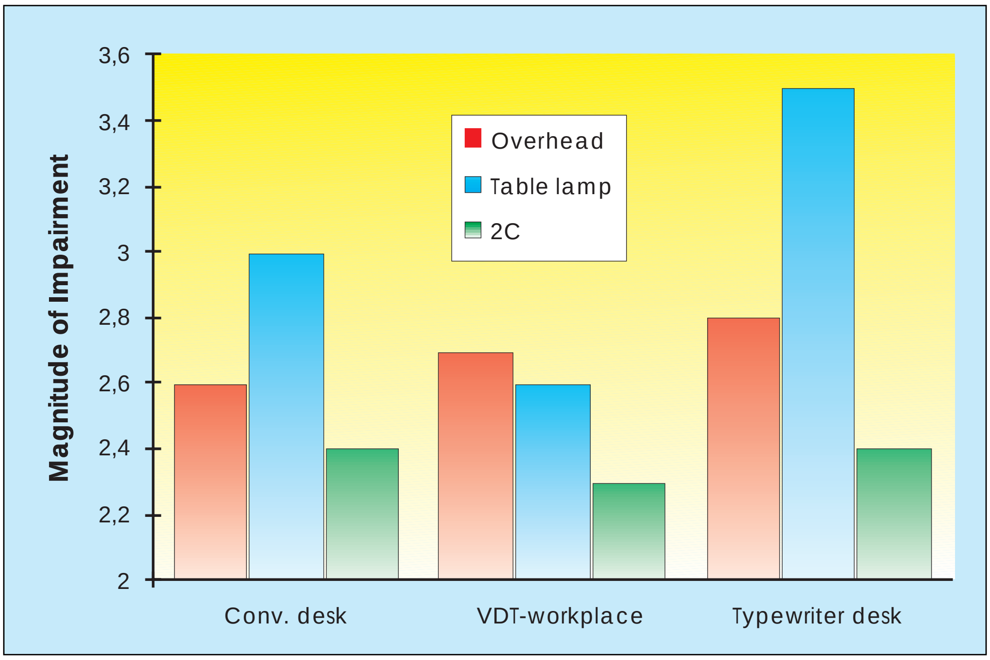
6.2.3 Influence of Type of Lighting

In this section, the validity of the above statement is tested for the different types of lighting taken into account. This was achieved by means of an analysis of variance which tested whether a significant difference can be established. Fig. 6.4 shows the result. The difference is both statistically significant and relevant.

According to this result, pure desk lighting causes almost twice as many complications as 2C-lighting, which received the most favorable rating, also faring better than pure overhead lighting. The percentages of persons who feel moderately to strongly impaired lie at 77% for desk lighting, 59% for overhead lighting, and 45% for 2C-lighting.

In order to be able to answer the question concerning the possible influence of equipment, we compared the impairments of persons working at conventional desks, VDT-workplaces, and typewriters. For this purpose, a parametric test (variance analysis) was calculated, the result of which is shown in Fig. 6.5. Accordingly, lighting with a table lamp only is significantly worse for work at a conventional workplace than are the two other forms of lighting, which in turn differed slightly from one another. For work at a VDT-workstation, 2C-lighting is by far the best type of lighting, whereas overhead lighting is the most unfavorable type for this kind of work. Desk lighting is the most unfavorable type of lighting for work with a typewriter, where 2C-lighting is best.

Fig. 6.5 Level of impairment resulting from different types of lighting at the conventional desk, the VDT-workstation, and at the typewriter desk. 2C lighting constitutes the most favorable type in all three cases.



6.2.4 Summary and Interpretation

The analysis of impairments shows that artificial lighting is not only judged to be uncomfortable, but is also felt to constitute an impairing working condition, comparable to other impairments such as dry air or noise. The degree to which this assessment is in fact valid depends on both the type of the room and of the lighting.

The demonstrated influence of room depth shows that impairment increases according to the degree to which the worker depends on artificial lighting for the completion of the work tasks. Those who have both a table lamp and overhead lighting (2C) feel least impaired. Among other things, this lower level of impairment is presumably caused by the freedom to use either or both of the lighting components. Effective personal control of the utilization of lighting seems to be the most important factor. Although this result is hardly surprising for anyone who is really in control of his or her immediate environment, it seems to be a new idea in industrial work areas after almost 80 years of ongoing systematic efforts to put the control of the working environments into the hands of experts and machinery.

The overall result that lighting conditions constitute a source of regular impairments for 57% of office users should give some food for thought for those responsible. Even today, seven years after the first publication of this figure and an analysis of possible reasons of the malaise, many lighting experts are still reluctant to accept that there may be “a problem”. Seven years is long enough either to accept unpleasant findings or to prove the opposite. The response of user organizations and users was very different to that of lighting experts and very positive.

We emphasize that the figure 57% regularly impaired office workers in Germany indicates that a higher proportion of other workers may suffer from the lighting of their workplace since the lighting of offices takes more benefit of existing regulations in general, and companies spend more time and money per unit on office workplaces than on others.

Lighting and Disturbances to Health

7 Lighting and Disturbances to Health

7.1 On the Term "Health"

Working conditions which are felt to constitute impairments do not necessarily also constitute a factor in health disturbances. However, the recognition of impairments to health primarily depends on the definition of the concept of "health" itself.

The most comprehensive definition of health is that provided by the World Health Organization (WHO) which stipulates that health represents a state of well-being, and not simply the absence of illness or disease. From this point of view, the situation described in Chapter 6 already constitutes proof of a disturbance to health, thus, artificial lighting should be considered a health hazard.

> *Note: There is no definition for a state deviating from the "healthy", "sickness" is not defined anywhere.*

Generally speaking, however, proof of a health impairment or hazard was formerly believed to presuppose a clinically demonstrable, permanent impairment to the functioning of the entire body or of individual organs. In some countries, the term "safety and health" in conjunction with human work is still understood as the opposite of physical injury in the very mechanistic sense. In the light of the definition of health by WHO and also in consideration of European Directives for improving safety and health of workers, such an approach is antiquated. The term "safety and health" in the European Union is based on the definition by the ILO (International Labour Organization) which is slightly restricted in comparison to the somewhat impractical definition by WHO. However, the ILO definition includes physical and mental factors which may impair the state of well-being.

The decision whether a specific work related factor is to be considered a health hazard can either be taken by finding a model for this factor exerting stress on workers (see next section) or derived from relevant legislation for protection of workers. The rational behind the latter is that a legislator will consider only such aspects in regulations which constitute a risk. In case of office work, the newest legislation is the European Directive 90/270/EEC, the so-called "VDT-Directive", and the German legislation based on this Directive, the so-called "VDT Work Ordinance" from December 1996. After the introduction of the two regulations, the employer is obligated to analyze workstations with regard to factors which may constitute "… ***possible risks to eyesight, physical problems and problems of mental stress*** ."

Thus, any work-related factor which may contribute to these risks shall be considered a hazard to safety and health.

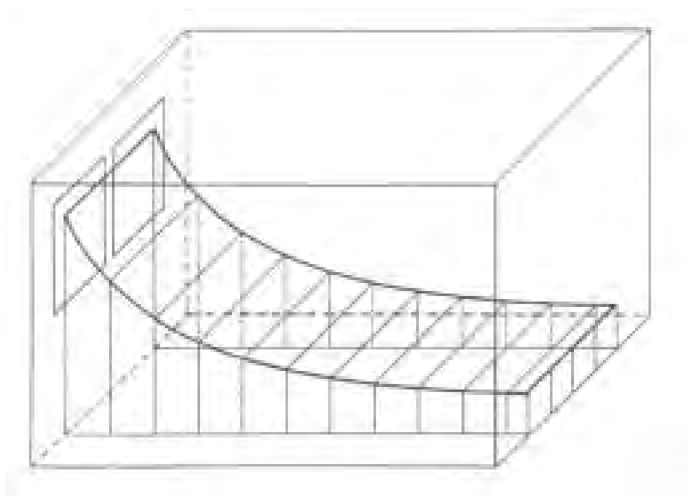
7.1.1 Model of Influence Mechanism

Disturbing environmental factors do not necessarily constitute a source of impairment to health when their influence is slight, for instance, or when they appear only rarely or for short durations. Before one can classify an environmental factor which is felt to be "uncomfortable" as a health-impairing factor, it is necessary to establish a model of its influence mechanism. The factor in question must exert a comprehensible influence on the organism in order for this organism to change at all. However, a change of an organism is not necessarily an impairment to health since all information from the environment cause changes in an organism. E.g., a warning signal is determined to change the "brainwaves" without being considered a health hazard. However, a continuous warning signal is likely to cause a "problem of mental stress" and could therefore constitute a risk.

A model of an influence mechanism does exist, though to varying degrees, in the case of artificial lighting: no matter at which indoor workplace, work takes place under artificial lighting, though for varying lengths of time, according to the particular work task. The effect that is generally assumed is positive: an improvement to our health and well-being. Since the twenties, lighting experts have made the rest of the world believe any thinkable impact of artificial lighting on humans would be positive, and possible negative effects (glare) would have been considered before introducing artificial light in working environments. Thus, no need was felt for a model of a negative influence of lighting.

In the framework of this project, the influence of artificial lighting was determined by means of a figure representing the distance between the workplaces and the windows. Since it is possible to calculate both the curve for the illuminance provided by daylight in a room from the window to the opposite end of the room (see Fig. 7.3), and the illuminance necessary for the completion of a given task, one can also determine on how many days of the year, and for what time period, it is theoretically necessary to work under artificial lighting. It has already been shown in chapter 6 that the distance of the workplace from the window constitutes a factor which has a demonstrable influence on the impairment of human work. In this respect, however, one should not overlook the fact that the selected influencing factor does not determine the daylight conditions in the room on its own. Further parameters such as window size, height of surrounding buildings, orientation of windows, etc. are also decisive in determining both the quality and the quantity of daylight.

Fig. 7.3 Curve of daylight illuminance in a room with windows on one side only



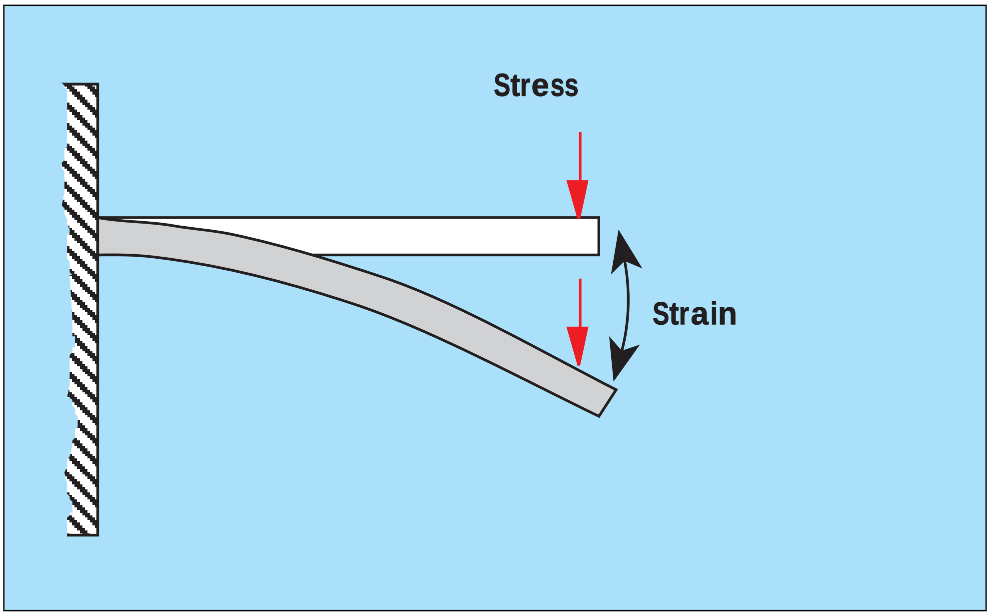
A second premise consists in the demonstration that the influence of an environmental factor does not only induce temporary changes in the organism - e.g. fatigue -, but also such changes which do not disappear after a period of rest at the end of a working day or even permanent damage. Proof of this assumption can only be produced clinically, however, and is not intended in the framework of this project. Such a proof is not required in Europe since the new legislation is based on the ILO definition of safety and health and not on the notion that a health hazard necessarily means a risk of a physical injury.

7.1.2 Stress/Strain Concept

Contrary to common usage of the term *"stress"* in its negative meaning, ergonomics distinguishes between *"stress"* as a neutral environmental factor and a certain *"strain"* as the effect of this factor. Fig. 7.4 shows the model, adapted from Rohmert, which is used in this respect.

In short, the idea represented by this illustration is as follows: depending on the abilities of a given organism, environmental factors of neutral valence called "stress" can lead to different changes in the state of this organism, which are called "strain". Rather than stress, it is the concept of strain which is connoted negatively in ergonomics. Stress has to be considered as neutral and not positive or negative.

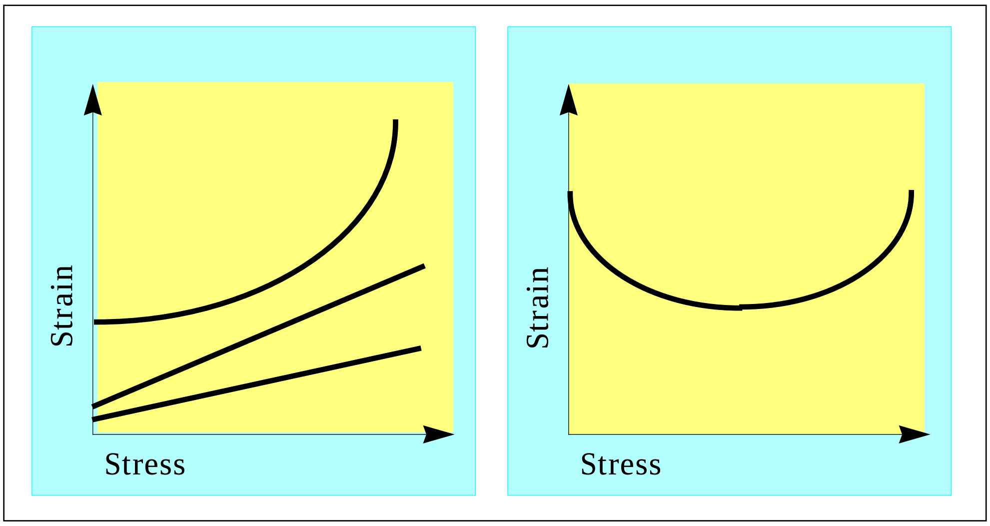
Fig. 7.4 Stress / Strain Concept adapted from Rohmert



The difference between “stress” and “strain” can be illustrated by the example of temperature: Generally speaking, a room temperature of 18°C represents a stress for the organism, since it is far lower than body temperature, thus leading to a loss of energy. For certain persons performing certain physical tasks or wearing certain clothing, this environmental temperature can also be “optimal”, however, causing only minimal or no strain. For other persons, in turn, it can also be either too low or too high, as in the instance of hard physical labor. Furthermore, personal factors, such as basic and temporary conditioning play an essential role. The physically measurable factor (stress) thus only represents or constitutes a negative factor (strain), when it impairs the organism. In an ergonomic analysis at a workplace, stress factors need to be measured or recorded with the aim of assessing the strain they cause.

The relationship between stress and strain can follow two different characteristics (Fig. 7.5). The diagram on the left shows curves which represent an increase in strain with increasing stress. Stressors which produce such effects, affect humans in similar ways as physical parameters affect a given material. If the effects of such factors on humans are to be decreased, the stress must be *minimized.* However, a great number of stressors produce entirely different effects which, as the diagram on the right reveals, are greatest under both low and high degrees of the intensity of stress, while

Fig. 7.5 Curves for strain in relation to stress. Linear or progressive increase (left) and U-shaped curve (right)



remaining less great under medium intensity. The effect of the complexity of a task on fatigue provides an example of such a relation: both simple activities and highly complex activities are more fatiguing than activities which present a manageable degree of complexity. Where such factors exist, the decrease or minimization of stress may produce negative effects; instead, stress must be *optimized.*

The human organism can be impaired or damaged not only by the strain itself, but also by its consequences. For instance, fatigue is not counted as detrimental to health, since its consequences are reversible and can be eliminated by means of rest and relaxation. However, where an individual is unable or unwilling to balance fatigue with rest and resorts to drugs instead, she or he suffers from damage not as a result of strain, but rather as a result of the method of coping with it.

7.1.3 Disturbance of Circadian Rhythm as Stress Factor

No unified stress / strain model for the lighting factor exists, since it is not possible to establish a relationship in terms of an increase in strain under increasing quantities of light. Thus, light occurs naturally with an extremely high intensity which exceeds that of artificial light by far. By means of comparison, the illuminance of the sun can lie at 100,000 lx or more, whereas office lighting generally lies at less than 1,000 lx. Consequently, all measures in lighting technology which are intended to protect humans tend to aim at eliminating situations with too little light. In many cases it can be shown that this procedure is indeed correct. Therefore, norms for example always prescribe minimal standards which may, of course, be exceeded. Even in cases where the values established in the norms are exceeded by a substantial amount, a harmful effect of artificial lighting on humans due to the intensity of incoming light is not to be expected.

On the other hand, it is easy to ascertain that people who find an illuminance of 500 lx to be “too bright” in the office, will consider an illuminance of 5,000 lx “too dark” in nature. The reasons for this are unknown. As was already discussed in more detail in chapter 1, one does know, however, that natural light has certain effects on human hormone production. Due to modern life-styles, which are far removed from natural conditions, this rhythm has been disturbed. As suggested above, so-called social “zeitgebers” partly replace the function of light as a natural zeitgeber. Such social zeitgebers include TV, for instance, which, over the course of the last 30 years, has even changed human sleeping habits (Ratzke, 1982). Recent surveys suggest that sleeping habits have been changed again after 1982 e.g., by new broadcasting systems or pricing for telecommunication services.

The use of artificial light itself constitutes a deviation from natural ways of living since it prolongs the day and shortens the night. It is a “stress” in the sense or ergonomics. Whether or not it constitutes “strain” however, cannot be evaluated within industrialized countries since all people there use artificial light to a certain degree.

Artificial lighting of workspace doubtlessly constitutes a mechanism which wholly or partially prevents the influence of natural light on the organism. In windowless rooms, it remains constant and unchanged throughout the day. In office rooms, which, as a rule, provide at least one visual contact with the outside, this is also true for those parts of the rooms which are located at a substantial distance away from the windows.

In the following section, we will examine whether certain bodily disturbances can be linked to lighting. Should this question be answered affirmatively, we will then examine which stress factor causes the strain: is it the result of the direct influence of artificial lighting, or is it caused indirectly through the prevention of the influence of natural daylight on the circadian rhythm? If the latter is true, then the cause for disturbances to health lies in the ways of dealing with the lighting problem and not in the direct impact of artificial light.

7.2 Disturbances to Health in Office Work

7.2.1 Environmental Factors and Disturbances to Health

In office work, the human body in particular is subject to certain forms of stress which affect the organs, or organ systems such as connective and supportive tissues, the central nervous system, the heart and circulation system, the sensory organs such as eyes and ears (for more details see Peters, 1976). The causes for these forms of stress can generally be related to the factors of room, workplace, sound and noise, air, and light.

The above-mentioned stress factors lead not only to forms of strain whose causes can be unequivocally localized, such as complications connected to posture, or poor seating; rather, they also produce unspecific detrimental effects to human well-being such as headaches or lethargy. The present project considers disturbances to both health and well-being which can be established on the basis of ratings.

Fig. 7.6 shows the section of the questionnaire relevant to this phase (2) of the investigation. It asks for symptoms which depend not only on lighting, but also on other environmental factors, and which can also be connected to personal factors, such as poor eyesight. In order to be able to evaluate the latter circumstance, we included the question whether the subject wore glasses, and if so, what type.

The scales for the rating of well-being were selected on the basis of the scales and the list of impairments (v. Zerssen, 1975). This list was revised in connection with a research project of the Federal Ministry for Research and Technology entitled “Disturbances to Health and Well-being in Air-conditioned Buildings” (Kröling, 1985). The scales rating *“circulatory weaknesses”*, *“lack of energy”*, and *“tendency to catch a cold”* were eliminated from the list of eleven scales relative to well-being. The scale for *“dry mucous membranes”* was replaced by *“dry eyes”*. The scale concerning *“rheumatic complications”* led to equivocal interpretations, as even physicians cannot agree on what is to be defined as a rheumatic complication or disease. In order to obtain reliable data, the subjects would have to be given an exact explanation of the symptoms that one wishes to determine. For a mall survey, this proved to be too complicated, and was therefore not taken into consideration. The questionnaire was completed by two additional scales for *“visual impairments”* and *“burning eyes”* in order to establish well-known symptoms of office- and VDT-work.

Fig. 7.6 Questions on detrimental health effects

Do you suffer from concrete disturbances of your health and well-being?

	strong	moder-ate	barely	not at all
Concentration weakness	❏	❏	❏	❏
Rapid fatigue	❏	❏	❏	❏
Grogginess	❏	❏	❏	❏
Irritability	❏	❏	❏	❏
Visual impairments	❏	❏	❏	❏
Headaches	❏	❏	❏	❏
Dry eyes	❏	❏	❏	❏
Burning eyes	❏	❏	❏	❏

In order to establish the connection between environmental conditions and the disturbances to health, we conducted regression analyses, choosing the impairing working conditions as the determining variable.

Variance analyses were used in order to establish a possible connection between lighting and disturbances to health. For the reasons presented in sect. 7.1 above, the analysis of the connection between disturbances to health and the distance between the workplace and the window formed the final part of the evaluation.

7.2.2 Frequency of Disturbances to Health

Tab. 7.2 shows the frequency of cases in which a subject was moderately to strongly affected by disturbances to health and well-being, arranged by frequency. Accordingly, *"visual impairments"* and *"burning eyes"* being the most frequent types of disturbance in office work and *"grogginess"* the least.

As was to be expected, these disturbances are caused by a variety of influencing factors, one of which is the particular equipment used. As can be seen in Tab. 7.3, those working at a desk are subject to less stress on almost all counts than those working with machines. Those working with typewriters are subject to the highest amount of

Tab. 7. 2 Percentage of office workers affected by disturbances to health and well-being

Disturbance	% of subjects
Visual impairments	**42.0**
Burning eyes	**40.0**
Concentration weakness	38.3
Rapid fatigue	37.3
Irritability	36.0
Headaches	34.0
Dry eyes	**31.0**
Grogginess	15.0

stress. The occurrence of visual impairments at VDT workplaces is 43% higher than at conventional office workplaces.

7.2.3 Influence of Vision on Disturbances to Health

In general the wearers of glasses do not complain about disturbances such as fatigue, irritability, and the like more frequently than those who do not wear glasses. However, the particular type of glasses has a strong effect in activities involving VDTs and typewriters. Those wearing reading glasses form the group which is subject to the highest degree of stress; they experience more frequent disturbances to their health than do the wearers of other types of glasses. Even though this influence has already been known for nearly 20 years (Çakir, 1978), and although persons working at VDTs should be protected by a corresponding set of regulations (ZH 1/618 and G37), it was still possible, even in 1990, to establish the influence that was determined nearly 20 years ago. It is possible to understand this as far as typewriter users are concerned, but not so for VDT users who are supposed to undergo regular eyesight tests.

Tab. 7. 3 Percentage of office workers affected by disturbances to health and well-being in relation to the type of equipment used (type of work).

Disturbance	% of subjects		
	Conv. desk	VDT workpl.	Typewriter
Visual impairments	**35**	**50**	**61**
Burning eyes	**34**	**49**	**49**
Concentration weakness	32	44	50
Rapid fatigue	31	44	44
Irritability	33	40	49
Headaches	29	40	48

7.2.4 Influence of Type of Lighting on Disturbances to Health

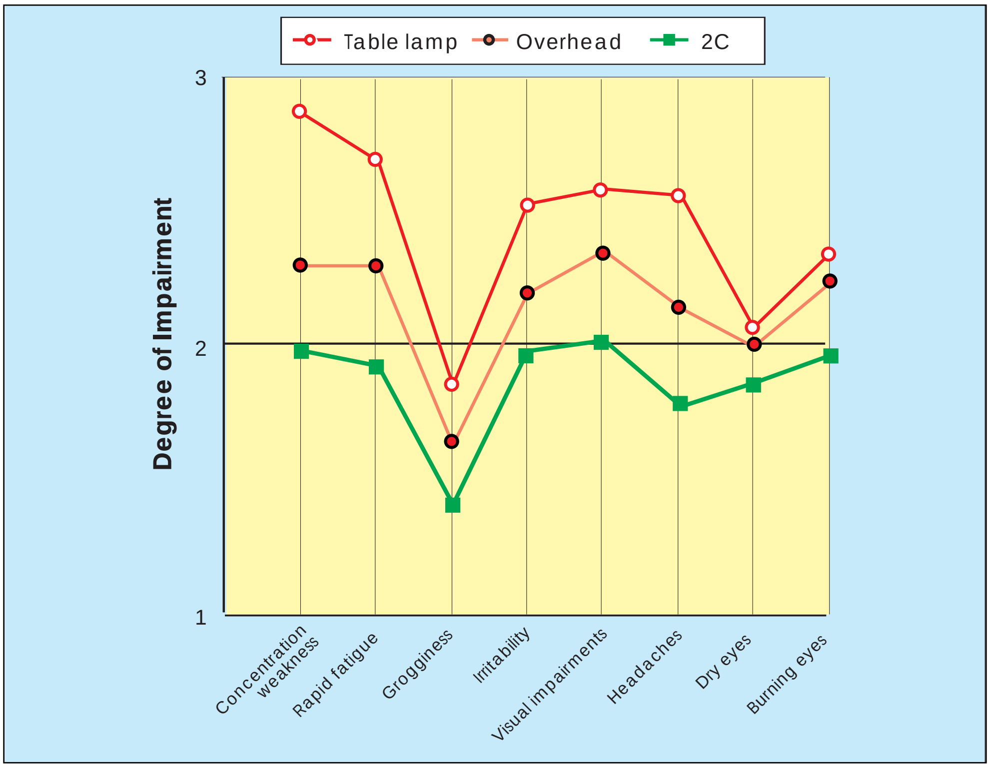
On the basis of the result presented above, the potential influence of the type of lighting on detrimental effects to health must be established by also taking into account the particular equipment used. For this purpose, we used two-factor variance analyses which permit the determination of the influence of both factors as well as their combined influence (interaction). The influence of a further variable, namely the distance from the window, had to be eliminated for this purpose. We therefore used a sample group with approximately equal distances of the workplace from the window in order to achieve an evaluation.

Tab. 7.4 shows the result of this analysis: with the exception of the complication "*dry eyes*", the type of lighting represents the dominant influence for all complications. None of the parameters that were taken into account are relevant for this variable. The influence of the type of work is only significant in those zones of the rooms where the overall effect of artificial light can be expected to be higher than that of daylight. The comparison between workplaces in these areas and those situated in the "*daylight zone*" reveals no significant effect of the type of work (see also Fig. 7.17).

Tab. 7. 4 Statistical significance of the influence of the type of lighting and of the type of work (***= 0,1%, **= 1%, *= 5%, n.s. = not significant)

Disturbance	**Influence factor**		
	Type of lighting	**Type of work**	**Interaction**
Visual impairments	★★★	★★	n.s.
Burning eyes	★★	**n.s.**	n.s.
Concentration weakness	★★★	★★	★★
Rapid fatigue	★★★	n.s.	n.s.
Irritability	★★★	★	★
Headaches	★★★	★★★	★★
Dry eyes	n.s.	★	n.s.
Grogginess	★★	★	n.s.

Fig. 7.7 Influence of type of lighting on the degree of disturbances to health (1 = no disturbance, 4= strong disturbance)



The influence that was determined for the different types of lighting is represented in Fig. 7.7: with one exception, the type of lighting has a highly significant effect on disturbances to health on all of the scales. Desk lighting is the most unfavorable type of lighting, 2C-lighting the most favorable on all scales. With one exception, 2C-lighting differs positively and significantly from the other types on all scales, and overhead lighting is significantly better than desk lighting on 6 of the scales.

7.3 Influence of Natural Light on Impairments and Disturbances to Health

7.3.1 Influence of Room Depth

The depth of a work-area in relation to its height mainly influences two environmental factors, indoor climate and supply of daylight. Before the introduction of the fluorescent lamp and of artificial air conditioning, office rooms were generally designed in a way that ensured a supply of daylight that could be considered sufficient, which also led to a relatively favorable natural supply of air. This concerned window size as an influencing factor just as much as it did the depth and height of a room.

Since the fifties, that is since the period in which most of the office buildings currently in use were constructed, the height of rooms has played little or no part in the literature on office building architecture. Where it does appear, it is usually in the context of the installation of air conditioning ducts or other technical supply installations. Thus, in Eiermann's and Kuhlmann's book “A *Study in Planning: Ideas for the Environment of Tomorrow”*, for instance, which has served as an exemplar for office design for over a decade, one cannot find a single remark on room height. We came to similar conclusions in our study of books on office building architecture - which, by the way, are sparse in Germany. Where room height did have any importance, it was in connection with applications for building permits, where the issues revolved around the maximization of usable floor space in office buildings given the restrictions placed on building heights by local and community councils. The point of reference, is now the Workplace Regulations' figures for minimal (internal) height in relation to the room's floor surface rather than the adequate provision of daylight: after all, daylight could simply be replaced by artificial light. Due to the availability of - cheap - artificial lighting, it was increasingly possible to design rooms of increased depth; as a consequence, air supply became increasingly worse in such rooms and this was sometimes exacerbated by lower ceiling heights. According to our investigations, the well-known negative effects of artificial air-conditioning should essentially be attributed to the architecture of office buildings and not, as is often assumed, to bad air-conditioning systems (Çakir et al., 1983).

The following passages are devoted to an analysis of the influence of room depths on room conditions, climate conditions, and impairments to humans. These observations are supplemented by an analysis of disturbances to health and / or well-being depending on the distance of the workplace from a window.

7.3.2 Distance from Window and Impairments

The distance of the workplace from the nearest window constitutes the main influencing factor in determining stress caused to humans by spatial conditions (Fig. 7.8). The assumption, based on physical evidence, that thermal comfort should be less great in the proximity of a window than further in the room, where neither the heat radiation nor the potential cold effect through the windows is as strong as in their immediate vicinity, cannot be documented by this study. Rather the opposite can be shown to be true (see Fig. 7.9 and Fig. 7.10). The sensation of excessively high "hot" temperatures is identical at all depths of the room, while impairment through overly cool temperatures tends to increase rather than decrease with greater distance from the window. Meanwhile, impairment through dry air also increases with increasing depth of the room (Fig. 7.11). It can be shown, therefore, that the depth of the room constitutes an essential factor in climate-related impairments.

As the impairments through climate increase, so too do those due to lighting conditions (Fig. 7.12). In addition, impairment due to *"too little daylight" is* also greater, as was to be expected (Fig. 7.13). Something that could not be expected, however, is represented in Fig. 7.14: only very few people feel impaired in their offices due to too much daylight. Remarkably enough, those seated close to a window do not feel more impaired than those who sit at distances of up to 6m from the nearest window.

The equipment has only a slight influence; persons working at VDTs complain somewhat more frequently than others about too much daylight. The influence of orientation seems to be relatively minor too, since the users of rooms facing the south or the southwest of buildings complain only slightly more frequently about too much daylight than the users of rooms facing north. This is different, however, for those working in rooms with windows on all four sides. They complain three times as often as the other groups. Apparently, *"too much daylight"* does not mean excessive illuminance, but rather glare due to poor arrangement of the windows.

Fig. 7.8 Influence of distance from window on stress caused by room conditions

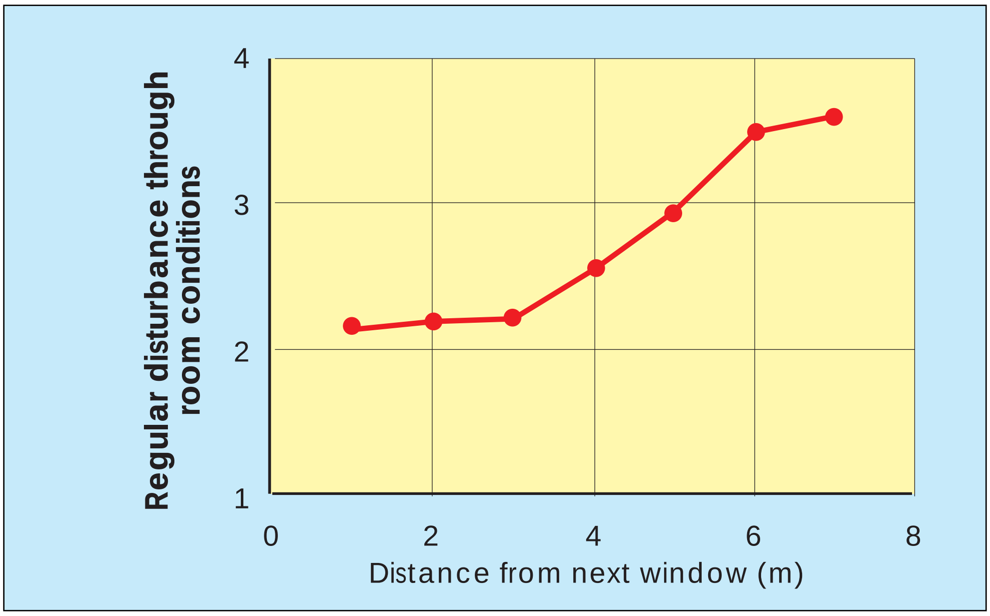


Fig. 7.9 Influence of distance from window on stress caused by hot temperatures

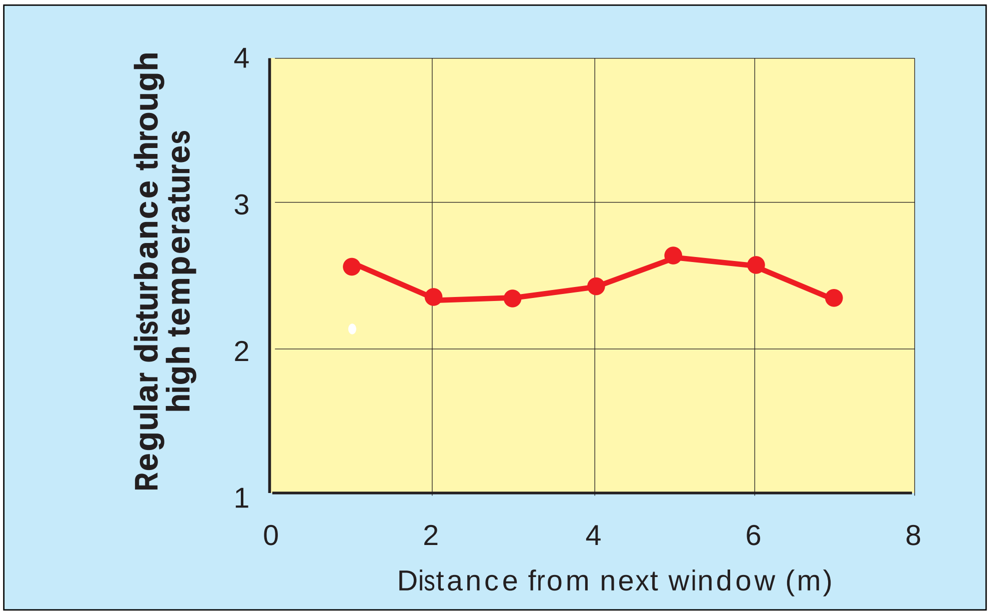


Fig. 7.10 Influence of distance from window on stress caused by cold temperatures

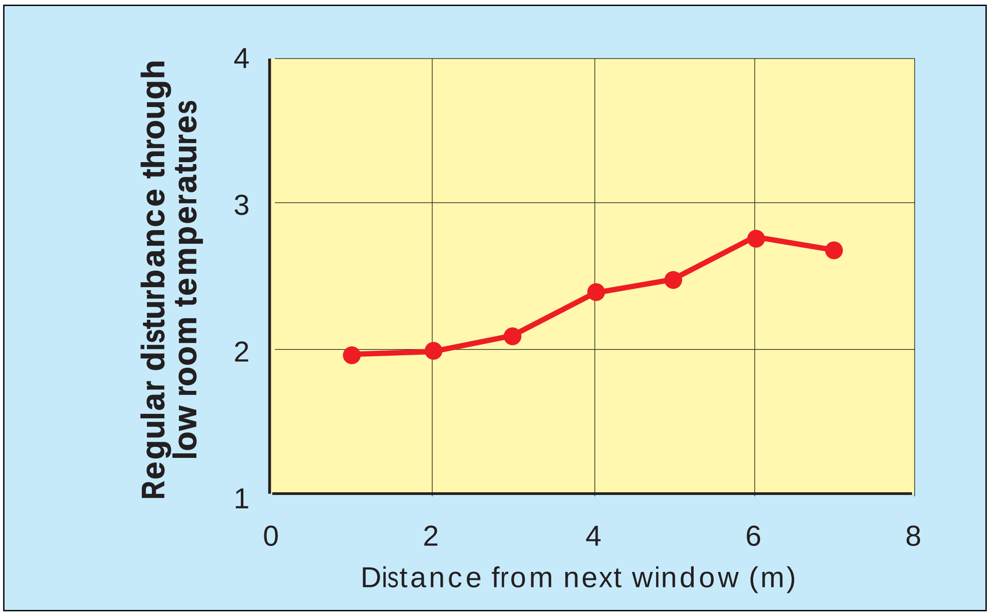


Fig. 7.11 Influence of distance from window on stress caused by dry air

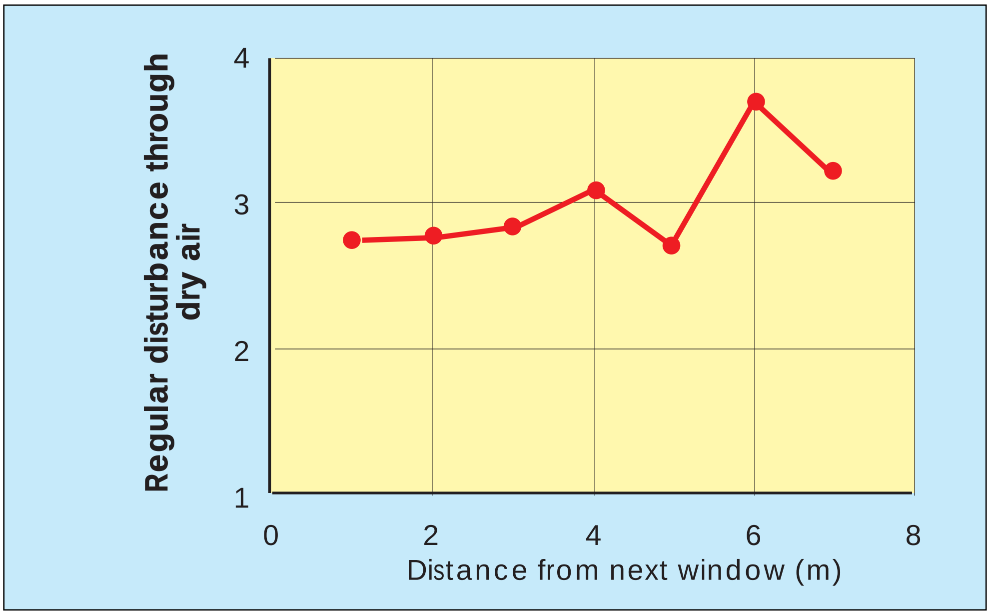


Fig. 7.12 Influence of distance of workplace from nearest window on stress caused by lighting conditions

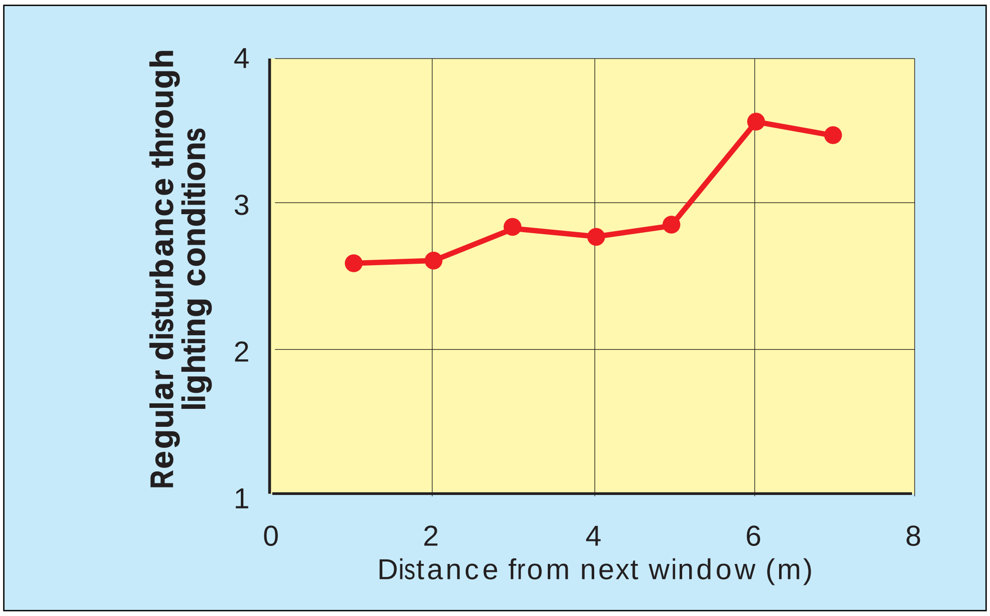


Fig. 7.13 Influence of distance from window on stress caused by too little daylight

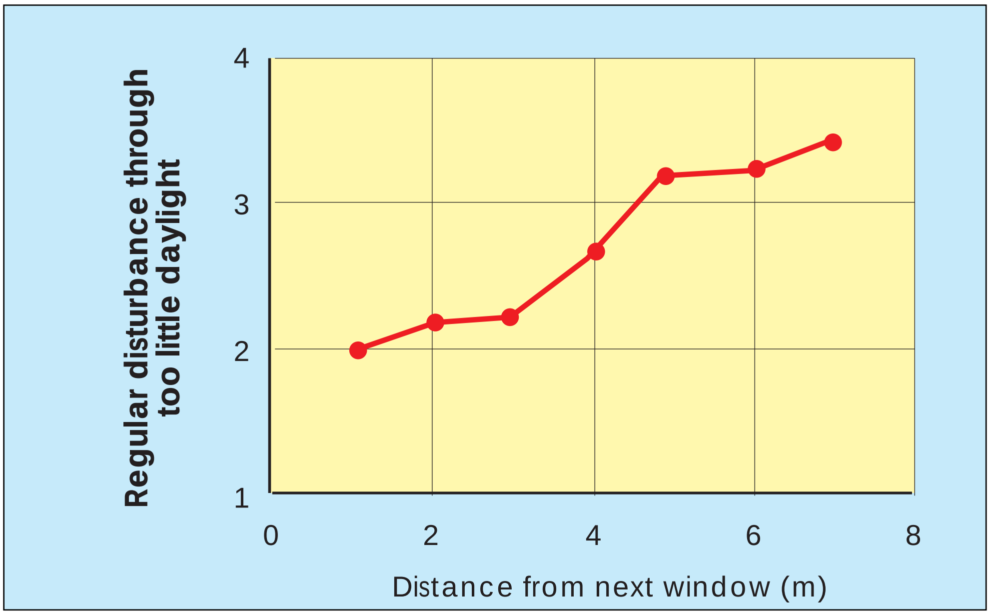
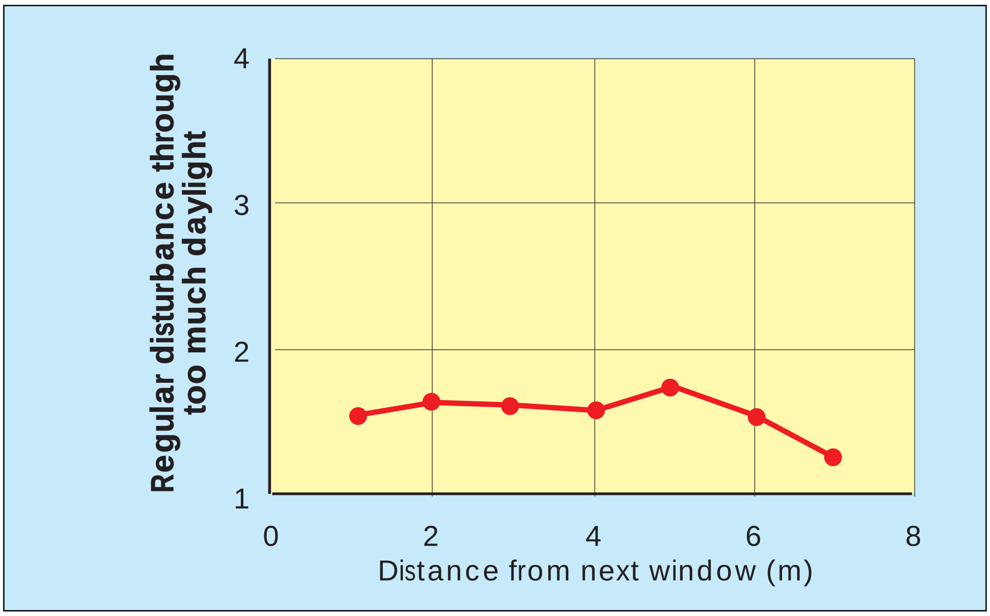


Fig. 7.14 Influence of distance from window on stress caused by too much daylight



7.3.3 Distance from Window and Disturbance to Health

All of the scales which were used for the registration of disturbances to health show a highly significant correlation with the variable *"too little daylight"*, and they follow approximately the same curve as this variable in relation to room depth, as can be seen in the examples in Fig. 7.15 *("rapid fatigue")* and Fig. 7.16 *("visual impairments")*. Additionally, the investigation also shows that this general trend applies for all types of equipment, i.e. fatigue basically follows the same curve for work at a desk as it does for work at a computer or typewriter. The lowest degrees of strain can be found at workplaces closest to a window.

Fig. 7.15 Influence of distance from window on rapid fatigue

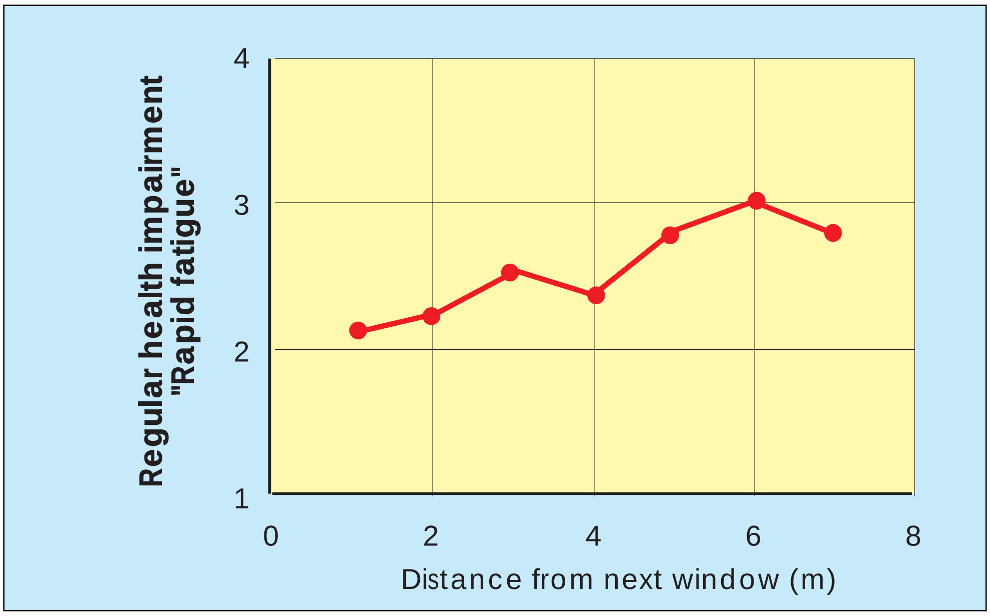


Fig. 7.16 Influence of distance from nearest window on visual impairments

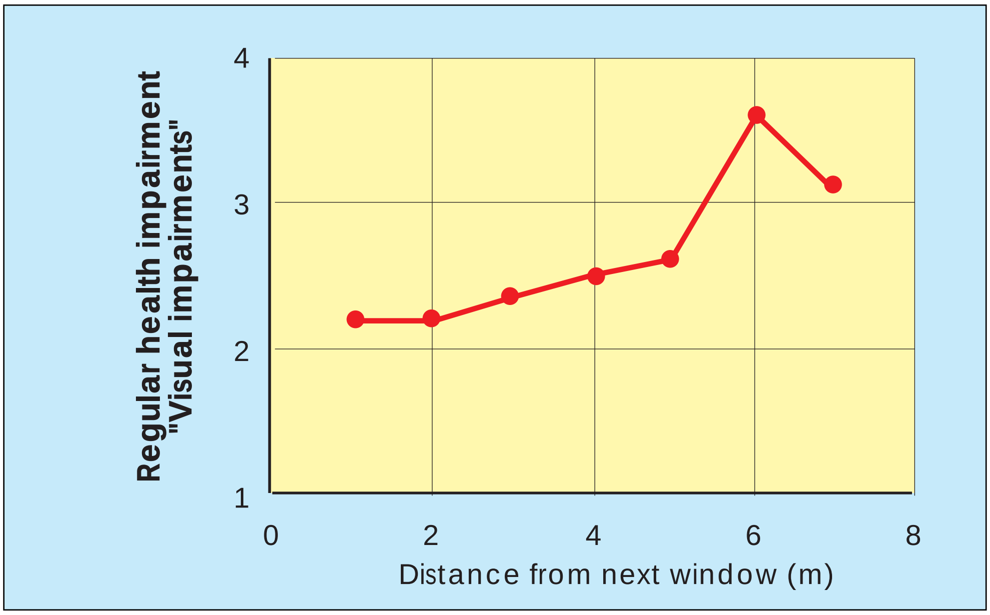
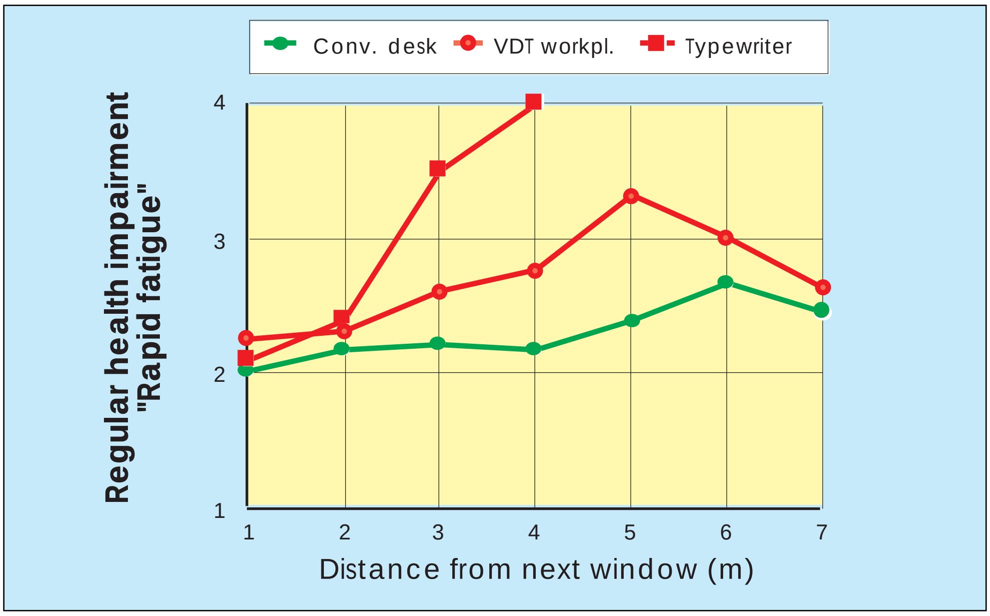


Fig. 7.17 Influence of distance of workplace from nearest window on fatigue for use of different types of equipment



7.4 Summary and Interpretation

The evaluation of the questionnaire shows that a substantial percentage of people working in offices suffer detrimental effects to health. Two of the most important stress factors, light and climate form a demonstrable contribution to these disturbances. In addition, these disturbances are also connected to the types of equipment used, though the effect of lighting is more significant. Thus, conventional work at a desk causes far fewer disturbances than work at a VDT or a typewriter. The influence of the type of lighting is much more important than that of the type of work. In room zones where daylight dominates, type of work has no influence on strain.

On the one hand, influence of light depends on whether we are dealing with natural or with artificial light, and on the other hand it also depends on the particular type of artificial lighting. Daylight has a positive influence on the disturbances to health independent of the particular equipment, i.e. its influence is as positive in the case of work with a VDT as it is in other office tasks. With increasing distance of the workplace from the window, or with the decreasing influence of daylight, all disturbances to health and well-being increase. However, in the vicinity of windows the type of work does not induce different effects on workers (see Fig. 7.17). This finding is in clear contradiction to the generally accepted belief that in these parts of work rooms, users of VDTs would be disturbed by detrimental effect of daylight and their workplaces should be positioned in areas away from the windows.

The influence of artificial light depends on the type of lighting used in a given workspace. Localized-lighting with table lamps, for instance, which is considered a comfortable source of light but is felt to have negative effects on room impression, shows the most negative influence of all. In any case, it is not permissible according to currently applicable norms of lighting technology.

General lighting in form of overhead lighting has a more favorable effect than localized lighting, yet it is still significantly less favorable than 2C-lighting. Since the type of lighting which the present phase 2 of the study interprets as “2C-lighting” consists of both an overhead lighting and table lamps, the positive influence is assumed to consist in the fact that this type of lighting offers the users more possibilities of regulating the lighting according to their wishes.

The results of this study indicate that the artificial lighting of office rooms does not fulfill the basic requirements set by DIN 5035. Artificial lighting does not succeed in fulfilling the self-set goal of creating equal visual conditions at all points of the rooms, nor does it counteract premature fatigue, which, according to the opinion of those concerned, it tends to promote instead. Well-being is not affected positively by currently installed artificial lighting, but rather negatively, its effects ranging from visual impairments to irritability and headaches, depending on the particular lighting installation. Artificial lighting is consequently not suited to serve as a replacement for daylight; it is merely a functional installation whose purpose it is to compensate for temporarily insufficient amounts of daylight. This compensation does not seem equally beneficial for all types of human work, as the influence differs. That is, conventional office work is less affected than work with VDTs, which, in turn, is less effected than work with typewriters.

According to the stress / strain concept, artificial lighting can not only be presumed to constitute a stress factor with demonstrable negative acceptance, but also as an essential stress factor, an increase in which also entails an increasingly negative influence on health and well-being. In work areas where the influence of daylight is dominant, the impairments of health and well-being are significantly lower than in areas where artificial lighting dominates. Thus, after 60 years of standardization, artificial lighting is still one of the negative factors inducing the *“sick building syndrome”*. Thus artificial lighting is to be considered a health hazard in the sense of European Directives.

These results are to be examined by experimental work with new types of lighting where other factors than lighting are well controlled and the technical characteristics of the installation are measured (see Chap. 11).

The results of this part of the study may be applied to work performed in the night time only with critical precaution, as they were acquired in work areas with daylight and for work organized to be performed during daytime.

Discussion of the Working Hypotheses

8 Discussion of the Working Hypotheses and Conclusions from Phase 2

8.1 Hypothesis 1

"The lighting of work-areas has a positive effect on the health and well-being of those who work there."

Based on the results of the present study, hypothesis 1, which was formulated in the above way in accordance with the norms' stated goals of creating equal visual conditions at all workplaces and promoting well-being, can only be verified for the case of natural lighting in the proximity of windows; it cannot be verified generally.

Rather, it emerged that with increasing distance from the windows, the lack of daylight is experienced as both a stress and a strain, and the available artificial light is not suited to alleviate this lack, even in cases where it is sufficient for the adequate recognition of the visual objects of the work task.

Only in rooms with windows on all four sides, and nowhere else, do complaints arise concerning an excessive amount of daylight. This result is particularly remarkable, since a substantial number of work rooms have no protection against an excessively strong influx of light and the workers are thus exposed entirely unprotected to sunlight. Consequently one should have expected corresponding complaints.

Even though it should be noted at this point that the design of German offices is generally not of a low standard and that a number of regulations for work safety already exist, the present result should provide an impetus for the improvement of lighting conditions. The protection granted by the legal requirements, which stipulate the visual contact of each workplace with the outside of the building, is obviously not sufficient.

The hypothesis can therefore not be verified for artificial lighting. Subjectively, the latter tends to be rated negatively, it is experienced as a constantly impairing working condition, and it leads to statistically demonstrable health disturbances. This means, lighting is a health hazard in the sense of new legislation on safety and health.

In view of the fact that artificial lighting is essential for organized forms of work, this result cannot be accepted without considering remedial measures. It should be noted at this point that this conclusion is made without taking into consideration those workplaces which are only equipped with table lamps in disregard of existing knowledge in the field of lighting technology.

8.2 Hypothesis 2

"The lighting of work-areas has a diminishing effect on human fatigue."

This hypothesis, which was also formulated in correspondence with the goals set forth by lighting norms, cannot be verified either.

Although there can be no doubt that the established effects would have been even more unfavorable if no suggestions as to good lighting design had been made and put it into practice at the right time, but the results of this study show that the standard of lighting is insufficiently developed to eliminate fatigue let alone to counteract it.

The decisive reason for this situation should probably be sought in the fact that, lighting technology as a "quasi- science" has an unjustifiable predominance over those branches of science which are concerned with the stress caused to humans at the workplace and with the artificial working environment, such as occupational psychology or the psychology of architecture. This does not legitimate a reproach to lighting technology for having rejected any utilizable concepts from the latter areas of science; rather one is forced to conclude that such concepts simply do not exist. Judging by our experience, even those who should be concerned about the health and safety of the working population, e.g. experts of occupational medicine, decline to formulate their own concepts which could then be put into practice by lighting experts. Instead, they accept technical standards as the best and only solutions. On the other hand, it must be stated that lighting technology has not been highly innovative in developing new systematic approaches. Most fundamental ideas lighting engineers follow today date back to the beginning of our century. Moreover, most of the "scientific evidence" to which lighting experts refer, were developed in the twenties, somewhere in the gray zone between marketing and research and development.

8.3 Hypothesis 3

"The effects of artificial lighting on health and well-being are determined by the type of artificial lighting of work-areas."

This hypothesis could be verified most impressively. The different types of lighting which were taken into consideration in this study have different effects on well-being and health. Since lighting technology has undergone major changes in the last few years, offering new concepts, one may assume that effective means for designing artificial lighting in a way which precludes negative influences now exist. The evolution of these concepts is explained and discussed in Chap. 9, and the effects of various stages of development are demonstrated in Chap. 10 and Chap. 11. The impact of new lighting concepts was investigated in phase 3 of the project (see Chap. 11) with a surprisingly positive outcome.

Since all lighting installations used in phase 3 were equipped with fluorescent lamps, the very positive outcome means that adverse effects of artificial lighting are unlikely to be caused by the type of lamp used but by their utilization in luminaires and the arrangement of lighting installations. This opinion corresponds with the arguments lighting experts have been putting forward for at least three decades.

8.4 Hypothesis 4

> *"Daylight has a more favorable effect on human health and well-being than artificial lighting."*

This hypothesis could also be verified. The favorable influence of daylight could not only be verified for conventional office workplaces, but also for VDT workstations, where one would generally tend to expect a negative influence.

The consequences of the verification of this hypothesis imply that one must assume the existence of environmental conditions with detrimental effects on health at all those workplaces where for certain reasons one is obliged to do without daylight either entirely or partially. This remark applies for CAD workplaces, for example, where unhampered work under daylight conditions and even under normal artificial lighting has remained a practical impossibility until today.

A further consequence should consist in a re-thinking of concepts for office space design. Although such re-thinking was begun about two decades ago (cf. Sieverts, 1980), apparently it has not yet been able to produce any substantial effects. At least part of the negative assessment of artificial lighting is traceable to disadvantageous room design with little daylight.

8.5 Hypothesis 5

> *"In the vicinity of a window, daylight has an unfavorable effect on work with a VDT."*

Based on the present results, this hypothesis can be discarded. The study provides no indications that suggest that VDT workstations should, in principle, be arranged any differently to other office workplaces.

Today, sufficient technical means exist for the elimination of any remaining problems involving screen reflectance or loss of contrast due to excessive illuminance (Bauer, 1987; Çakir, 1988). Knowledge of this fact was first published in 1978 (Çakir et al., 1978), and technical solutions have been available since 1982 (Çakir, A., Çakir, G., 1983). The irony of developing a concept for *"VDT-lighting"* when robust VDTs which are usable under any form of lighting do exist, is only surpassed by the irony of establishing a worldwide standard on VDUs in 1990 which contains no standards on glare guarding. If undesirable effects do occur at such workplaces, the reason is usually an inappropriate display unit and not the windows.

The result of the project should be interpreted in the sense that the impact of positive factors associated with daylight outweighs that of the negative factors. While the negative factors (e.g. reflections on screens) directly affect visual processes, positive factors such as communication with the external world, triggering the circadian rhythm and the production of hormones have an influence on other functions of the body.

This result does not mean VDT workplaces should be placed as close to the windows as possible. It indicates the need for a careful trade-off between visual and non-visual factors while designing the workspace, where the positive effects of daylight (contact with the outside world, etc.) are maximized and the negative effects (reflections, loss of contrast) are minimized.

8.6 Hypothesis 6

> *"Users of VDTs are not affected more negatively by artificial lighting than those working at conventional office workplaces. "*

The study provides only little evidence to for the verification of this hypothesis. Instead it can be noted that strain on persons working at VDTs is higher than for those working at conventional office workplaces according to almost all of the parameters that were taken into consideration. The results of the phases 1 and 2 of the project do not provide a basis for an answer to the question whether this can be traced to the lighting alone. However, the investigations reported in chapter 11 show that improved lighting concepts may reduce health impairments in such a way that the difference between VDT workers and other office workers is much smaller than in phase 2 of the project. This means, that in general, artificial lighting contributes substantially to strain at VDT workplaces, which, however, can be reduced or even avoided to a significant extent by selecting the appropriate type of lighting.

8.7 Summary

All in all the verification of the working hypotheses shows that the basic assumptions which lie at the heart of current lighting practices in work-areas are not accurate. Instead, the following statements can be made:

- Artificial lighting offers no fully adequate replacement for daylight.
- Artificial lighting does not reduce fatigue, on the contrary, it contributes to rapid fatigue.
- In office areas, daylight in the vicinity of windows does not constitute an environmental factor against which the best possible protection is required. Instead, simple user-operated glare-control provisions may be used to achieve maximum acceptability and comfort. Architects and organizers should focus on maximizing the utilization of natural light rather than minimizing it as recommended by some “experts” who probably never have explored the outcome of their advice.
- Room zones which are located in the vicinity of a window are characterized by more favorable environmental conditions than those areas in which artificial lighting predominates. The recommendations that are contained in the standards and based on the idea of “maximum protection against screen reflectance” proved to be wrong. They may help to remove apparent sources of discomfort, but not to establish comfortable lighting concepts.

The main conclusion of this phase of the project, namely that natural lighting is superior to artificial lighting, does not contribute to the task of finding the best possible solution for artificial lighting, which remains a necessary element in any industrial working environment. This task, and the results of the search are discussed in Chapters 10 and 11.

Since it seems likely that no certain solution can be found which may be the best under all circumstances, Chapter 12 describes legal safety and health requirements and a method for selecting a “usable” solution.

Description of the Development of Lighting Concepts

9 Description of the Development of Lighting Concepts

9.1 General Statements

This part of the report describes the common lighting concepts of the last few decades, which now determine the general picture in offices. This synopsis, which reaches back to the founding days of the Federal Republic of Germany, does not, however, include the entirety of currently existing lighting installations, whose pre-history dates back to the Thirties. Some of the lighting in today s offices is as old as the building in which it is installed, in some cases over four decades. A twenty year old lighting installation is by no means uncommon.

This description is intended to facilitate the comprehension of the development of lighting technology which is very well documented in the applicable norms. The latter also offer a good survey of the respective *state of scientific knowledge*, since science and technology have at all times been more closely interconnected in this area than in almost all other fields. However over the last ten years, science has lost its influence in this field, because it is believed that lighting does not represent a suitable object for research.

For a better understanding of the investigation, a knowledge of certain concept and features of lighting technology is necessary The following section is devoted to explaining some of these.

9.2 Basic Concepts in Lighting Technology

The following paragraphs explain some important basic concepts in lighting technology, relating them to the formulations of the lighting norms. The definitions of these terms, as they appear in the norm, are precise, but at times less than clear; for the sake of exactness, they are given in the appendix.

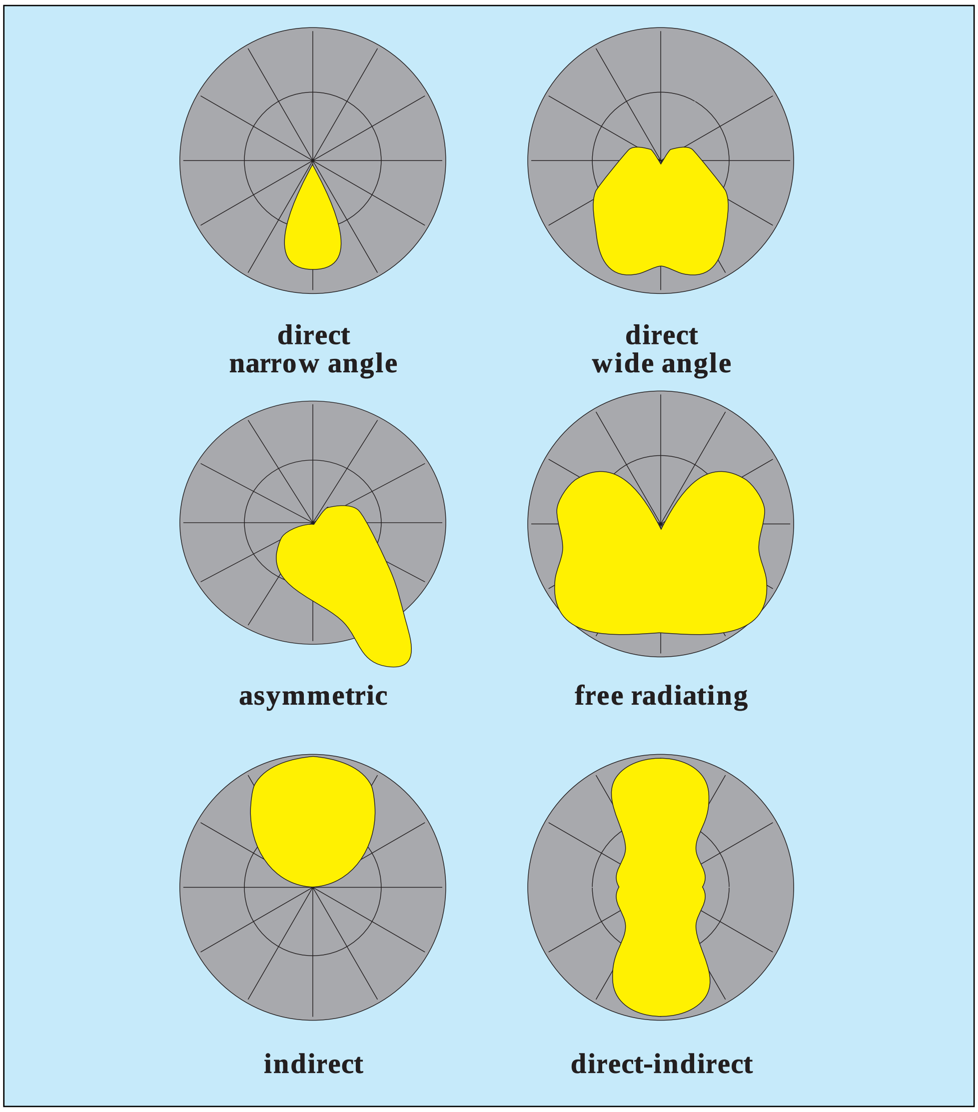
9.2.1 Luminous Flux

Luminous flux is the quantity of light per unit of time. Generally speaking, this term is of no immediate relevance for lighting practices, though it is important indirectly: it is common practice in lighting technology to indicate, or calculate, the so-called economic viability of a given lamp, where the benefit is figured in terms of luminous flux, whereas the cost consists in the price of the lamp and the required amount of energy. Over the course of the last decades, this approach has led, among other things, to an increased *luminance* of new lamps, which in turn creates glare problems that must be taken into account in applicable design measures. A particularly crass demonstration of this development can be found in modern automobile headlights which use discharge lamps. These lamps cause glare even in daylight and at night the only way of coping with them is either to look away or to let a vehicle with such lamps overtake, in contrast the glare caused by normal headlights is made to appear completely humane.

9.2.2 Luminous Intensity

Luminous intensity is a figure for the characterization of a given light source, representing the luminous flux which is emitted per unit *solid angle* in a specific direction.

Fig. 9.1 Curves for luminous intensity distribution (Spieser, et al, Handbuch der Beleuchtung [Lighting Manual], 1975)



It is possible to determine the adequacy of a light source (lamp or luminaire) for a certain lighting task from the spatial distribution of luminous intensity (Fig. 9.1). For this reason the distribution of luminous intensity of luminaires is of direct importance in lighting practices.

Narrow angle luminaires (top left) strongly concentrate the light on a narrowly defined space below the unit, whereas wide angle luminaires (top right) illuminate a large area. Asymmetrical luminaires are used when the area designated for illumination is not located directly under the device, e.g. when the luminaires are fixed on the window side of a work-area for the purpose of illuminating the interior.

Free radiating luminaires emit their light in the way in which it is produced, (Example: the right-hand figure in the middle shows the distribution for an incandescent lamp). Such luminaires should not be used at workplaces, since they generally tend to glare strongly. The figure on the lower left shows an indirect luminaire. Its light is directed entirely towards the upper hemisphere, the distribution can be narrow to wide angle, by which means, it determines the maximum luminance on the ceiling.

With currently available technology for luminaires using fluorescent lamps, it is possible to obtain a broad variety of luminous intensity distributions, ranging from narrow angle direct to indirect. The particular characteristics assigned to a given luminaire determine not only those characteristics of the entire lighting installation which are important from the point of view of lighting technology; they also generally determine the entire impression of the room.

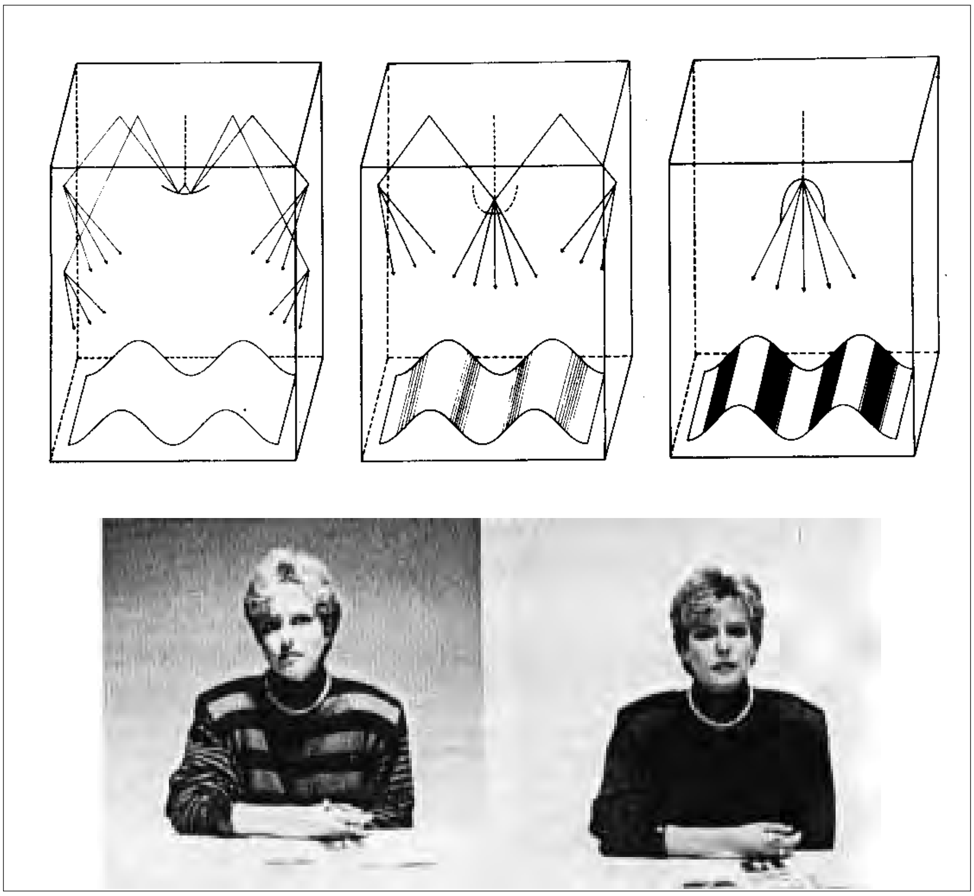
9.2.3 Luminance

Luminance is the term in lighting technology which expresses (somewhat) the impression of brightness of a given object. It is measured in cd/m^2. All physiologically relevant factors such as glare, contrast, contrast sensibility, and the like, are functions of luminance. The magnitude of luminances which occur in nature, and to which the human eye can adapt, cover a span of approximately 10 to the power of 11. In office rooms, such orders of magnitude do not occur. Here, a black screen has the lowest luminance with approximately 1-5 cd/m^2, whereas a modern compact fluorescent lamp would have the highest luminance with about 40,000 cd/m^2; by comparison, a sheet of white paper has a luminance of approx. 100 cd/m^2. (Note: brightness itself is not a measurable concept.)

Luminance is a property of an object which can differ substantially for one and the same object depending on the respective position of the observer. This effect is most apparent for glossy objects and it lessens the more matt an object is. There are two ways of obtaining a constant luminance for all observation situations, namely by assuring either that the object reflects the incoming light diffusely, or that the incidence of light is evenly distributed over all parts of the space. The former approach has been broadly applied in the finish of writing paper and of the toner for office printers, for example. Unfortunately, not all visual objects can be changed in this way, and one is therefore forced to take lighting measures in order to avoid gloss on visual objects - insofar as this is desired (cf. also *reflected glare* and *contrast rendering)*. It is not however possible to create a matt paper surface for high quality color printing. The reason for this is easily explained with an ink-jet printer. If completely the same object were printed on matt office paper, semi-matt ink printing paper and high gloss paper, the result is three widely differing appearances.

In practice, an even distribution of incoming light could be obtained by means of the exclusive use of indirect lighting. This form of lighting is generally undesirable, due to fears that, the spatial appearance of visual objects could be impaired. For this reason one attempts, as a rule, to create a mixture of diffuse and direct incidence of light. In an office room, the proportion of these two elements is essentially determined by the distribution of luminous intensity of the luminaire and by the reflective properties of the wall surfaces and the furniture. Fig. 9.2 shows the effect of the distribution of luminous intensity on the visual appearance of objects. The upper part of the figure represents three different distributions and their effect on a fictional object, while the lower half shows two pictures of a person under strongly diffuse lighting and under strongly directed lighting respectively. The appearance of objects is determined by the *distribution* of luminance from viewer's point of view, which in turn depends on the spatial distribution of light. Entirely diffuse lighting (top left) leads to a luminance of spatial objects which is identical from all directions, whereas the luminance is highly dependent on the point of view in the case of directional lighting. In practice, it is not possible to obtain fully diffuse lighting even with indirect luminaires, since the wall surfaces are not completely white and the only radiating surface is the room ceiling. Fully direct lighting with narrow angle luminaires tends to be an exception which is used deliberately for the purpose of creating certain effects, as for instance in theater foyers with spot lighting and dark wall surfaces. The most extremely direct distribution of luminous flux (“BAP”- or “VDT”-luminaires) for general work areas results in a diffuse proportion of approximately 10% of the illuminance due to the reflectance from furniture, ceilings, and walls. This proportion is even less with downlights equipped with energy saving lamps. For this reason they are only suitable for workplace lighting in exceptional circumstances, despite frequent claims to the opposite.

Fig. 9.2 The appearance of a three-dimensional object depending on the distribution of illuminance (top) and the “modeling” of a face under different luminous intensity distributions (bottom left: direct; bottom right: predominantly indirect). (Top: Hartmann, 1982; bottom: Sieverts, 1988)

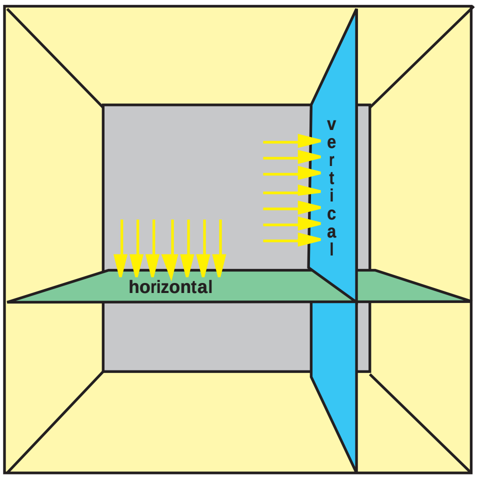


9.2.4 Illuminance

Illuminance is the incident luminous flux per area unit measured in Lux (lx). Since light spreads in a linear fashion, it is always necessary to specify the plane where the illuminance is measured or determined (see Fig. 9.3) for a given illuminance value. With some exceptions, in the case of workplace lighting this plane is usually figured as the horizontal plane at the level of a fictional workplace (0.85 m). The illuminance measured in the horizontal is called “*horizontal illuminance*”.

In order to express the illumination of vertically oriented objects, such as walls or filing shelves, measurements are made in a vertical plane (“*vertical* illuminance”). The horizontal plane is the standard for all lighting norms as the usual working

Fig. 9.3 Common planes of measurement for illuminance

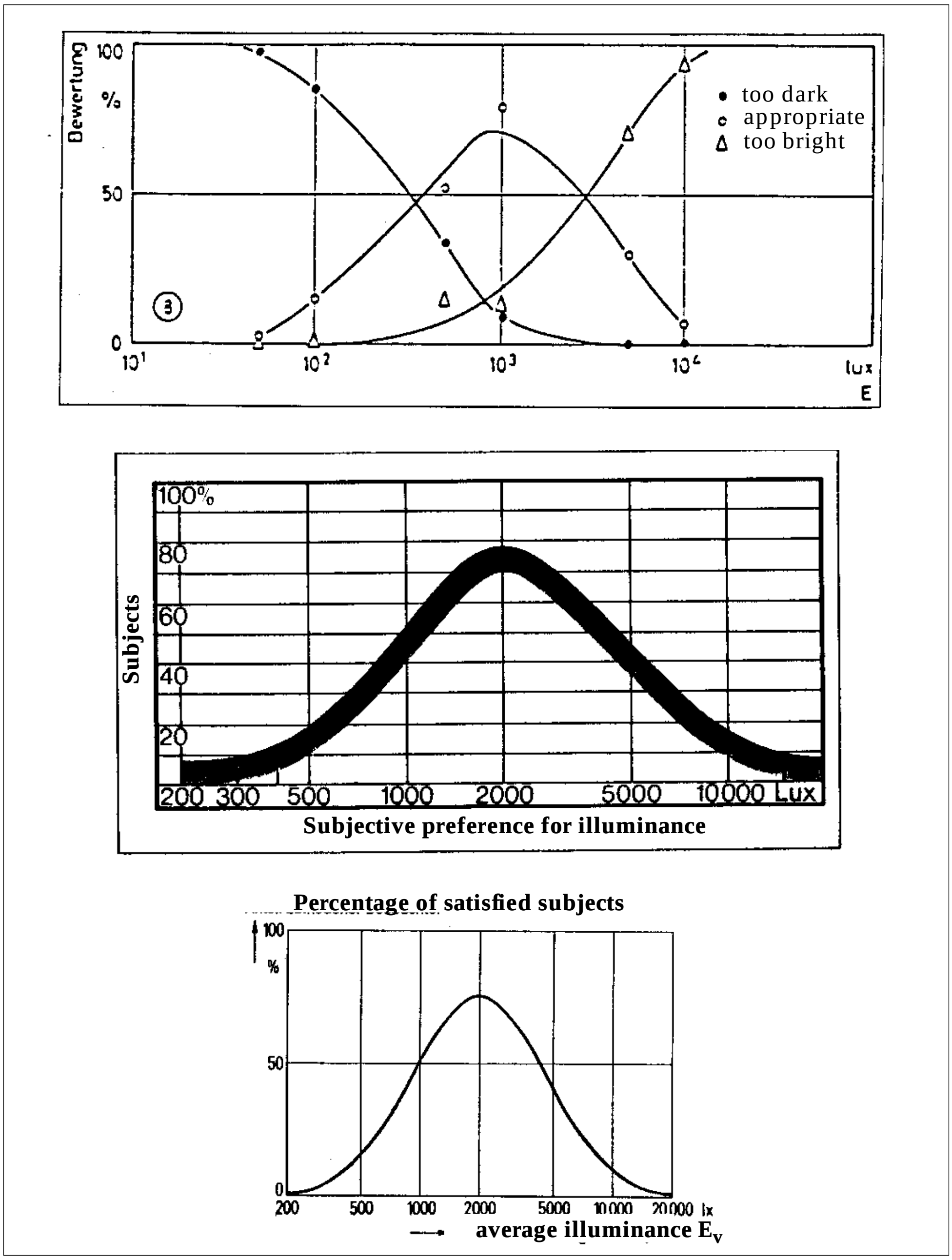


plane for many tasks is the table-top whereas the vertical plane is important in specific usages (technical drawing, libraries, shelves etc.).

The literature on lighting technology as well as the secondary literature very frequently confuse these two terms, this circumstance has led, in turn, to ostensibly new insights that produce a great deal of uncertainty for those involved in lighting practice. Take, for example, the "development" of demands on illuminance as an instance of such confusion: even into the 80's, the secondary literature in particular maintained that the "demands" on illuminance had increased substantially, and that need in this field increased by a factor of 2 each decade. However, a closer examination of the literature which serves to justify this view reveals, that the latter is at least partly the result of careless misinterpretations, as will be shown in the following. It is worth consideration if this really occurred through negligence.

The first investigation, which lies at the basis for a demand of "1,000 lx", was conducted by Bodmann (Fig. 9.4, top). According to this investigation, an illuminance of 1,000 lx represents a subjective optimum. What is neglected in the literature, however, are the circumstances under which this value was established: it referred to the illuminance on a particular visual object and not the illuminance in a room in which the subjects had worked over an extended period of time. Later studies by Fischer (Fischer, 1970) are cited for the purpose of justifying the introduction of an even higher preferred illuminance of **2**,000 lx. This study is cited, for example, in *"Lighting Application"* and in the book on *"Humane Work Conceptions"*, published by the German Federation of Labor Unions (Fig. 9.4, middle; DGB, 1978); both cases include the remark that the preferred level of lighting can lie above the nominal illuminance values recommended by DIN 5035 for certain activities.

Fig. 9.4 Data on subjectively preferred illuminance values. The figure in the middle shows a doubling of illuminance relative to the top figure; however, this is the result of misuse in citations from the literature, as can be seen in the bottom figure.



According to the particular norm that is invoked, however, the nominal illuminance level applies for the **entire horizontal plane** of the work-area, and not for the individual visual object. In fact, Fischer's study actually was concerned with something quite different, namely with the avoidance of the perception of silhouettes in open-plan offices in a situation, where the subjects would judge the face of a person standing in front of a window. As can be seen in Fig. 9.4 (bottom), the object of the investigation consisted of the *vertical* illuminance from the room's interior in the direction facing the window; this has nothing to do with nominal illuminance. There seems to be some kind of (deliberate) misunderstanding. The curves in the diagrams are identical their meanings are, however, utterly different. (Note: *How one generates 2000 lx facing a window without disturbing the environment was not revealed by the author*). Should it be true that the demands on illuminance, i.e. on the quantity of light, have changed in offices between 1960 and 1990, then the need could only have decreased, for the poorly readable forms and documents which were common at the time (e.g. carbon copies produced with spent carbons, or manuscripts marked with pencils) have largely disappeared from offices. Generally speaking, the legibility of the material has increased, while the importance of paper-bound information has generally decreased.

This circumstance suggests the necessity of examining the "scientific" basis for currently common opinion on correct lighting, especially on illuminance, which is still referred to as the salient characteristic in the workspace. In general it is believed that the basis is concerned with visual performance, as according to DIN 5035 part 1 the illumination of work places has the task of making possible the effortless recognition of visual objects. The investigations of Bodmann contradict this assumption. Bodmann showed in his laboratory experiments on lighting "Lighting Levels and Visual Tasks" (Bodmann 1962) that visual performance hardly increases above an illuminance of 100 lx. According to the results at that time common office tasks could be carried out under a tenth of the illuminance recommended today i.e. around 50 lx. A higher illuminance was justified, according to visual performance required - if the viewed object is very dark and hardly shows any contrast. In the experiments cited, a level of 400 lx for reading of 1,9 mm figures on a background with a reflectance of 0,11 was investigated. This is the equivalent of a newspaper which is printed on practically black-gray paper. That Bodmann recommended generally higher illuminance has nothing to do with the visual performance which supposedly led to the recommendation in DIN 5035 part 2. Bodmann argues "*.... with this it should be shown that the recommendations which have been made for reasons of visual performance are limited at the top and at the bottom by other factors which are just as important as visual performance to the environment of the working persons....*" It is possible to illuminate the desired " environment of working persons“ much better and more economically today by use of indirect lighting rather than through higher illuminance in the sphere of work with which the norms are exclusively concerned.

When speaking about the criteria for illuminance, which are to be found not only in the norms but also in legislation (for example in the Workplace Ordinance of the Federal Republic of Germany), although it is frequently claimed that they are based on objective facts, they nearly always resort to subjective opinion. The investigations which are supposed to be their foundations are methodologically so wretched, that if they were handed in as a student’s term paper they would have little prospect of success.

Illuminance is in principle an important concept, but it is of limited relevance in offices where, for other reasons, the illuminance should be 200 lx. Especially in terms of VDT work places where no paper is used at all, the value of high illuminance is questionable.

9.2.5 Shadowiness

Shadowiness is a value which expresses the way in which spatial objects, such as faces, for example, are modeled. To this end, the relation between horizontally and vertically incident light is calculated at a given point of the room. Under artificial lighting, the result is a value of approximately 0.5 for purely indirect lighting, and 0.2 to 0.3 for direct radiating narrow angle luminaires. Where the value is highest, the faces appear “flat”, whereas at the lowest value, strong shadows become visible in the eye sockets (cf.Fig. 9.2, bottom).

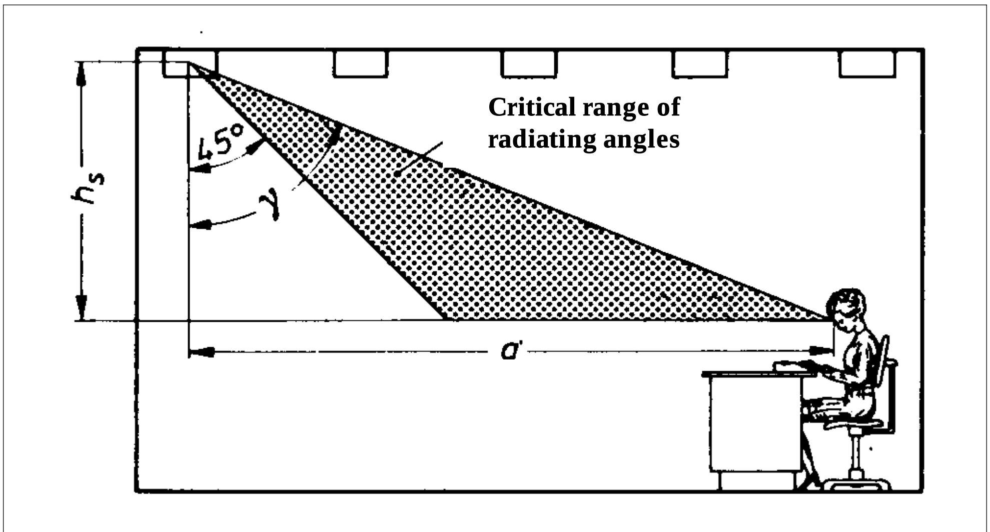
9.2.6 Direct Glare

The term *glare* refers to disturbances due to excessively high degrees of luminance and / or to excessive variations of luminance in the visual field (DIN 5035, part 1).

Direct glare refers to glare resulting from objects with high luminance, e.g. from lamps or visible segments of the sky. It can reduce visual performance *(disability* glare) or create unpleasant sensations *(discomfort* glare). As a rule, luminaires for interior lighting and their possible arrangements are designed in such a way that *disability glare* plays no role. *Discomfort glare* is a form of glare which is judged solely under the aspect of a *“sensation of disturbance”*. If a person stays in such a room for an extended period of time, this type of glare leads to premature fatigue and to reduced performance, activation, and well-being (DIN 5035, part 1). According to Çakir (Çakir, 1975), the concept “discomfort glare” alone is not sufficient for the subjective evaluation of a given lighting installation, since it does not take into account the positive effects of light. The positive effects are described in terms of *pleasantness*. In the absence of strong disturbances, *pleasantness* is largely independent of sensation of disturbance i.e. the discomfort is almost completely independently judged from pleasantness.

In interior lighting, direct glare is reduced or avoided by paying attention to the so-called glare limitation curves. Measures taken in this respect primarily concern discomfort glare, although they do also reduce potential disability glare. Discomfort glare is considered to be sufficiently limited, when the luminance of luminaires with radiating angles of 45° to 85° is reduced according to the Söllner-curves (Fig. 9.5). These curves apply for a line of sight which is directed slightly downward; they are not valid, however for the area between 0° and 45°, or for horizontal and upwardly oriented lines of sight. Söllner's curves are, however, being replaced by a new method - (UGR ***u***nified ***g***lare ***r***ating). It is not yet certain when this new method is going to become part of the standardization as this is supposed to happen within the framework of European standardization and this can take up to a decade. (Note: These curves have been around for more than a quarter of our century. Surprisingly, hardly anybody can explain what they really mean.)

Fig. 9.5 Area in which the glare limitation (luminance limitation) after Söllner applies (DIN 5035 Part 1).



9.2.7 Reflected Glare

Reflected glare arises due to the reflectance of bright objects on directly or at least partially directly reflecting surfaces (see Fig. 9.6, FGL 1976; DGB, 1978). It could be avoided by means of completely matt visual objects. Generally this is not possible, and measures in the field of lighting technology of the kind shown inFig. 9.7 thus become necessary. *(Note Picture 9.6 right was probably taken under diffused lighting as under directional lighting a bent surface always shows reflected glare.)*

Fig. 9.6 Appearance of the pages of a book under unfavorable and under favorable lighting conditions (from: FGL, Lighting Applications, 1976)

As can also be seen in this figure, such measures presuppose a certain arrangement of the workplace relative to the luminaires, which often cannot be realized in practice. Furthermore, as can be seen in the right-hand part of the figure, the avoidance of reflected glare can only be achieved for a small area of the work surface. Formerly this was enough as the visual object in an office was a sheet of paper and it was usually placed in this area during work. Today however, a there is a keyboard in its place which is not matt or flat as paper is, and for this reason can cause glare.

In order to avoid glare in the way described above, appropriate distributions of luminous intensity were implemented, for example, where the light is given off more strongly to the side (see Fig. 9.8). For these luminaires, the highest level of illuminance is not to be found underneath the luminaires - theoretically, no workplace is located in this space -, but rather in the zone where the workplaces are supposed to be situated. Obviously this protection only works for flat objects while bent objects such as keys on a keyboard or the book shown in the picture will still reflect. The effect illustrated is known to anybody who has ever tried to examine a photograph or a transparency or even read a glossy magazine under normal office lighting.

Fig. 9.7 Orientation of a (single) workplace with respect to lighting for the avoidance of reflected glare (from: FGL, Lighting Applications, 1976).

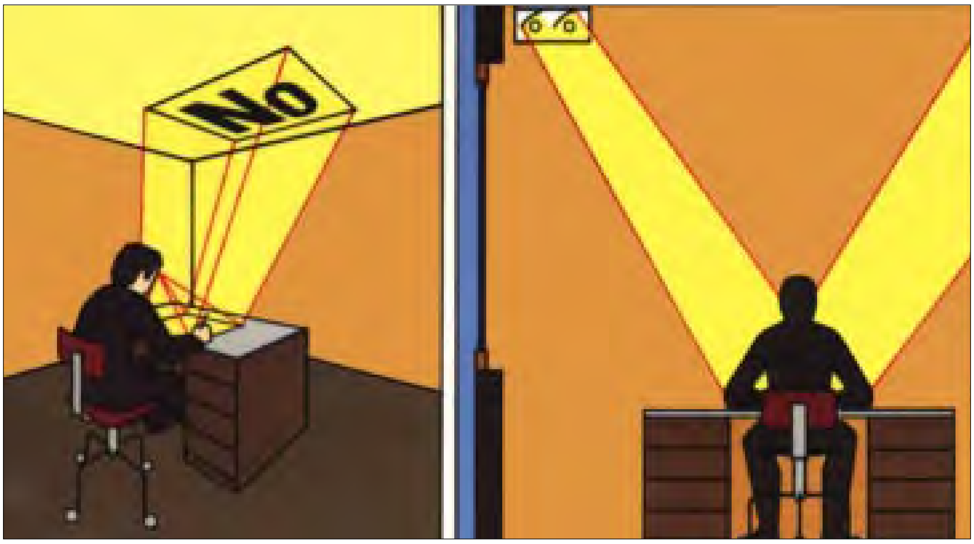
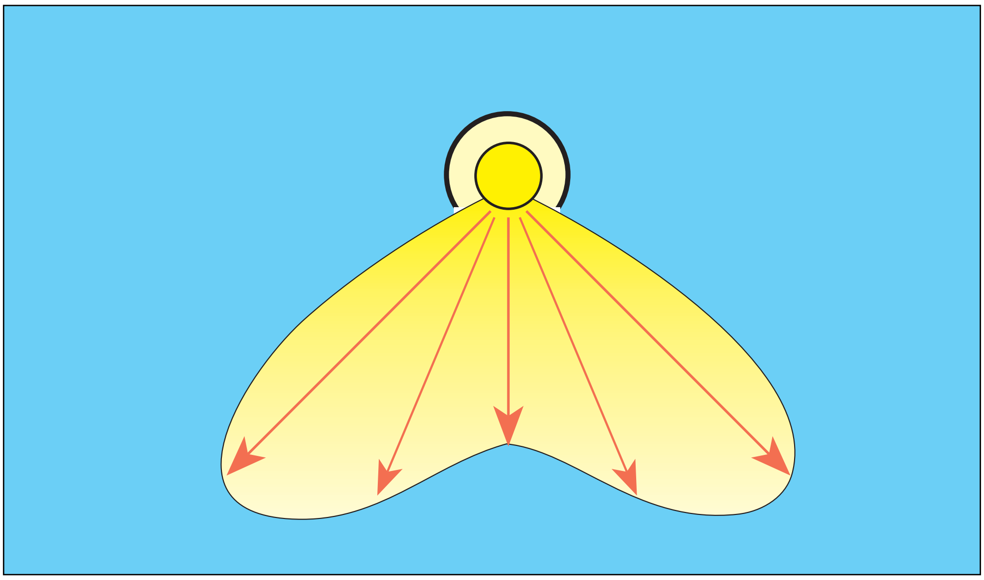


Fig. 9.8 Distribution of luminous intensity of a luminaire, which minimizes reflected glare



There is another way, however, in which reflected glare can be avoided. One possible measure consists in the reduction of the luminance of the object, in this case of the source of light.

Such a measure was not necessary before, as light sources only had a low luminance and a large, extensive surface. 30 years ago it was not possible to look directly at the lights as there was an opal diffuser in front of it. This had a luminance of about 2000 cd / m^2. Modern light sources (such as the most recent developments of the florescent lamp) do not just shine with a higher luminous efficacy but have increased, through their compact dimensions, in luminance by a factor of five in comparison with older lamps of the same capacity. If a worker shifts his gaze from the horizontal upwards, he is looking into 20 times the luminance, as for a long time now, a mirrored louver has been directed downwards to maximize the illuminance on the work surface. This constellation of high luminance on small lighted areas has led to reflected glare and has in fact made it of significance for the first time.

A second possibility consists in increasing the proportion of diffused light in the total flux that hits the surface; this can be achieved by taking the measures mentioned above, e.g. by choosing an appropriate distribution of the luminous intensity of the luminaires. These measures reduce the danger of reflected glare and enhance the representation of details on glossy surfaces.

9.2.8 Contrast and Contrast Rendering

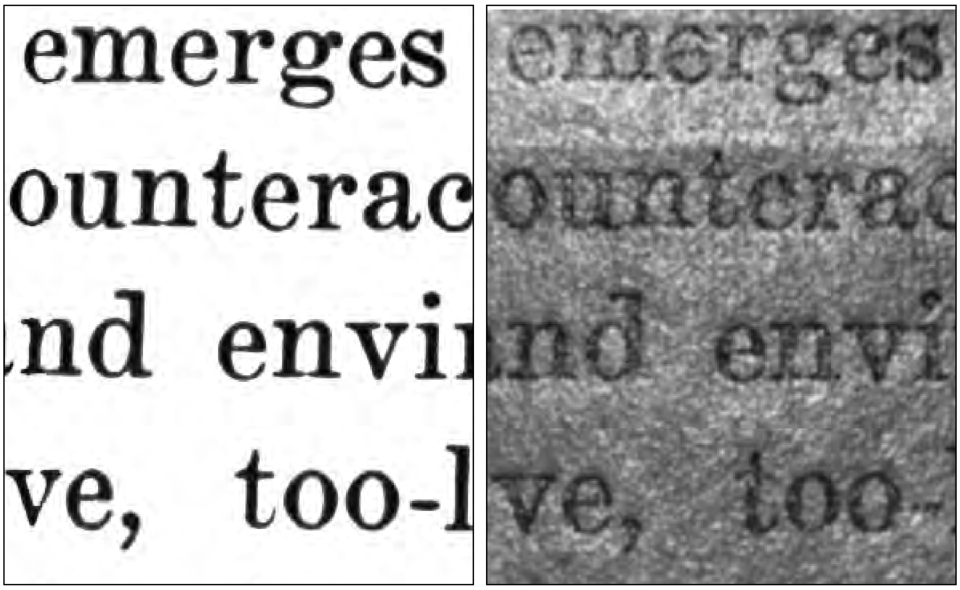
Visual objects are only perceived by the eye when they are distinguished from their environment by at least one optical property, e.g. their color. The most important distinguishing characteristic for text does not consist, however, in its color, but rather in the relationship between the luminance of the object (the characters) on the one hand, and its environment on the other, *contrast* (Fig. 9.9).

Contrast is only a definitely determinable value independent from viewing geometry for matt objects and matt backgrounds. When the print and / or the background is glossy, this value changes in an undesirable manner (Fig. 9.10). Under unfavorable visual conditions, contrast can even become reduced to zero: the object can no longer be distinguished from the background. In the worst possible case it reverses i.e. white paper appears black and black print appears brighter.

The *contrast rendering factor is* a measure in lighting arrangements that relates to the rendering of contrasts. It describes the relationship between contrast under particular conditions on the one hand, and under conditions of reference on the other. For the purpose of creating equal, i.e. equally good, visual conditions at all points of the office, the contrast rendering factor must have the same value at all points and, above all, be independent of the conditions of observation. Most lighting systems depend on direct radiating luminaires using high luminance lamps. With such equipment equally good contrast rendering cannot be realized at all points of a

Fig. 9.9 Contrast and readability

Fig. 9.10 Changes in the readability of a text under lighting arrangements with different contrast rendering factors. (*Note: The effect is easily to demonstrate with a glossy magazine under direct lighting.*)



room but only in parts of it and for certain viewing conditions. Knowing this, many experts may tend not to integrate contrast rendering in lighting standards. To date this undisputed demand has not been integrated into the lighting norms and in Germany this is unlikely to happen in the near future as there are no plans to develop any new lighting norms.

That the contrast rendering factor has been ignored is not due to a lack of knowledge but rather to its practicality. Its calculation for large zones is still work intensive and measurement is even more difficult especially as the only supplier of the measuring equipment needed has ceased production. Further to this, the practicians lack even the remotest understanding of the importance of this factor.

9.3 Quality Criteria in Lighting Technology

The following quality criteria provide the basis for currently applicable lighting norms in Germany:

- Level of lighting
- Balanced distribution of luminance
- Limitation of glare
- Direction of light and shadowiness
- Luminous (perceived) color and color rendering

9.3.1 Objectives

The treatment and the explanations of these quality criteria in the text of the norm are of varying precision. For the criterion *“level of lighting”,* nothing is indicated except for the “nominal” illuminance in the plane of the work surface, i.e. the mean value for the entire room and over time. For a person working at a particular workplace, however, this is not a perceptible quantity, since it is not possible to “see” illuminance let alone its aspects of time and space. Furthermore, for such a person, it is irrelevant whether the workplace two places along is well lit or not. Hence, a sufficient mean value for the entire room is of relevance for the designer, not necessarily, however, for those concerned. The latter may benefit only from the requirement that at no time may the illuminance lie below 60% of the nominal value (i.e. under 300 lx in offices) for any workplace.

One statement on illuminance which is contained in the norm, but often if not always overlooked, is of vital relevance for at least one half of the working population: *“The assignment of a certain value of the nominal illuminance to a visual task refers to persons with normal eyesight.”* At least one half of the working population in the Federal Republic of Germany, however, does not have normal eyesight. What is of essential importance in this respect is the fact that the corrections of these eye problems are faulty in approximately 30% of all cases (Çakir, 1978; Kaufmann et al., 1972). So the norms are used to protect those who least need it, while the problems of those with the greatest need are swept under the carpet - a notable contradiction of ergonomic principles.

Since the impression of the room does not only depend on this fictional figure, but essentially also on the - visible -luminance of the room surfaces, it is left to the skill of the interior designer to achieve a favorable room impression by means of an appropriate choice of colors and degrees of reflectance. Those statements in the norm that concern the *distribution of luminance* and which are of any practical relevance, only refer to degrees of reflectance, the choice of which is strongly limited, however, given the fact that degrees of reflectance are tied to color. If one wishes to achieve the impression of bright walls or partitions under lighting which is directed strongly towards the work surface, one can only choose white or extremely unsaturated color shades. This means that the free choice of colors is increasingly restricted with the increasing orientation of the distribution of luminous intensity towards the narrow angle characteristic. If the designer wants to fashion a room in a way that is “congenial to VDT use”, she or he is left with only a very restricted range of choices, being obligated to apply part 7 of DIN 5035 which recommends extremely low degrees of reflectance for the room surfaces in order to avoid the reflection of objects and room surfaces on the screens. It is easy to establish where these recommendations have been followed and why it would have been better not to, simply by looking through the door: The room looks like a cave; lighting reduces the illuminance onto the wall cutting luminance by 50%, this is then halved again by the reduced reflection factor. A cure which is worse than the disease!

The limitation of glare, i.e. of reflected glare or direct glare, is considered in detail in the norm. Whereas the limitation of direct glare is related to the design of the luminaires and of the luminous ceiling surfaces, i.e. to tasks that concern the producer, the task of avoiding reflected glare is left mainly to the interior designer. It is the designer who must find an appropriate position for the workplace, as well as the correct properties for visible surfaces of equipment, desks, paper, VDTs, keyboards, etc. No advice is given on what to do if the required qualities cannot be achieved, even though it is exactly this which is needed by the interior designer.

The section on *direction of light incidence and shadowiness* merely deals with the limitation of shadowiness and provides a minimum standard; however, it contains no remarks on the correct direction of light incidence. Earlier insights to the effect that light should contain at least a certain proportion of directed light coming from the same direction as the available daylight, remain unmentioned. Just as forgotten is the earlier finding that the light should have a preferred direction.

Exact requirements are given as far as *luminous color* and *color rendering* are concerned. For the interior designer, the most important statement of the norm in this respect may be contained in the following sentence:

“*Together with the lighting level, the luminous color of the illuminating light, the color rendering in the room, the distribution of light throughout the room, and the coloration of the room all are decisive in determining the luminous environment and thus also the emotional influence on humans. All of these components should be balanced with each other.*”

9.3.2 Significance of the Quality Criteria

DIN 5035, part 1 specifies that a lighting installation can only comply with the given set of demands when all quality criteria are taken into account. Yet, this clearly formulated stipulation is weakened in the following sentence: "*According to the type and difficulty of the visual task, and/or depending on the type of room, certain criteria may be granted priority over others.*" This clause was applied in the field of office lighting in the case of the introduction of a supplementary qualitative characteristic for VDT workplaces: *Avoidance of disturbing reflections on the screen* (DIN 5035, part 7, 3rd paragraph). If it is really necessary to give all office rooms the "cave look", when there are more intelligent and, more importantly, cheaper options such as the positive contrast and glare guarding of visual display units, is certainly worth checking. The recommendations contained in DIN 5035 part 7 were based on a test with a (one) visual display which was not glare guarded and did not represent the standard of technology available at the time the test was carried out (before 1980).

Although the qualitative characteristics for lighting technology are supposed to be of equal importance, at least one difference exists: some of these characteristics have a different legal significance as a legal directive for workplaces (DIN 5035, part 2) than do the others. Among the former are illuminance (nominal value), luminous color and color rendering, as well as the limitation of direct glare. Some of the quality criteria are thus treated more equally than others.

9.4 On the Development of Interior Lighting Technology Prior to 1979

9.4.1 Development of the Lighting Norm DIN 5035

The norm DIN 5035 which governs interior lighting has undergone significant changes since the founding of the Federal Republic of Germany; yet this has gone largely unnoticed by the public. Lighting technology has always been and remains a matter of *expertise*, except for the minor, though significant, misfortune consisting in the fact that ***not all*** experts who deal with interior design can make their influence felt. Consequently, the norms for lighting technology on the one hand and for building construction technology on the other, for example, are elaborated in separate committees, although not a single building exists in Germany which has no artificial lighting.

Over the course of the first three decades of its existence, the Federal Republic witnessed changes not only in lighting technology itself, but also in the goals set forth by the norms. Thus, according to the directives contained in DIN 5035 in 1935 (DK 628.93; version (11/35)), artificial lighting was to serve the following purpose: "*Inte-*

rior artificial lighting must correspond to health and beauty requirements, while being functional and economical." These directives were based on 7 quality criteria, of which three have disappeared over the years as far as their function as primary goals is concerned, though they have reappeared in other locations. These include *local uniformity, noiselessness of the lighting, and maintenance of the lighting installation. Local uniformity,* in particular, has shrunk in importance to the status of a note in the 1979 edition. With this step, the primary function of general lighting to provide equally good visual conditions in the entire room was practically abandoned. How can one provide a certain level of visual comfort at different places if the most important of the basic requirements (illuminance) is not fulfilled?

The edition of 1953 provides the following formulation for the demands placed on lighting: *"Artificial lighting must comply with hygienic requirements; it must be economical and contribute to the impression of the room."* By contrast, the 1979 edition stipulates only one "must"-requirement for the illumination of work-areas: *"In work-areas, the lighting must facilitate an effortless recognition of visual objects."*

What is more important than the change in stated goals, is the conceptual change: According to DIN 5035 from 1953, there existed two concepts, general lighting - with low illuminance - and "task lighting with supplementary general lighting." Where only general lighting was used, the immediate work area was always supposed to be brighter than the surrounding environment to avoid an impairment of vision caused by parts of the field of vision which do not add to information, i.e. a bright desk the lighting of which makes the recognition of the information, for example, reading material more difficult. Furthermore, lighting was to be installed in a manner that would assure the correspondence between the direction of the incidence of artificial light on the one hand, and of natural light on the other.

A draft from 1962 already shows significant changes. In particular, this draft stipulates that workplaces should be equipped either with general lighting, or with a form of localized lighting where general lighting provides at least 20% of the total illuminance (10% for certain tasks).

According to this norm, the design of the workplace is strongly determined by daylight: *"Wherever possible, workplaces are oriented according to the incidence of daylight. In such cases, artificial lighting should be adapted to the quality of daylight."*

By contrast, the most recent section of the norm, DIN 5035 part 7, which applies for all workplaces with VDTs (which is to say for basically all future offices), recommends placing workplaces at the greatest possible distance from the window in order to avoid disturbances through daylight.

The first signs of these changes date back to the 70's. In the 1972 edition, the norm had already "emancipated" itself to a large extent from the role of daylight, which now received only marginal attention. It is no coincidence that this occurs in the heyday of open-plan offices. The direction of light incidence is mentioned only in connection with the avoidance of shadows and reflected glare; general lighting represents the preferred concept, since it has become possible for lighting technology to provide the required illuminance values with only one single component. General lighting is primarily required for work-areas where the workplaces are not definitely fixed: *"If equal visual conditions are to be created for all workplaces, general lighting is required for work-areas with workplaces that are not definitely fixed."* Seven years later, the requirement reads as follows: "As *a rule, rooms **are to be lit** by general lighting which should create approximately equal visual conditions at all points of the room and underscore the general impression of the room."* Although it is easy to see why equal visual conditions should be created at *all workplaces*, the desire to achieve the same goal for *all points* of the room requires some explanation. Is it the work-areas that have changed, or the visual tasks? It seems most plausible to assume that the purpose has changed, tending toward the flexible use of work-areas, i.e. the free placement of workplaces at all points, as well as the possibility of introducing subsequent changes to the arrangement without corresponding changes in the lighting installation. Taken on its own, this purpose still corresponds to current demands, though only for large rooms. In smaller rooms, however, which constitute the majority of all available rooms, this creates problems. Additionally, flexibility is limited again by the other requirements contained in the same norm. It is in any case difficult to recognize a definite concept behind all this, should there indeed be one.

The supporters of general lighting never tire of stressing the advantages which it undoubtedly has. Why are its disadvantages so seldom discussed. Even in the representation of a scientist who was not aversed to the concept they come across as fairly shattering.

"(1) The general level of lighting must be decided according to the highest visual requirements, this means that even in places where the visual task is not recommended the lighting should be of a high level.

(2) The direction of incident light i.e. the relationship between directional and diffused illumination is made the same for every workplace by the installation. Inevitably, it can only be optimal if the same task is being done at every workplace. (Note for this to be possible all desks in the room must be arranged in exactly the same manner.)

(3) If the room is uniformly brightly furnished and decorated in the interests of a high coefficient of utilization factor, general lighting all too often leads to a reduction in contrast for which the term "light sauce" is all too perfect. This last point very often represents the cause for complaints about visual conditions at the workplace and illumination, although lighting technicians can prove with a good conscience that the lighting level and also its even distribution, the lack of glare and the color of the light are all in accordance with the norm."

The motto that lies behind the idea of general lighting is " **Equal light for everyone**"(Hartmann,1977). This principle contradicts basic ergonomic principles which assume the difference in people. That different people require different lighting for the same visual task has been known in the field of lighting technology for a long time. Why take an incorrect principle as the main aim of a technology which should be, and is so important for every working person? There is a good and a bad reason for this. The good reason is as follows workplaces are used by various people and sometimes it is not possible or necessary to change the lighting. For this reason general lighting is the only reasonable solution, even if it is wrong. Such a course of action is not at all uncommon and even has a respectable name - optimizing. For example, it is not realistic to dimension parkbenches or staircases in public buildings other than according to the principle of “the same for everybody.“ So general lighting is called for in many applications of lighting technology. How to make it as least incorrect as possible, can be read in the literature of ergonomics.

The bad reason for preferring general lighting was described in a very exact way by Hartmann: “*....in parallel with the triumph of florescent lamps, incandescent lamps disappeared from workrooms and with it the individual illumination of small work spaces retreated further into the background.As further to this florescent lamps and incandescent lamps harmonized badly with each other the individual lighting was increasingly banned from the workplace.There are indeed desk luminaires equipped with florescent lamps but these are cumbersome due to their size, and they often have a tendency to flicker in a disturbing manner which can only be compensated by two lamps in series which makes the whole lighting even more unwieldy.* (Hartmann, 1977) This reason became outdated ten years ago when compact florescent lamps and electronic ballasts went on sale at acceptable prices. The installations built according to the principles of general lighting and the prejudice against task lighting (referred to as “individual lighting“ in the norms) have, however, remained.

The illumination which is supposed to be installed respectively used according to DIN 5035, is based on an incorrect principle, which has no basis for today‘s offices and VDT workplaces. Further to this the current legal position on VDT workplaces also contradicts this (VDT Workplace Ordinance of 21.12.1996) where the requirements are described as follows: “*15. The lighting must correspond to the visual task and* ***be suited to the visual ability of the user; ...“***

There is only one recognizable trend in the entire development of the norm over the course of these years: for reasons of visual physiology (recognizability), certain illuminance values on the work objects were already required in 1953, although they could only be implemented by means of task lighting, due to inadequate lighting technology. As a rule, the values that are given were established in short-term experiments that determined the illuminance on work objects. Over the years, these (slightly updated) values began to be applied to the entire work-area, i.e. to all points of the room; however, no scientifically grounded justification for this procedure exists to date. Possibly because nobody has ever looked for one. The effect of lighting on room impression seems to be of little interest.

The 1979 edition of the norm permits task lighting only if a number of conditions are fulfilled; the latter are formulated in a manner, however, which practically limits local lighting to only a few workplaces with a nominal illuminance of 1,000 lx. In other words, what appeared as a general rule in 1953 has been ruled out since 1979. Although those who are familiar with offices that are lit on the basis of the 1953 model, will undoubtedly be struck by the positive aspects of current lighting concepts. However, the result of our study confirms the fact that the goals of creating an enhanced room impression and of promoting health, have by no means been achieved yet. On account of the disadvantages of general lighting already described by Hartmann and the false principles on which it is based, it was not even necessary to conduct a study to establish this.

Din 5035 part 1 was meaninglessly modified in 1990. No use was made of new scientific findings including the essential conclusion that the illuminance recommendations lack scientific basis (see Chapter 10). Part 7 was changed just as little even though the same laboratory which formulated the basis of the norm had conducted a new studies which suggested a need for change.

9.4.2 Development of Lighting Technology

In order to describe the situation that is reflected in this study, it is helpful to consider the development not only of the norms, but also of lighting technology over the past three decades. Since there is generally an interval of approximately ten years between the development of a lighting concept and its broad circulation, the development will be described separately for the 70’s and the 80's. To begin with, the description that follows is a word for word quotation from a brochure printed by the Trilux company on the occasion of its 75th anniversary (Rick-Lenze, 1987). (Note: Passages on political developments and on the development of exterior lighting were omitted from the quoted text, without any alteration to its meaning). “*The revitalization of industrial production in Germany coincides with the widespread use of fluorescent lamps... Not only in industrial lighting does the light source with a triple luminous flux assert itself against the incandescent lamp...*

*The lighting technology specialists will deal (*in 1955, editors note*) with improving calculation methods...*

In the mid-fifties, improved lamp and lighting technologies, as well as increasing wealth, allow the development of lighting applications that offer an abundance of light and are in a sense exemplary... massive brightness is praised. The broadcasting studio of Hessen Radio (Hessischer Rundfunk; Fig. 9.11) *in Frankfurt (Main) is equipped with a “luminous ceiling.” By the standards of the time, the lighting installation qualifies as “completely glare-free”...*

The ceiling lighting in a conference room in Frankfurt (Main) corresponds to the ideas of 1956 regarding adequate and timely room atmosphere...” (seeFig. 9.12)

Fig. 9.11 Luminous ceiling of the broadcasting studio of the Hesse Radio in the year 1956: the lighting installation qualifies as “completely glare-free” by the standards of the time. (Rick-Lenze et al,1987)

Fig. 9.12 Conference room of a company in Frankfurt/Main in the 50´s equipped with large area luminaires (Rick-Lenze et al, 1987)

Rooms like this conference room are still in use today, though only in a few cases. At this point one should mention some of the characteristic properties of the latter form of lighting: relatively low level of illuminance of 200 lx to 400 lx; lower luminance values of fluorescent lamps compared to modern lamps; and, as can be seen in the picture, large area, diffuse radiating luminaires, covered with white diffusers. The luminance of these diffusers amounted to approximately 2,000 cd / m^2. Luminaires with white diffusers, some of which were hung above the desks, while others were mounted on the ceilings, were frequently used in the workrooms of this era, which lasted roughly until 1970.

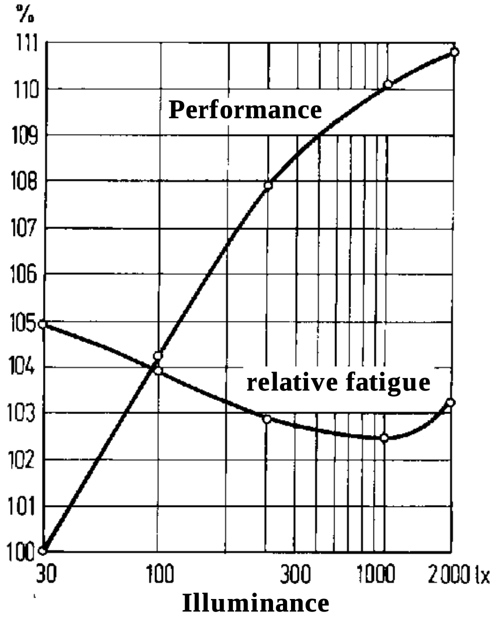
However, at the time, technological developments were already beginning to take a different direction, which followed a new image of the office: namely the concept of the open-plan office, which had been developed in the fifties by the Quickborn Team. This type of office was intended to integrate not only the people within one room, but also the service technology in the ceiling. This left no room for ceiling mounted luminaires, since they conflicted with the air conditioning system. Yet, these years witnessed an occurrence which had a decisive influence on the course of events:

" In 1961, the German Institute for Lighting (Deutsches Lichtinstitut e.V.) *initiated the 1,000 lx-movement. Scientific research on the subjective evaluation of illuminance supports this campaign. The norm for indoor lighting (DIN 5035 from 1963) ratifies these insights, declaring them to be the state-of-the-art of technology."*

The "1,000 lx-campaign" was founded with a diagram from the prehistory of lighting technology that is uncritically cited by unionists, as well as occupational psychologists, and which is occasionally still cited even today (Fig. 9.13). However, the conditions and the type of visual task for which the increase in performance that is shown in the diagram was established, are rarely mentioned: the diagram shows the result of a study of the activity of **stringing pearls** under incandescent lighting (Hartmann, 1981). A closer look at the diagram reveals that obviously there must be a methodological error involved, since even today nobody can measure a 0.5% change in the degree of fatigue as it is shown in the curve for relative fatigue between 200 lx and 1,000 lx. If this were possible, one would have to ask what kind of fatigue is implied when one wants to achieve a 0.5% improvement by paying five times the price for lighting equipment and energy. In addition, it is not really fatigue that is being analyzed, but rather error frequency. Furthermore, the diagram shows that between 300 lx and 1,000 lx performance increases by a total of only 1%. This should provide food for thought.

The interpretation of the curve for "fatigue" above 1,000 lx is highly questionable, too. This interpretation maintains that above 1,000 lx, fatigue increases. According

Fig. 9.13 "Performance" and "fatigue" as function of the illuminance. This figure, often used to "prove" the need for high illuminance levels in industrial environments, is the result of an experiment of the early 30´s with the task "stringing pearls"



to Hartmann, the effect which is shown here is derived exclusively from an experiment with incandescent lamps which, in addition to producing a small amount of light also produce a lot of heat; consequently, the presumed "fatigue" may also have been the result of additional heat created. Increasing the illuminance from 30 lx to 2000 lx also meant amplifying the infrared radiation hitting the subject by a factor 66. If the experiment were repeated outdoors, it would certainly be quite simple to demonstrate that even 10,000 lx provide no reason for fatigue.

Yet, the demand for higher illuminance values has other good reasons, such as the age of the workers, anomalies of the visual system, and particular visual tasks. People over 60, for example, require at least twice as much light for a given visual task than a twenty-year-old, and frequently even the best office lighting is not sufficient for error-free deciphering of the fourth carbon of a given document. If one wanted to let the demands placed on lighting be determined by the needs of older workers and by the requirements for the execution of difficult visual tasks, one would indeed have to recommend very high illuminance values. In the case of the preferred lighting concept, i.e. general lighting, many more people than the number established in our study would experience glare and other discomfort.

These insights are not really all that new; in fact, they could already be won from another justification of the 1,000 lx-movement, namely from Bodmann's investigations (Bodmann, 1961): even an illuminance of 1,000 lx on the working materials was considered *"too dark"* by 10% of those asked, while 20% considered this to be *"too bright"* at the time, i.e. 30% were dissatisfied. This is not really surprising as in every test where individual differences are not given preference, i.e. in every optimization 30% are, by definition, dissatisfied. The conclusion that must be drawn from Bodman's study is: The judgement of people in respect to the correct level of illuminance is so different that the preferred area spans ten to the power of two, a ratio of 1 to 100. Is it possible to fulfill the expectations of general lighting "equal light for every one " in the light of such differences?

The 1,000 lx-movement was limited by outdated luminaire design concepts with excessive glare. Thus, in order to protect humans from glare, the glare limitation curves according to Söllner were introduced, which still function as the basis for glare limitation in indoor lighting even today. The appealing form of these curves tends to mask the fact, however, that the establishment of these insights does not hold up to methodological standards (Haubner, 1970). Just like the claims for illuminance, which were derived from experiments with isolated visual tasks and subsequently prescribed first for all workplaces and then for all points of the room without any coherent scientific justification, the glare limitation curves, too, were established in short-time exposure tests, only to be subsequently applied to lighting installations with entirely different lighting technological characteristics. These curves were based on values for discomfort glare, which, according to DIN 5035, only develops its negative effects after an extended stay in the room. Nonetheless, the curves were established in model rooms and in precisely those short-time exposure tests. This criticism is also valid for other glare studies, on which the glare value systems of other nations were based as these were also short time exposure tests.

In the course of the 60 s and 70's, a number of investigations were carried out for the purpose of putting the quality criteria for lighting into practice (Rick-Lenze): *"In the following years, scientific institutes in universities as well as the industrial research laboratories will work persistently on developing the quality criteria for lighting. Rather than measuring the quality of lighting only quantitatively, lighting technology is now concerned primarily with fulfilling different qualitative criteria....*

In indoor lighting, limitation of direct glare has been integrated into the DIN-norm as of 1972."

During the 70 s, luminaire design underwent considerable changes, the main purpose of which was the integration of lighting, air conditioning, and acoustics in the ceiling, as well as the reduction of glare. And so began the battle for ceiling space: the lighting technician fought with the air-conditioning technician and he in turn fought against the acoustic technician. What came out of it was not the result of a compromise where everyone had profited from the others. Rather the lighting technician lost freedom and had to make do with less ceiling space. This moved the designers to develop the so called “air-conditioning luminaire“ which was integrated into the ducts of the air conditioning. It is open to question whether it was a good idea to aspirate unfiltered air out of the room past the lamps and mirror optics. New technology was lost to opal diffusers which kept the warm air flow, for the most part, away from the users. The load on people was increased slightly but certainly to a noticeable extent. In other forms of lighting opal diffusers lost their place to prismatic covers which in turn were replaced by louvers (open grids). Initially, these louvers were white, and produced a somewhat diffuse light. They were followed by a type of metal louver with a more strongly direct luminous distribution, the development of which culminated in the highly polished reflector louvers of the *“VDT-luminaires”*.

In the meantime, the old fluorescent lamps with luminance values of approximately 8,000 cd / m^2 were replaced by the new, thinner lamps with luminance values that are at least twice as high. In the years immediately following the introduction of the new lamps, users were prompted by full-page newspaper advertisements to install the new *“economical”* lamps in the old mounts, which led to an increased glare effect. The latest step in this direction consists in the development of compact fluorescent lamps with even higher degrees of luminance, which are constructed to fit old sockets. And now energy suppliers are warning the users: *“Compared to incandescent lamps, compact fluorescent lamps consume less energy for the same amount of light. Yet, they are also more complicated. Incorrect installation of compact fluorescent lamps can cause up to 80% less light.”* (Vereinigung Deutscher Elektrizitätswerke [Association of German Power Stations],1989).

Over the years, these changes have occasioned a step-by-step modification in the specifications of all the quality criteria. Thus, the luminance governing potential reflected glare no longer lies at 2,000 cd / m^2, as had been the case for the luminaires with opal diffusers, but rather at appr. 15,000 cd / m^2 for new thin lamps, and appr. 40,000 cd / m^2 for compact fluorescent lamps. The relevant factor for shadowiness no longer lies at 0.5; instead, for one out of two workplaces, it falls below 0.3 despite stipulations in DIN 5035, part 1 to the effect that values for shadowiness that lie below 0.3 should be avoided lest they cause unpleasant shadows on faces. Due to the installation of narrow angle luminaires, the proportion of diffuse light has sunk to about 10%, causing the luminance of the ceiling to fall to a minimum. The luminance of the walls, too, has become rather low, since most of the light is directed towards the horizontal plane that is defined as the work surface.

Thus, a “standard” type of lighting developed for which the 1975 “Handbuch fur Beleuchtung” [“Lighting Handbook”] provides the following commentary: “*Louvers with narrow angle light distribution, however, are only appropriate in exceptional cases. When they are not combined with other types of lighting, they create harsh shadows and an unsatisfactory room impression (dark ceilings).*” (Spieser et al., 1975). Thus, beginning with the 1986 edition of DIN 5035, part 7, preference was given to precisely the kind of light distribution for future office lighting which had been rejected, for good reasons, in a standard volume published by the Lighting Technology Associations in German-speaking countries (FRG, Austria, and Switzerland) already in 1975.

Questions of economic viability in lighting technology, which have a decisive influence on customer decisions, are almost always concerned with the criterion of illuminance; i.e. they are concerned with one out of five quality criteria that should *all* be taken into account, according to the norm. The resulting privilege of one single quality criterion at the expense of the others presumably constitutes the main reason for the unfavorable evaluation of currently existing office lighting installations. As was shown in section “9.2.4 Illuminance“ even in 1962 these criteria were irrelevant in terms of normal office tasks if the illuminance was over 100 lx. In terms of working with VDT equipment to the criteria are not just irrelevant but obstructive. The quality of office lighting and its thrift are measured according to the least important criteria, whereas other more important criteria are discriminated against. The poor reputation of the florescent light due to its “cold light“ is greatly attributable to this way of thinking. In the decades when white luminous colors were associated with a greater luminous efficacy than warm white, they were given preference for financial reasons and the users of the room could complain as much as they wanted about cold light. Nobody ever asked them if they wouldn‘t rather have 400 lx in warm white or 500 lx in daylight white.

There have been, then, a number of developments that have a negative effect on the lighting situation. These developments essentially derive from the fact that one has not taken into account *all* influencing factors related to light, but rather only ***some*** of these factors which appeared important or useful to the experts. Yet, the selection of the *important* criteria was by no means as arbitrary as a superficial view of the development might suggest. Rather, the development was already sketched at the beginning of the century, as can be seen, for example, in Couve's contribution (Couve, 1930): *"Only general lighting is appropriate for larger work-areas were groups work regularly under artificial lighting."* Many diagrams which still serve to justify the increase in human performance under higher illuminance go back to studies from the twenties which served as a basis for the project *"Beauty of Labor"* in the Third Reich.

Similarly, the experts' attempts to eliminate the influence of the individual on the work environment by means of more or less rigid norms also have their origins at the beginning of this century. Fritz describes the continuous development of ideas on lighting technology as follows: *"The workers are deprived of the freedom to control the lighting conditions in the work-area according to their own wishes. Localized lighting, which could be handled individually, is being replaced by centrally controlled general lighting, the amount and distribution of which is in the hands of specialists for organization and for lighting.... The process of the centralization of executive power in the workroom culminates in the introduction of centrally controlled general lighting in the work-area. The determination of spatial working conditions is fully in the hands of others. Personal appropriation of the immediate working environment is limited to an absolute minimum. There is a total lack of the kind of adaptation to individual lighting needs that is vital for office work. Individual differences regarding eyesight and the dependence of lighting needs on age, as well as pathological visual disturbances remain unacknowledged and are at the mercy of the rigid uniformity of artificial lighting."* (Fritz, 1983).

Finally, it should be mentioned that the 1,000 lx-movement was quietly put to rest with the revision of DIN 5035 in 1979. It is now only necessary for open-plan offices with moderate wall reflectance, and since hardly anyone in Germany still designs open-plan offices, it is practically no longer applied. Yet, the need of older workers for high illuminance in the case of difficult visual tasks remains. On the other hand, it should also be noted that the degree to which the goal of reducing direct glare has been put into practice exceeds original expectations.

So much for the description of those developments which determine current lighting practice. However, lighting technology did not come to a standstill at this level; rather, it developed new concepts during the eighties, which had been conceived earlier, but could not be put into practice, it seemed, due to the high costs involved. Possibly in the last five years more new lighting concepts have appeared than in the twenty years before. Unfortunately the consumers are not keeping pace with the innovations of the suppliers. For example in the federal state of Hamburg the target has been set of replacing the lamps currently in use with others which give off the same illuminance at half the energy costs (Kiesel and Pinnau 1997). A praiseworthy undertaking, were it not for the problem of the way it is being effected. Standard luminaires are being installed without consideration of the kind of work or the type of building - "*... the thousandfold luminaires installed are becoming a mass product due to the systematic renovation work*"- Light quality is not the important matter in the Federal State of Hamburg, the be-all and end-all is cost saving.

9.4.3 On the Development of Lighting Technology since 1980

Among other things, the development of the last 15 years has been characterized by the increasing technical perfection of direct luminaires with narrow angle distribution, and also by the development of luminaires which were supposed to eliminate the above-mentioned negative effects, though now without neglecting the positive aspects - little or no direct glare. These luminaires differ essentially from earlier models in that they emit a substantial proportion of indirect light, thus creating more favorable room conditions. For two versions of this type of luminaires it is no longer necessary to take into account the lighting arrangement when positioning the workplace (Indirect luminaires, CRF luminaires).

Further to this, since the middle of the eighties new fixtures have been developed the lamps of which are practically or completely invisible when observed from the workroom (secondary luminaires). The light falls onto the workplace via a reflector.

A further development of these years consists in the development of workplace oriented luminaires which differ strongly from common "table lamps" both in a technical respect and as far as safety and security is concerned. "Table lamps" were a product, which lighting technicians wanted to have nothing to do with; now "task lights", i.e. luminaires designed for task lighting, are a working tool with their own norm (DIN 5035 part 8). This norm defines the required quality which distinguishes a usable luminaire for task lighting from an ordinary table lamp.

Furthermore, there seems to be a development away from the need to use the kind of standard luminaires which had to be favored for reasons of economic viability in the 60's. Today the supplier can offer a lighting system of one kind with which it is possible to implement practically any required distribution from narrow angle to indirect angle within one lighting system. This is not merely a matter of technical detail; rather, it means a relatively great degree of freedom for the user in influencing lighting quality according to her or his own ideas, without moving beyond the realm of economic feasibility.

As a result of the development of lamp and luminaire technology it has become possible to implement various lighting arrangements under economically viable conditions. The principally different variants are shown in Fig. 9.14.

- *Direct Lighting with louvered luminaires*
  Usually equipped with florescent lamps. The VDT design has effective glare reduction (200 cd / m^2 under 50° or 60°, full luminance is visible by looking from underneath.

- *Semi-direct Lighting with louvered luminaires*
  Usually equipped with florescent lamps indirect light makes up 30% of the light output similarly glare controlled as the VDT luminaires mounted under a matt ceiling;
  in the CRF design, indirect light makes up over 50% of the light output, strongly diminished luminance when looked at from underneath. Task lighting optional.

- *Direct-Direct Lighting and Task Lighting* (also known as 2C) as above but with additional task lighting.

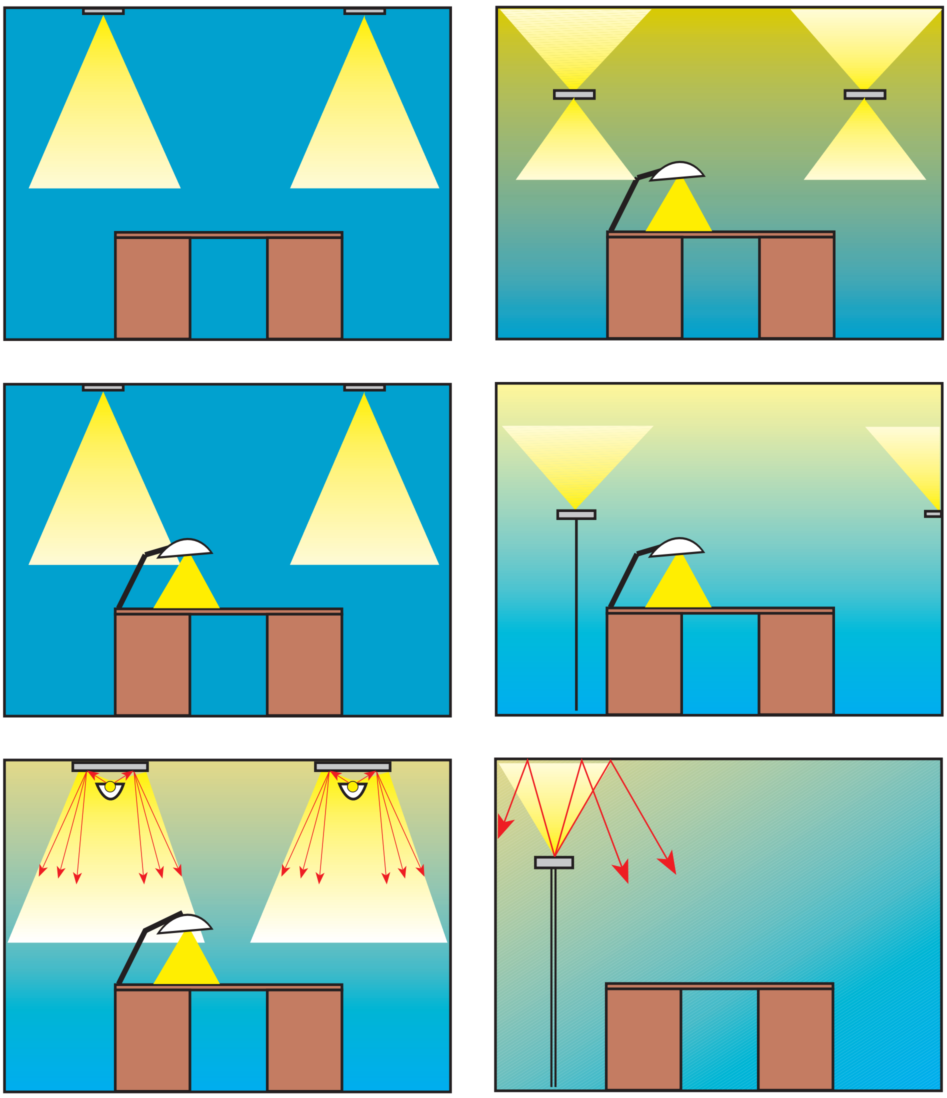
- *Semi-Indirect Lighting with two separate components*
  Room illumination is indirect, task lighting belongs to the same concept, indirect lighting also with high intensity discharge lamps.

- *Secondary Luminaire with its own reflector*
  Large surface matt reflector, no direct light from the lamp in the user area, low luminance, reflector can be a light sail or a special ceiling element.

- *Secondary Luminaires with the ceiling as the reflector*
  Combination of uplighters and partly or largely a direct reflecting ceiling, equipped with high intensity discharge or florescent lamps (not to be confused with indirect luminaires which light a matt ceiling.

Fig. 9.14 Implementable types of lighting

Top left	Direct lighting, ceiling mount
Top right	Semi-direct lighting, suspended from ceiling
Middle left	Direct-Direct-lighting, ceiling and workplace mount
Middle right	Indirect-Direct-Lighting, any mount
bottom	Two forms of “secondary lighting”



9.4.4 On Task Light as a New Class of Luminaire

In principle every type of luminaire is suitable for “localized lighting“ which is defined as “illumination of a workplace in addition to general lighting.“ It was necessary to define localized lighting in a standard, as working equipment for professional use should fulfill certain criteria which are not needed for a living room luminaire for example. In addition to this, our studies conducted before the 80s have shown us that “table lamps” can cause more problems than they solve. Last but by no means least, our studies have shown that although table lamps are in general very popular, the pressure to use them as the only means of illumination causes more health complaints than any other form of lighting (see Chapter 7).

In consequence the existence of room lighting was made a prerequisite in the when the criteria were being established. Due to their financial and other advantages the room lighting is nearly always equipped with florescent lamps. Task lighting should then always be compatible with room lighting which is based on florescent lamps.

“Task light” was defined as “*a luminaire for the illumination of a single place..... which is designated as a workplace.*“ It serves as individual illumination for a certain workplace, in contrast to room illumination which does not just provide the workplace with light but also makes movement within the room possible.

A further criteria is that, sensible “localized lighting“ is an individual illumination for persons, who all have the same rights to the fulfillment of their individual needs, but it should cause no disadvantage to the colleagues with whom they are working. Therefore task lighting should be made in such a way, that even in the narrowest possible positioning of two desks (head to head), its use does not cause any disturbance for the neighboring table. Certain requirements for glare control and limiting the adjustability of the luminaires arise from this criteria. At an angle of 30° above the horizontal the average luminance may not be any more than 1000 cd / m^2. It must be <200 cd / m^2 if the luminaire is positioned closer than 800 mm to the eyes of the user.

As the most critical but sensible use of task lighting is found at VDT workplaces, it should not lead to any glare by reflection if it is used in accordance to the specifications. This aspect represents the biggest difference between a common table lamp and “task light”. This means that as a working tool which is supposed to have been developed for a specific use, it should have as few negative side effects as possible. This gives rise to the need for certain standards on the luminance intensity distribution.

A further design point concerns the double edged effect of light: the illumination of an object improves its visibility, but simultaneously worsens the ease with which neighboring objects can be recognized which are not illuminated as well. For this reason task lights must illuminate a minimum area to a sufficiently equal extent and the distribution of illuminance must not be a vertex. This surface must be large enough that it is as rarely necessary as possible that the user has to move an object or adjust the task light in order to be able to see properly. This minimum area (main working area) has been established as 600mm x 600mm for normal office work which is the equivalent of four sheets of DIN A4 paper. Within this minimum space it is possible to place two documents printed on both sides next to each other and be able to read both sides without having to move them into the light. Inside the main working area the minimum level of illuminance should be 10% or more of the maximum level allowed. Good task lights achieve much better levels.

For the sake of the compactness of the form, task lighting is, as a rule, equipped with high luminance lamps which can lead to glare by reflection on visual objects which are positioned on a horizontal level. It is therefore essential that the luminaire is adjustable or has been arranged in such a way that glare is avoided. The norm DIN 5035 part 8 allows non adjustable task lighting, even though it is usually required for avoiding glare by reflection that the luminaire can be adjusted. The manufacturer must give details for installation which is suitable from a lighting technology point of view.

Flickering must be avoided through suitable measures. These are not individually defined in the norm. The user should preferably make use of electronic ballasts, and if using other technical solutions they should be able to avoid flickering to an equal extent.

As task lighting influences the room climate and thermal comfort, planning of localized lighting should take the room climate into consideration. This can be ignored if the energy consumption the luminaire is not more than 20W. The energy consumption must be specified by the manufacturer.

While selecting a product, the user should make sure that the head of the luminaire is as cool as possible and does not greatly exceed 40 °C even after prolonged use. This is sensible as it means that shocks arising from accidentally touching the luminaires can be avoided. Such a shock effect is already possible at temperatures far below the allowed temperature of the luminaires surface. This condition was set with burns in mind and not the unpleasant effect which is caused by surfaces of a relatively high temperature, which is not, however, high enough to constitute a danger of burning. The other reason for the surfaces to be as cool as possible is the irritating effect of thermal radiation. This should be kept as low as possible.

Such considerations are superfluous for compact florescent lamps, however with other types of lamps the user should check if the luminaires do not become too warm when they are in use for longer periods of time. The material of some luminaires have been known to change color due to the effects of overheating during long periods of use.

If the room surfaces are brightened to such a degree that there is an acceptable balance of luminance between the inside of the room and the outside world, the illuminance of the working surface is between 200lx and 300 lx. Good task lights can provide an average illuminance of 500 to 700lx with considerably low energy consumption. The total illuminance of the room will then be around 1000 lx even if the room only fulfills the minimum requirements for constantly occupied work rooms as set in DIN 5035 Part 2 (200 lx) or even exceed some of the other requirements. In this manner the requirement for visual tasks (100 lx) has been exceeded by a factor of ten. Visual comfort is increased not because the objects are easier to recognize because of the increased luminance but rather due to the directionality of the illumination. The total effect is much greater than if the general lighting were to be increased in the same proportion. At last the aims of the “1000 lx Movement“ of the Sixties have been achieved, however, without the “light sauce“.

Results of Phase 1

10 Selected Results of Phase 1

10.1 Carrying out Phase 1

Phase 1 of the project comprises of the surveys on lighting technology which were carried out over the last decade in connection with ergonomic studies in approximately 80 company projects in the administrative sector.

Among other things, these studies aimed at recording the strain on workers in these companies by means of a questionnaire, as well as attempting to determine causes for visual stress and to suggest remedial measures. By contrast to the usual research projects on the topic of lighting, which, although they may result in theoretically desirable solutions are often technically impossible to implement at the time, however, this project only had to obtain results which could be achieved, and for which existing interior architecture and *available* technology played a substantial role.

Since the lighting of the work space does not constitute the sole cause of visual problems (even though this may appear to be the case from the point of view of those concerned), the solutions that were found are not only of a lighting technological nature. The case studies that are described in the following pages represent a shortened version of the results of those investigations in which lighting played a demonstrable causal role. The fact that these case studies yielded generalizable results can be seen, for example, in the lively reader response which was occasioned by the publication of partial results; many readers had the feeling that the study had taken place in their own companies. The discussion became even livelier after the results had aroused great media attention. The theme created so much interest, which is still current today that this chapter is being republished with only a few editorial alterations.

10.2 Survey Method

The case studies used a standardized questionnaire which asks for all aspects of office work except for pay. This questionnaire was developed in connection with the “VDT-Workplace”-Project of the Federal Ministry for Labor and Social Affairs (see also Çakir, Reuter, 1978), and was later adapted for further office activities (Çakir et al., 1983).

The following factors are recorded:

PERSONAL DATA	Age, gender, activity, glasses, body height, task, working time etc.
Assessment of working conditions	
DEMANDS	Work related demands on attention and concentration, endurance, and ability to react.
OVERLOAD	Overload caused by work, e.g. work pace or degree of difficulty
UNDERLOAD	Demands which are too low, monotony, boredom, little responsibility (“underloading”)
PERSONAL CONTROL	Degree to which the work activity can be planned personally, interruptions of the work process, etc.
QUALIFICATION	Correspondence between the activity's profile of demands on the one hand, and personal qualifications on the other
BREAKS	Evaluation of breaks
NOISE	Disturbance due to conversations, machine noise
CLIMATE	Evaluation of room climate
LIGHTING	Pleasantness of lighting and sensation of disturbance
WORK EQUIPMENT, TOOLS	Chair, desk, tools, technical disturbances
FATIGUE	Self-reported fatigue, need for rest and relaxation or activity
VISUAL PROBLEMS	Asthenopic complaints, which become felt as strain on the eyes
IMPAIRMENTS TO HEALTH	Physical impairments, such as back pain, headaches, etc.
MEDICAL APPOINTMENTS	Doctor's appointments due to physical impairments (eye problems, back pains, headaches, etc.)

The comprehensive registration of all factors relating to work related human stress as well as their statistical dependence alongside personal characteristics and the activity, facilitates the analysis of whether or not, and if so, to what degree, the evaluation of the working situation can be traced to the work itself, to personal characteristics, or to physical environmental conditions.

As had already been established in previous investigations, a close correlation exists between the “fatigue” factor and the subjects' behavior in the private realm, i.e. the higher they rate their self-reported fatigue, the lower the involvement in social activities in their private life (Reuter, 1979). This factor is determined to a degree of 65% to 76% (multiple correlation) by further factors registered in the questionnaire. Therefore, a stronger statistically demonstrable connection exists.

In the framework of these investigations, it was also determined that a demonstrable relation exists between physical strain on the one hand and the lighting technological measurements relating to direct glare on the other (Çakir, Reuter, 1978). Accordingly one should expect the gradual reduction of direct glare in the

course of the development of lighting technology to have a positive effect on strain if the simultaneous change in other qualitative characteristics of lighting is insignificant or less influential than direct glare, which has been reduced substantially.

10.3 General Statements

10.3.1 Deviation of Actual Practice from the Assumptions in Lighting Technology

In the majority of all the workplaces that we examined (90% and more), lighting was planned and installed without the help of lighting technology consulting. Even in large new building projects (e.g. two main administration buildings with 700 and 2000 employees), company representatives stated that the actual decision on lighting had been taken in conjunction with the building conception of the architect; the scope for their decisions had been practically predetermined by ceiling construction on the one hand, and by the client's budget on the other. In one particularly flagrant case, not even the choice of lamps and luminaires was free, since it had been restricted to luminaires which would fit lamps of a length of one meter.

Naturally, the existing interior architecture constitutes the decisive influencing factor for the choice of lighting in the case of refurbishing, which account for approximately 90% of all new installations of lighting systems

This constitutes a clear contradiction to the assumptions of lighting technology which imagines itself to be at the heart of events: in the idealized form of the cooperation of the lighting engineer with all other parties involved, the lighting concept should become a part of the architectural concept (Fig. 10.1).

Fig 10.1 Idealized representation of the cooperation between persons and groups involved in planning on the one hand and the lighting engineer (bottom, left) on the other. (Source: FGL)
(clockwise from lighting engineer: Consultants: acoustics, air-conditioning, occupational medicine; client, architect, office organizer; engineers: electrical engineer, ceiling, electrical installation)

No matter how appealing this picture may be, it looks quite different, unfortunately, in practice (Tab. 5, Çakir, 1986). Furthermore, this picture fails to represent a number of persons who should and must be integrated into the planning process: the safety engineer, the technical supervisory official of the TCA, and representatives of the staff that will move into the future office.

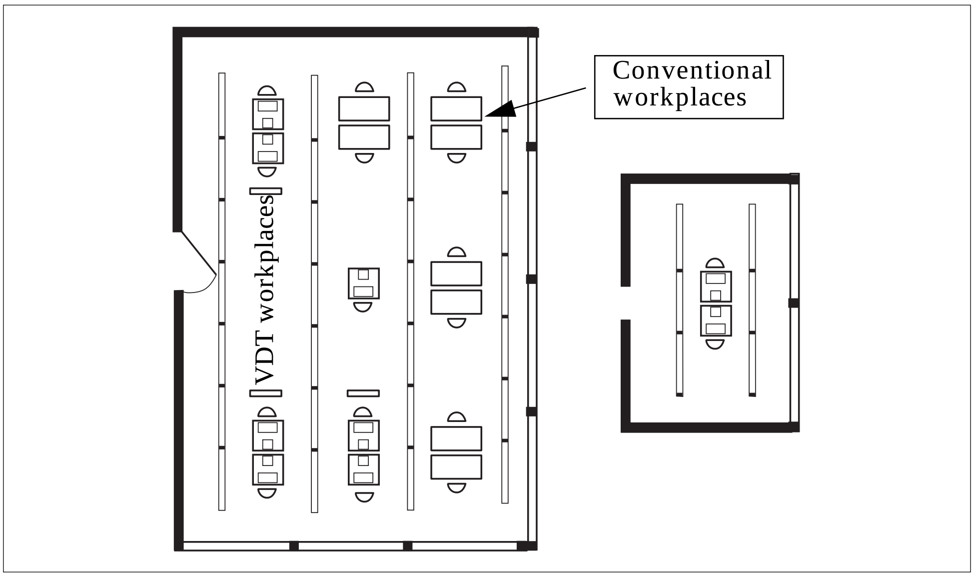
Tab. 10. 5 Some differences between the actual conditions in practice and the idealized representation of the cooperation between persons and groups involved in planning on the one hand and the lighting engineer on the other

Lighting planning in theory ...	**...and in practice**
The client decides that lighting is utilized according to the tasks.	The client leaves lighting in architect´s care ant the architect passes the planning task to the electrical engineer. Careful planning by lighting consultants is limited to some big projects. In addition, while planning speculative buildings, the client does not know the task. In leasing offices the client knows the future office user but still plans the lighting according to his own interest
The architect coordinates efficient cooperation of the parties involved.	The architect has to battle to harmonize conflicting interests of the consultants and engineers (e.g. acoustics, lighting, air-conditioning) and to keep the costs within the budget.
The office organizer outlines the visual tasks for the different rooms and parts of the rooms.	The office organizer does not know which office machines will be brought in in the next 5 - 10 years and therefore cannot predict the visual tasks.
The consultant for occupational medicine formulates relevant knowledge to be considered by the lighting engineer.	The consultant for occupational medicine has to consider DIN 5035 which has been formulated without decisive influence of her / his profession. She / he cannot formulate recommendations in contradiction to DIN 5035 part 2 as this standard is legally binding.

The persons involved in the decision making process have only a limited degree of freedom, especially as currently in most cases new lighting installations are not planned for new buildings, but rather for refurbishing projects, in which the scope of possibilities is even more restricted than in new constructions

In order to pursue individual plans, and to develop an improved concept with respect to minimum standards, the practitioner in the company would at least be obliged to master the contents of all relevant norms and to determine the necessary improvements for the particular case at hand. In addition, she / he would have to justify any such improvements vis-a-vis the client. This turns out to be extremely difficult, especially in view of the fact that for new office lighting, which is generally designed for VDT work, not only one, but rather two norms exist at once. According to DW 5035, part 7, this practitioner would have to know which VDUs will be used in which room, since the necessary properties of the lighting depend on the properties of the screens - diagonal, curve of the tube, inclination, etc. Furthermore, if she / he takes the norm seriously, the engineer will be obliged to place VDT workstations on the inner side of the room only (Fig. 10.2). *(Note the pictures included stem from the draft of DIN 5035 -7 they have been changed or left out according to need without any change to the lighting concept..*)

Fig 10.2 Recommended arrangement of VDT workstations in large and small work rooms respectively (DIN 5035 Part 7, draft; *the left figure has since been altered and the right one deleted.*)



What is supposed to happen to the rest of the room if the company intends to, or even has to, install only workplaces with VDTs? In practice, work rooms with the amount of open space shown in these pictures unfortunately do not exist; one would rather have to speak of a general lack of space. In addition, other factors such as cost development, i.e. rent prices for office space, do not promise to alleviate the problem - much the contrary. Besides, nobody wants to work in this - classroom - arrangement. It should be added that the new VDT-luminaires no longer provide a form of distribution of lighting intensity that would ensure the optimal avoidance of reflected glare for this arrangement of the workplaces (Fig. 10.3). These luminaires illuminate the workplace surfaces with a lower illuminance level than those surfaces were no workplace is supposed to be located. If the arrangement shown does have a scientific basis, then the lighting cannot be general lighting as it does not create equal visual conditions at all points of the room which, according to DIN 5035 Part 1, it should.

The actual reasons for the now apparent discrepancy between (lighting technological) theory and reality, which confronts all those involved, lie in the development of lighting technology which was sketched in Chapter 9 and which has taken little notice of existing office layouts, as well as in the absence of any coordination between the norms for lighting on the one hand and for building construction on the other.

10.3.2 Formulation of the Problem from the Point of View of the Organizer

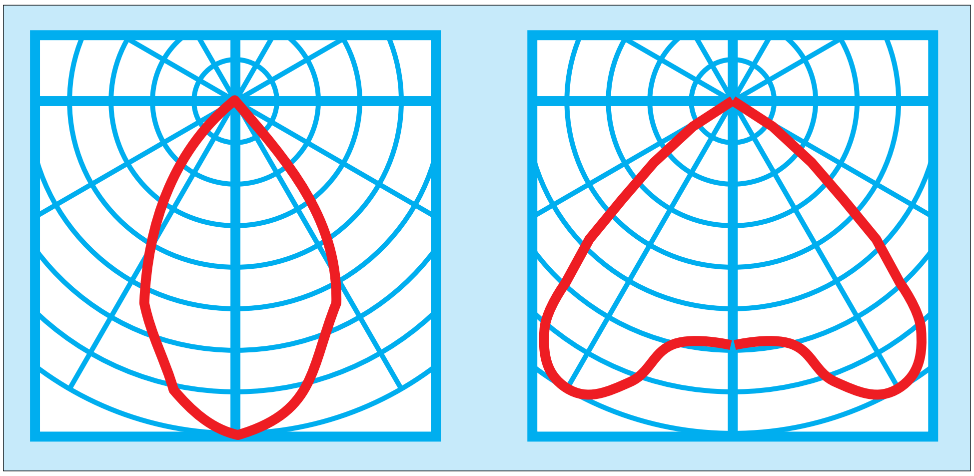
In practice, the organizer is not only charged with solving the lighting problem, but is also forced to deal with a whole array of problems. Thus there exists a broad gap between the required model solutions and the model provided by the lighting norms. This gap results from the following demands and facts, which will discussed below in more detail:

- variability in the positioning of workplaces
- combined desks with angled worksurfaces
- dominance of technology in office design
- shortage of office space
- differences in lighting needs of individual workers

Variability in the positioning of workplaces

For approximately one decade, office technology and design have been subject to an unprecedented development which has led, among other things, to the necessity of a variable arrangement of workplaces according to organizational requirements. It is

Fig 10.3 Difference between the distribution of luminous intensity for BAP-luminaires on the one hand and the appropriate distribution for avoiding reflected glare on the other (both from the same producer catalog)



BAP-distribution

“Batwing-distribution”

not possible to determine from the beginning who will work individually and who will work in a team, and a solution, once it is found, is unlikely to remain in place for ever. Therefore, there is only a slim chance that any limitations imposed on the positioning of workplaces by external factors will be implemented in practice.

Consequence : Even if the organizer arranges the workplaces in a way that is favorable, i.e. in compliance with the norms, as far as lighting is concerned, yet unfavorable for the work process, the employees will re-establish the “order” they desire.

Combined desks with angled worksurfaces

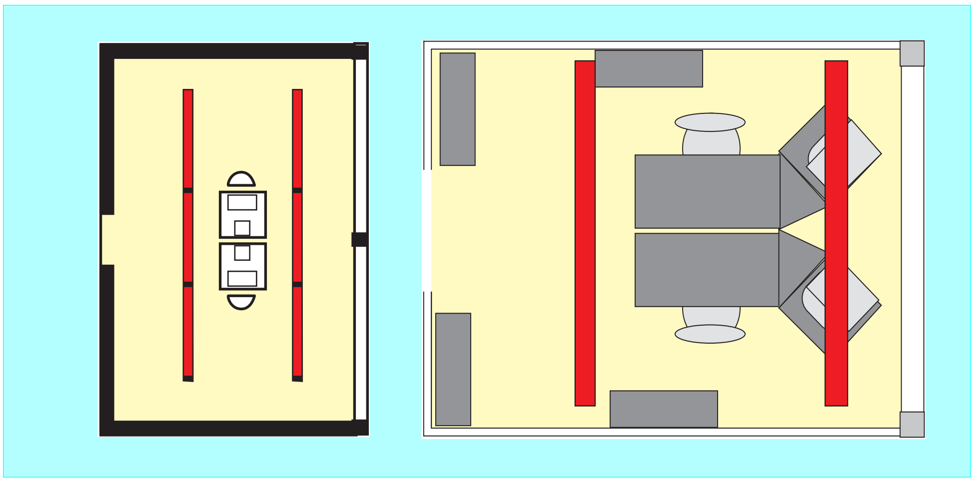
Workplaces are no longer equipped with desks with standard sizes only, worksurfaces can be interlinked and expanded even underneath the luminaires. The arrangement shown in Fig. 10.2 is therefore nothing but theory for many work rooms. This was already so, before the norms for the illumination of VDT workplaces came into force.

Consequence : Even a lighting installation that is planned in accordance with regulations cannot guarantee that workplaces are in fact located and used were they should be.

Dominance of technology in office design

Among other things, the endeavor to integrate modern technology into old buildings also means that the supply of power- and data-network-lines for the workplace cannot always be assured in the desired fashion. With few exceptions, workplaces are generally arranged as shown in Fig. 10.18 on the right and supplied from the window side. If workplaces were indeed arranged as stipulated by the norm, the cables would either have to be left dangling in the air or require a cable bridge. In addition, there are only few rooms in office architecture that correspond to the dimensions represented in the norm; most rooms are narrow and deep, so that only the chosen few with a lot of space could relate to this picture. Realizing this, the “solution” shown in this figure was removed from the standard leaving the question of the recommended layout still unanswered.

Fig 10.18 Recommended arrangement of workplaces in standards (DIN 5035 Part 7, draft) in comparison with usual layouts (right). Work rooms with proportions of the room in the left of the figure are very seldom, the use of workstations with such dimensions is limited to data entry. In theory, such tables do not comply with other German regulations.



Consequence: The lighting of office rooms cannot be implemented in accordance with the recommendations of lighting technology. The string of luminaires in front of the window hangs above the screens and causes glare on the keyboard at least.

Shortage of office space

Office space is sparse and expensive. Consequently it must be used efficiently. Since the basic (company) standards for office spaces have not changed over the past three decades, while desk surface has increased by at least 30% in average, the orientation of workplaces according to lighting circumstances is a luxury which only a few can afford. Large-scale administrations are even trying to reduce available surface space even further. In the near future, the shortage of office space will increase rather than decrease.

Consequence : The well-meaning propositions in the norm have no chance of being generally implemented. Though they are correct, they lack a connection with practice.

Differences in lighting needs of individual workers

The norms attempt to determine illuminance in a way that will maximize the number of satisfied users. As has already been mentioned, however, this applies only for those with normal eyesight. This procedure is basically appropriate, but it does not represent a possibility for satisfying individual needs. Theoretically, however, such a maximization can never satisfy more than 70%. This is a figure that is generally valid for any process of optimization, where it is necessary to calculate with 15% dissatisfaction on both ends. In other words, an "optimally" adjusted parameter, such as illuminance or room temperature will be too high for 15% and too low for another 15%. This leaves approximately 30% dissatisfied at workplaces which employ approximately one half of the working population. This figure is unacceptable, since among some 20 million office workers in the Federal Republic of Germany, this amounts to 6 million people! Indeed, according to the results of the present study, the number of those who were dissatisfied with the lighting situation was higher than only 30%. Theoretically, this, too, can be explained, since approximately one half of all those working in offices does not have normal eyesight, and the eyesight corrections have not been optimally carried out in a substantial number of cases.

10.3.3 Conclusions

The above remarks show that there is a broad gap between the demands arising from practice and the possibilities that are offered as solutions. In practice, the positioning and use of workplaces depends on many criteria (see fig. 10.5), though only rarely on lighting. In the majority of all workplaces this results in unfavorable visual conditions. This, too, provides an explanation for the degree of dissatisfaction with the lighting situation.

The disturbances to health and well-being that were described in chapters 5 to 7 could have been established theoretically as well. They have conceptual reasons, being caused, among other things, by the lack of individualization of lighting. From an ergonomic point of view, the course of action connected with the concept of general lighting would be adequate only if an individualization cannot be introduced, or if it has other negative consequences in practice. Room temperature, for instance, cannot be individualized in a shared room. Given the impossibility of individualization, it is ergonomically wrong to adjust a concept to the needs of the group which is least concerned, in this case the group with normal eyesight. Rather, the standard should be constituted by those who are most strongly affected.

In general, there are no factual constraints that impede or even prohibit an individualization of workroom lighting; this is only the case in some parts of the working world, such as industrial halls, workplaces involving shift work, etc. In the case of office work, the existence of such factual constraints is generally to be negated.

10.4 Statements on Illuminance at the Workplace

The workplace investigations foregrounded the question, which level of workplace illuminance would be the most favorable from an ergonomical point of view, and whether this figure corresponded to applicable norms, after all on of these is a legally binding directive for work areas.

Despite the intensity with which this question was pursued, an unequivocal answer could not be found. Among other things, this is due to the fact that figures measured in existing installations differed widely from one another in practice, and hence could not be evaluated. The expectation that some decades after lighting norms came into effect, one should encounter a situation in which at least some values could be calculated correctly, was not fulfilled.

Thus, even in projects in which we had formulated the lighting specifications and subsequently measured the actual values in practice ourselves, we were confronted with situations such as the following:

13. In a large company, approximately 1,000 rooms in 30 German cities were to be equipped with one and the same type of luminaires according to the guidelines of DIN 5035. When the installation was completed, it turned out that the average original illuminance values on the worksurfaces varied between 350 and 950 lx, rather than lying at the preset value of 625 lx, which is derived from the nominal illuminance of 500 lx plus a planning margin of +25%.
14. When comparing illuminance values of lighting systems which were installed by different producers at different sites, yet following the same specification - nominal illuminance of 500 lx according to DIN 5035 - we measured values between 300 lx and 1,700 lx for the newly installed systems.

These experiences suggest that even after a prolonged development, current methods for the calculation of lighting measurements are less precise than the methods used for weather forecasts, and that consequently they cannot constitute the necessary basis for scientific investigation. We have to leave open the basic question concerning the value of a directive for occupational safety and health when the most important and the most easily implemented value in lighting technology, namely illuminance, can only be realized with such a degree of imprecision. One possible explanation for the fact that practitioners do not detect this problem is the irrelevance of the illuminance as a quality criterion for office work.

Despite these reservations concerning the methods for calculating lighting parameters, our investigations in phase 1 do already yield a result: if the quality criteria for lighting are respected and reasonably applied, artificial indoor lighting cannot have illuminance levels which are *"too high"*. The assessments of workers who consider the lighting of a given room to be *"too bright"* or *"too dark"* do not correlate with the illuminance at their workplace; rather, they are generally associated with an unbalanced distribution of luminance within the room, i.e. the wall and ceiling surfaces appear to be too dark whereas the working materials seem too bright, or vice versa.

As was shown in the research project of the Federal Institute for Work Safety entitled *"Instrument for the establishment of ergonomically necessary illumination at the workplace"* (Krochmann and Kirschbaum, 1983), the specifications for illuminance in DIN 5035, part 2, which, as has already been cited, form the basis of legal requirements (Directive 7 / 1), lack a scientifically based foundation:

"These investigations show that it appears sensible to establish the range of values for luminance and illuminance which can be considered optimal for actual workplaces, in order to create optimal conditions for better, more humane working environments by taking into account the aspect of pleasantness."

Based on the results of our study, this statement can only be confirmed. Krochmann's and Kirschbaum's suggestion has yet to be put into practice 14 years after its publication.14 years is a long time to put right a proven lack in the basis of a norm work even if it is by no means easy as even in the design stage, illuminance, which is the easiest value to measure in lighting technology, already causes problems.

10.5 Case Studies

In the following section six case studies are presented, each highlighting a specific problem.

10.5.1 Case Study No. 1:

What is the Benefit of Increased Illuminance?

This case study was intended to investigate the effect of increased illuminance. As becomes clear in the following description of the conditions under which the investigation was carried out, changes in illuminance are coextensive with a number of other changes. 130 female workers participated in this study. More detailed information on this cast study can be found in the literature (Çakir, 1979).

Investigated Effect: The influence of illuminance on fatigue and on disturbances to well-being for illuminance values of 500 lx and of 1,000 lx for equal tasks at equal VDUs.

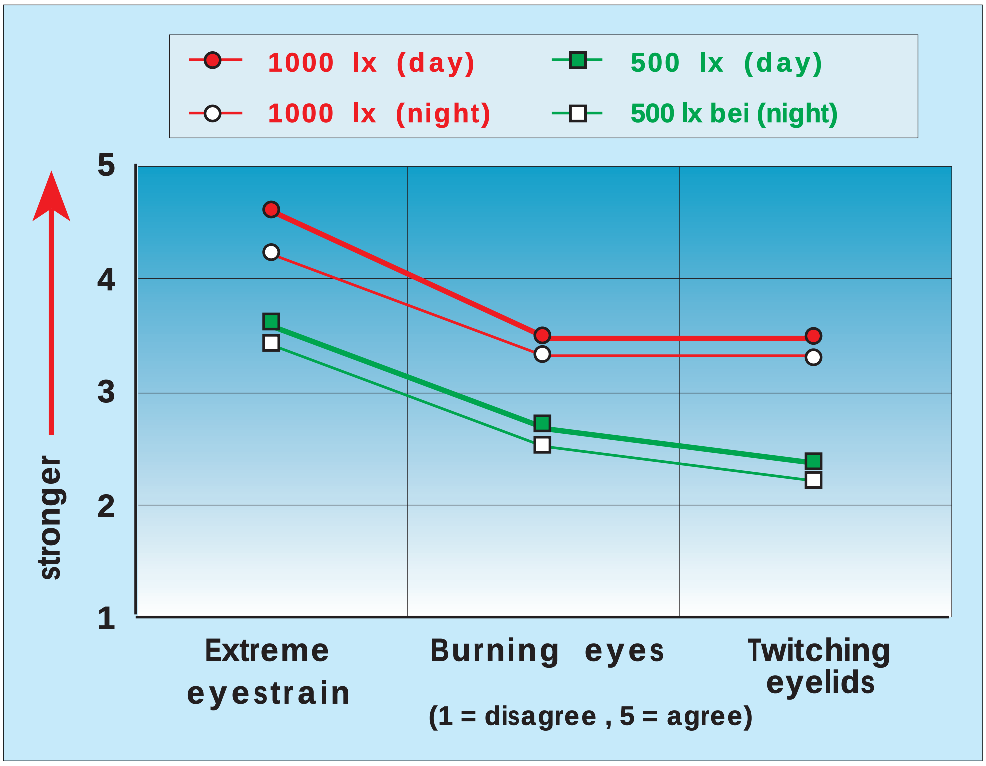
Marginal Conditions: The work rooms were of different dimensions, the 1,000 lx system was installed in an open-plan office and involved the use of *"dark-light" lu*minaires. In this room, direct glare was avoided completely. The systems with an illuminance of 500 lx were installed in two group workrooms with 25 workplaces each; integrated ceiling luminaires with diffusing covers were used. From the point of view of quality criteria in lighting technology, the daylight rooms differed favorably from the open-plan office as far as shadowiness and glare by reflection were conceded, though the values for direct glare were less favorable. Under daylight conditions, reflections were distinctly visible on the screens, and contrast was reduced. The ceiling was dark in both rooms, especially in the open-plan office, due to the strong glare reduction in the design of the luminaires. In this room, the luminance of the visible luminaire surfaces below 45° lay at approximately 50% of the luminance of the remaining ceiling surface.

In both cases, the investigation was carried out both by day and by night; this was facilitated by the existence of a late shift.

We expected a much more favorable evaluation, and a more favorable effect on performance, for the very costly illumination of the open-plan office, which created no direct glare and no reflected glare on the screens, since in addition, it facilitated improved readability of the working documents. Perfect legibility of the working material at the tested workplaces, was very important, as those working there sometimes had to type very old and hardly legible documents into the computer if possible with no mistakes. The demands on visual ability were extremely high.

Result: Visual stress was very great, and far greater at 1,000 lx than at 500 lx under both daylight and night conditions (Fig. 10.4). The pleasantness of lighting was almost identical for both installations. Only the comparison of the results for daytime and nighttime differed (Fig. 10.5).

Fig 10.4 Visual impairments for equal work and equal tools at 1,000 lx and 500 lx, respectively. At night, the evaluation is slightly more favorable.



The investigation of the subjects performance revealed that it was greater in the daylight room. Persons working in this room felt less tired after work than did those who worked in the open-plan office at 1,000 lx.

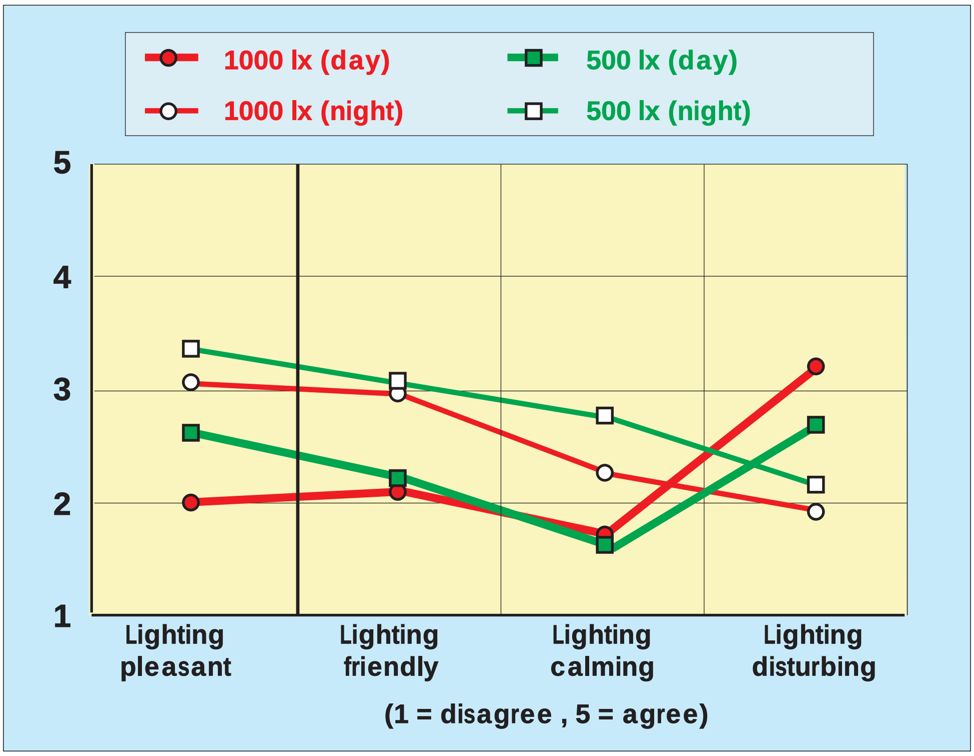
Conclusion: This case study demonstrates that the increased illuminance level has a tendentially negative effect on visual stress, although the opposite was expected on account of the extremely high visual demands.

Where differences in pleasantness were found, **they could** not be traced to the investigated effect, but rather to daylight. The most probable reason for this circumstance is presumably the dark ceiling in both rooms, which reinforces glare from the windows during the daytime.

10.5.2 Case Study No. 2:

What is the benefit of glare reduction by means of polished metal reflector louvers?

Fig 10.5 Pleasantness of lighting for 1,000 lx and for 500 lx. Lighting with 1,000 lx tends to be judged less favorably than lighting with 500 lx. Both are judged more favorably at night than during daytime.



This case study was carried out in an open-plan office with conventional office work. A lighting installation by ceiling-integrated luminaires with opaque-white louvers was evaluated, and this assessment was compared to an evaluation by the same subjects of a new lighting installation with improved glare reduction. The glare reduction characteristics were similar to those of BAP-luminaires. The reason for the replacement of the old installation was the glare produced by the luminaires, which remained, however, within the limits set by the glare limitation curves. 38 persons participated in the study.

Investigated Effect: The influence of the luminaire type.

Marginal Conditions: None changed; the only difference between the working situations consisted in the altered characteristics of the lighting.

Result: The survey, which was conducted three months after the installation of the new lighting system, yielded no noteworthy differences between the evaluation of the latter and the evaluation of the original lighting system which had received an unfavorable evaluation. Over the course of these three months, as well as during the following months, however, many workers moved their workplaces around because they felt disturbed by the luminaires above their workplaces. Given the glare limitation curves of our norms, such a disturbance should not occur. Even one year after the installation of the lighting system, the workers complained about the feeling that *“the ceiling was falling on their heads”*, due to the now very dark ceiling.

Conclusion: Although the replacement of the lighting system did adapt the installation to the 1983 state of the art of available lighting technology, the situation of the workers was not improved. The effect of the reduction of direct glare was apparently annulled by the deterioration of other quality criteria.

10.5.3 Case Study No. 3:

What is the benefit of improved glare reduction for luminaires in cellular offices?

In this study, the lighting system of an 8 person cellular office was replaced by a similar installation as in case study no. 2. The old lighting consisted of ceiling mounted luminaires with diffusing covers, whereas the new installation used BAP-luminaires which complied with the requirements of DIN 5035, part 7.

Investigated Effect: The influence of the type of luminaire in cellular offices.

Marginal Conditions: None changed; the only difference between the working situations consisted in the altered characteristics of the lighting.

Result: Even though illuminance on the work surfaces was doubled, all those involved complained that the room had now acquired a “bedroom atmosphere.” The room appeared to be darker than before, since the walls and the ceiling were now much darker. Here, too, the moving of chairs and desks ensued, because of the “glare” of the luminaires. Even one year after its installation, the new lighting system has not been accepted by the workers.

Conclusion: In cellular offices, a positive effect of narrow angle luminaires cannot be demonstrated; on the contrary, the effect appears to be negative.

10.5.4 Case Study No. 4:

How precise are planning methods of lighting technology in practice?

This case study was intended to demonstrate that the above-mentioned flaws can be eliminated by means of careful planning. This is the study which was already mentioned in the section dealing with “Statements on Illuminance.” This case was premised on the assumption that due to the substantial volume of the order, planning was conducted with especially great care.

The result of the study is based on measurements that were carried out in approx. 1,000 rooms (cellular offices with up to 4 persons).

Investigated Effect: Demonstration of a positive change in the evaluation of lighting as a result of careful planning.

Marginal Conditions: The plans were devised by different planners within the supplier's company. The rooms were of different heights and widths.

Result: We refrained from questioning the subjects, since the planners did not even comply with the planning instructions, which had been described in great detail. Here, too, the above-mentioned bedroom effect occurred. This case did have one side effect, however: according to the contract, the supplier was obliged to provide additional equipment at his own expense for all those rooms in which illuminance remained insufficient by terms of the standards. Six years after the installation, the workers were reported to be still unhappy with the visual conditions.

Conclusion: Apparently, flaws in lighting are not only determined by the technology itself, but also by unsuccessful planning.

10.5.5 Case Study No. 5:

When is glare reduction by means of narrow angle luminaires beneficial?

In this case study, large rooms with an area of appr. 100 m^2 and with ceiling heights ranging from 2.75 m to 3.5 m, as well as small rooms with heights between 2.6 m and 3.2 m, were equipped with BAP-luminaires with louvers for 60° and 50° glare reduction. All rooms received daylight and were adequately protected from the sun. In the small rooms, the lighting was installed according to the projected positioning of the workplaces; in the large rooms, the workplaces could be arranged favorably with respect to the lighting. 120 persons participated in the survey.

Marginal Conditions: The lighting could be planned relatively freely. The positioning of the workplaces could be adapted to the arrangement of the lighting.

Result: In the large rooms, an appealing room impression could be created with both types of louvers, when the ceilings were higher than 3.2 m. In these rooms, the questioning that was carried out approximately one year after the workers had moved in showed a much better assessment than in the small rooms. In both cases, however, the evaluation was more favorable than in the previous case studies. The subjects' judgements reveal no differences for the different degrees of glare reduction.

Conclusion: From the point of view of the worker, the favorable positioning of the workplaces has a demonstrable effect on the evaluation of the lighting itself. In the places where the conditions of the norm can be kept to, the illumination is more positively judged.

Luminaires with narrow luminance limit angles are appropriate for high and large rooms, in which their improved glare reduction becomes effective.

10.5.6 Case Study No. 6:

What is the use of new lighting concepts?

In this case study, the three lighting concepts which are described below were tested in small office rooms; out of these three, the two systems which proved to be more favorable were subsequently installed in a large number of rooms. The first of these concepts was a modern version of the *"BAP-luminaires"*, the second a so-called *"CRF-luminaire"*, and the third was a *"2C-lighting"* with indirect luminaires and task lighting which complied with ergonomic requirements.

The three concepts were chosen for the following reasons:

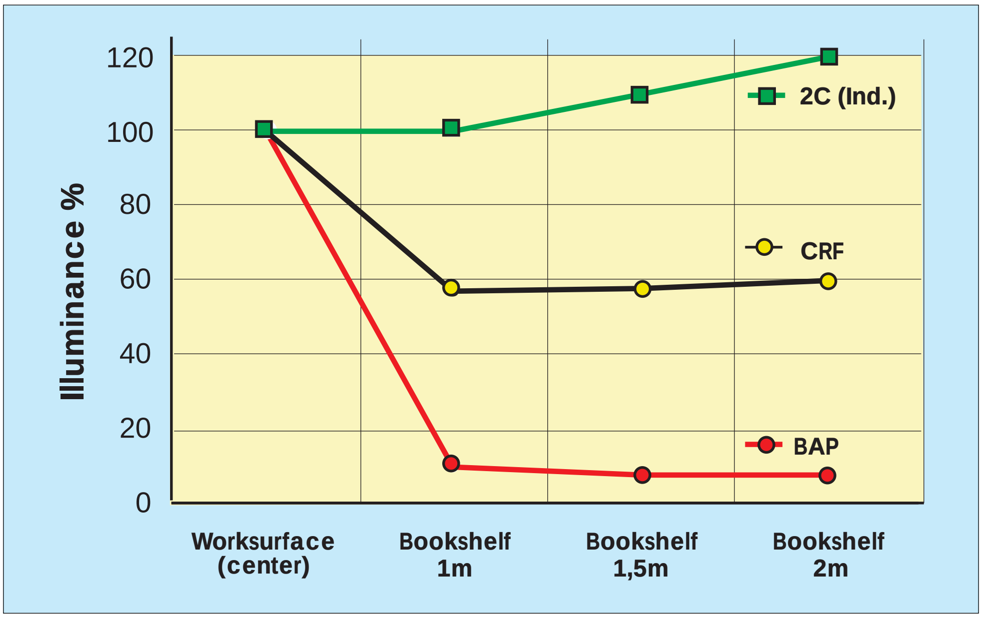
- The CRF-luminaire is a luminaire which supposedly creates no reflected glare even under unfavorable conditions for the positioning of the workplace. CRF stands for *Contrast Rendering Factor;* the term is used to indicate that this concept is characterized by an improved rendering of contrast.
- The 2C-lighting was realized in part with the help of standing luminaires, and partly with wall-mounted luminaires.
- The BAP-luminaires that were used fulfilled, and still fulfill, the requirements in the norms.

Investigated Effect: Influence of the lighting concept.

Marginal Conditions: The rooms had ceiling heights which are unfavorable for lighting (2.5 m to 2.7 m). Given the overall area of the room, the work surfaces were extraordinarily large; they were equipped with the most diverse office machines. The rooms are equipped with shelves that were used quite frequently.

Result: In the preliminary phase of the study, the lighting with BAP-luminaires was abandoned, since the room acquired a somber appearance due to the unfavorable distribution of luminance on the walls. This distribution can be calculated by means of Fig. 10.6 which shows the distribution of illuminance on the room surfaces. Even when the walls had high reflectance values, their luminance was less than 10% of the luminance of the tables, while the shelves full of files appeared even darker.

Fig 10.6 Distribution of illuminance on room surfaces in % of the value on the work surface (*Note: The distribution depends also on room characteristics. Therefore, this figure cannot be generalized.*)



The illuminance which was produced by the CRF- and 2C-luminaires was practically identical at all points of the work surface (angled desk combination), whereas the illuminance of the BAP-luminaire was irregular (relationship minimum : maximum = 1:2).

The respective preferences of the different users for one of the two other concepts presumably can be attributed to room conditions rather than to the properties of the lighting systems themselves. In those rooms in which the walls were covered by shelves, CRF-lighting was preferred, in all others the 2C-lighting was preferred. In both cases, however, the users decided to use the task lighting. (*Note: the experiences of those concerned must have brought about lasting effects according to the latest reports in the daily press about a newly finished building where they were able to influence the lighting.*

Downlights were installed as general lighting and task lighting in addition to this. The press were informed that the former was only to meet the norm requirements and the latter were used regardless of this.)

Despite the adverse room conditions which prevailed in the field of this study, both concepts encountered a high degree of acceptance, even if only after a relatively long period of adjustment, which lasted several months. Given the long-term experience with the above and other case studies which are not described in this report, the acceptance was unexpectedly positive, thus providing grounds for the hope that with the help of these concepts the health disturbances described in this study cannot only be eliminated, but indeed that the positive effect which is intended by the norms can in fact be achieved.

Yet, the result of this case study cannot simply be generalized, since this is a study that involved a substantial amount of consulting activity; as a rule, this does not hold true for common practice. For a generalization to the effect that a certain concept is generally better than others, all objects of comparison must be planned and installed under equal conditions (for generalizable results see Chapter 11).

10.6 What is *New* in New Lighting Concepts?

Having established that over the last decades, lighting technology has undergone constant changes, without resulting in a positive trend as far as its acceptance is concerned, we now would like to illustrate what is new in the concepts that were last mentioned and pursue the question of whether the new also contains the promise of improved quality.

Though today's light sources are not new, they are different. Fluorescent lamps continue to dominate the market for office lighting; however, important developments have taken place. We did not investigate whether or not the fluorescent lamp itself presents a disturbance to health, since there are not enough workplaces with alternative types of lamps for such an investigation to be actually feasible. Moreover, the futile debates on this question among experts are as old as the fluorescent lamp itself, and current contributions to the debate have nothing new to add from a methodological point of view either.

What is indeed new, however, is the following qualitative characteristic: Flickerfree fluorescent light became standard technology due to the development of fully electronic ballasts. Though critics had pointed to flicker as the cause of a multitude of impairments, experts in lighting technology expressed their doubts concerning this causal nexus despite that the connection between flickering and headaches had already been proven in the 80‘s. Today, it is precisely these experts who use the arguments of the earlier critics for the purpose of convincing the users of the advantages of such ballasts.

The CRF-luminaire concept does offer a new quality, in the following respects:

- It permits limited, though sufficient, variability in the arrangement of workplaces.
- When a number of desks are grouped together, the qualitative characteristics remain approximately equally good for the thus enlarged work surface; in particular, contrast rendering, even for glossy objects, is of comparable quality at all points of the workplace.
- If it seems beneficial, for whatever reason, to position a workplace in the vicinity of a window, this does not necessarily entail a deterioration of visual conditions.
- This type of lighting has already proven to be valuable under conditions of great shortage of work space, and one should expect even more positive effects under improved conditions.
- The situation does not change for workers with different lighting needs.
- The room impression is improved, rooms appear brighter and especially larger and more spacious than under conventional types of lighting.
- Vertical surfaces, i.e. filing cabinets and shelves, are lit with an illuminance comparable to the illuminance for horizontal work surfaces. The lighting thus provides for two utilizable workplanes for visual work.

The list shows that this new concept meets the requirements of humans working in offices. Given the fact that it also corresponds to new organizational demands in essential respects, this type of lighting can be described as advantageous, according to current knowledge.

The 2C-lighting concept, with two separate sources for the proportions of direct and indirect light respectively, also offers a new quality of lighting:

- Variability in the positioning of workplaces is practically independent of lighting.
- When a number of desks are linked together, the qualitative characteristics remain approximately equally good for the thus enlarged work surface; in particular, contrast rendering, even for glossy objects, is of comparable quality at all points of the workplace.

- If the technology used at the workplace, or the workers themselves, suggest a position close to a window, this is not necessarily connected to a deterioration of visual conditions.
- This type of lighting has already proven to be valuable under conditions of great surface shortage, and one should expect even more positive effects under improved conditions.
- For workers with different lighting needs, the situation is greatly improved thanks to the proportion of direct light from task lighting. Wherever necessary, it is now possible to achieve relatively high illuminance levels on the work plane.
- The room impression is improved, rooms appear brighter and especially larger and more spacious than under other types of lighting.
- Vertical surfaces, i.e. filing cabinets and shelves, are lit with approximately the same illuminance as horizontal work surfaces. The lighting thus provides not only for one, but for two utilizable workplanes.
- It is possible to determine the direction of the light according to the respective visual task or to personal preference, without affecting other workplaces.

The changes that this lighting concept effectuates in the overall qualitative characteristics of lighting are shown in Table 10.2, which shows again that this is likely to be a new and better concept for the lighting of work areas.

Whoever is acquainted with the furnishing of rooms in other fields and with the role of light in interior design, or whoever has seen pictures of individually designed offices, will, without difficulty, notice the presence of a number of old design aspects.

The literature also suggests that the improvements which were established in our study should have been expected for conceptional reasons (Hartmann, 1982): *"For decades, prevailing opinion held that almost all lighting problems could be solved by means of good general lighting. Only a small number of experts resisted this opinion, pointing out that special task lighting does not only have a number of advantages in some special cases in the industrial field (e.g. machine luminaires), but that this is in fact true in general - even in the case of office lighting. Thus, in a physiologically correct manner, the working surface can be illuminated rather brightly, while the immediate environment is illuminated less strongly, and is therefore less bright. In addition, it is relatively easy to keep direct glare to a minimum, and reflected glare, too, can be controlled quite well by an appropriate positioning of the luminaire with respect to the working surface. The proportion of direct lighting which * thus achieved is still quite high and could never be obtained by general lighting alone....*

Not only from a physiological point of view, but also from a psychological and an economic standpoint, 2C-lighting is a system which is capable of recreating something of the individual character of the workplace precisely in larger rooms. At the moment, however, the broad implementation of this system is presumably still limited by the relatively high costs of the installation."

As can be seen in this quotation, the improvements which are demonstrated by our study were expected for physiological as well as for psychological reasons even in 1982, when the state of development of task lighting luminaires was still relatively unfavorable. What is different now, is that the costs of the installations is no longer prohibitively high, 2C lighting is establishing itself and furthermore task lights of a functional quality now exist, which Hartmann, could only have dreamed of at the time he was writing.

In Chapter 11 the results of studies are presented which were first thought up on account of the results already given in this chapter. The reasons for another examination of conclusively proved results has already been explained.

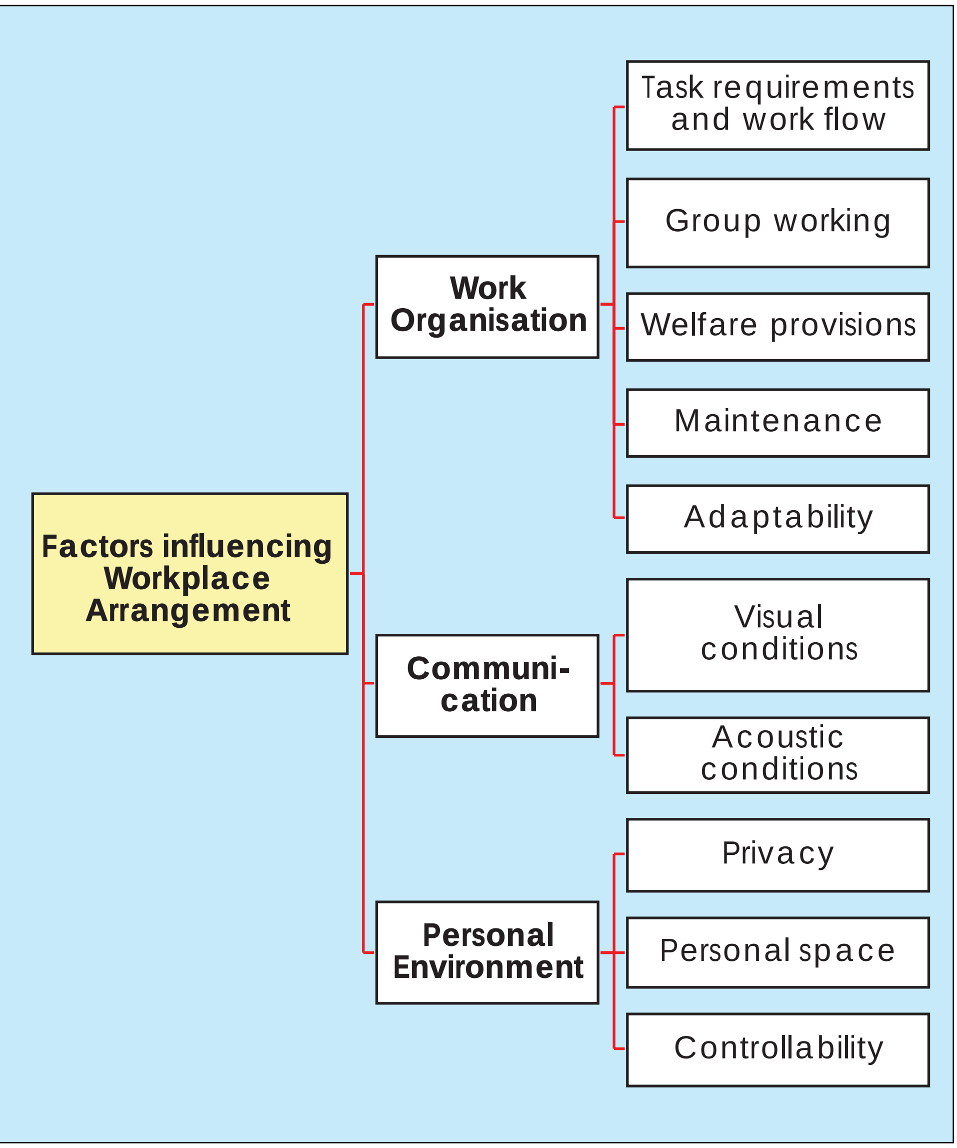
An additional argument for the experiment reported in Chap. 11 is shown in Fig. 10.7. The picture shows that visual conditions are only one factor among many and artificial illumination only constitutes a part of visual conditions. If we look closer at the points illustrated, it is easier to understand why the practitioners do not want to submit to the restriction of lighting technology and why they probably cannot. In any case, it would be possible to avoid potential disadvantages for workers by careful design. Exactly this point should be tested in the experiments described in Chapter 11.

Table 10.2 displays the benefits of "2C-lighting", in theory. The question is, whether these theoretical advantages will be experienced by the users, if so, whether the positive effects can be generalized.

Tab. 10. 6 Comparison of lighting quality for direct general lighting with one component and 2C-lighting, respectively

Criterion	General lighting, direct	2C-Lighting, indirect/direct
Illuminance on the worksurface	dependent of the workplace location and orientation	independent of the workplace location and orientation
	individual control limited to switch on / off	individual control on significant parameters
Luminance distribution in the room	unbalanced: Desktops too bright, ceilings and walls too dark	favorable: all surfaces with comparable luminances
Glare guarding	direct glare: effective only for inclined visual field	direct glare: effective in any direction
	veiling reflections: avoidable only by correct location of the workplace Avoidance of reflections on flat objects	veiling reflections: avoidable for most visual objects Reflection is also avoidable for 3D objects
Directionality and Shadowiness	light incidence depending on workplace orientation	light incidence partly under user control
	shadowiness to high if direct glare restricted	optimum shadowiness and restricted direct glare
Light Color	Nearly totally dependent on the lamps and luminaires.	Correctable by ceiling color
Flexibility of Workplace Orientation	extremely restricted	no restrictions

Fig 10.7 Grounds for workplace arrangement (ISO DIS 9241/6). Visual conditions constitute only one of many factors and artificial lighting is only part of the factor "visual conditions"



11 Comparative Study on the Influence of Different Lighting Concepts on Humans

11.1 Purpose of the Investigation

This part of the overall project was carried out between 1991 and 1996. The purpose of the study was to examine the influence of lighting systems which were expected to turn out better than in part 2 of the project. For this reason problematic installations were not chosen, rather those which were supposed to have a better level of acceptance. The choice was made according to the following criteria.

The working conditions in the rooms selected should not be problematic in respect to the artificial illumination. For this reason deep working rooms, where the real problem is the lack of daylight and not the qualities of the artificial lighting, were excluded from the experiment. Also excluded were workplaces for CAD use and others with micro film reading apparatus, as the visual load has more to do with the work tools.

The lighting installation should have come about only after a comprehensible design process which is common in everyday practice. The users should have worked under the lighting concerned for at least two months before they were questioned.

In addition, discomfort glare cannot occur in any of the rooms due to the dimensions of the room and the qualities of the lighting - in any case not according to the Söllner curves.

11.2 Method

11.2.1 Selection of Lighting Installations

The selection of the lighting installations was based on the data provided by the producers. We contacted the organizations in which the inquiry was to be conducted by mail, asking them to participate. In the case of some of the participants we were contacted by the companies and were able to cooperate in the planning of the lighting. In these cases (15 installations) it was possible to make sure that the design of the installations was done on the basis of DIN 5025 parts 1,2, and 7. The installation were put through a thorough technical examination in spite of this. The suppliers and planners were informed of this examination and its procedures in advance and were asked to fulfill the requirements of the norm.

The following exclusive criteria were used in the selection process:

Proper design of each installation

Industrial production and genesis common in practice. Exceptions to this include, for example, lighting of a room to create an impression of prestige, lighting of a room which is contrary to the wishes of the users, e.g. rented offices, offices in airports etc. and model installations which are not intended to become common practice.

Advice which does not exceed the normal measure. As the results showed in Chapter 10 intensive consultation in respect to lighting planning and room furnishing or arrangement can lead to a higher acceptance of the lighting and the results compiled were not the same as those, which the same technology would have received under normal circumstances. In addition to this, a possible positive result would only be valid until the next employees moved in or until the next rearrangement of the room.

No unfavorable room conditions which would reduce acceptance of the lighting. For example, cupboards which are too high, over populated and too narrow workrooms, room limiting surfaces which are too dark etc.

The agreement of workers´ representatives in advance.

As already mentioned, in the frame of a comparative study the following types of lighting systems were examined.

- Ceiling mounted lighting with BAP luminaires from different manufacturers.
- Semi direct lighting.
- CRF luminaires from various manufacturers and exporters
- Purely indirect lighting
- Optimized 2C lighting with a separate indirect and direct component indirect luminaires for room lighting and direct luminaires for task lighting.

Secondary luminaires could not be included in the study as the objects available seemed problematic at the first examination. One company which would have liked to have helped us in the study had illumination which was set up in such a way that workplaces could only be positioned a very few places in the room and even in these positions a four fold shadows were easily seen even in daylight. A further installation (as shown in figure 9.14 bottom right) where the whole ceiling serves as a mirror could also have been investigated. In this case it is possible to predict a negative result in advance, as the ceiling not only glares in all directions but makes every movement at the workplace and in the gangways visible. In another case the workplaces and the lighting had to be coordinated as there was only enough illuminance in the center of the desk. For every alteration to the workplace the lighting had to be mechanically adjusted. All this does not constitute a major negative factor which is reason enough to reject secondary luminaires. It is in fact possible to create unusable systems with every kind of illumination. For this reason we see the other luminaires of this kind, which we have seen, as positive in concept.

11.2.2 Theoretical Advantages and Disadvantages of the Investigated Types of Lighting

This passage describes the theoretical advantages and disadvantages of the investigated types of lighting. It should be pointed out that the number of positive and of negative characteristics yield no indication as to the quality of a given type of lighting. So it is theoretically possible that a single positive criterion can form the basis for preferring one type just as much as a single negative point may justify a complete rejection. The user is therefore advised not to try to calculate the pros and cons against each other rather to produce an overall rating under the conditions of the room.

There is no type of lighting which is recommendable in all circumstances just as there is none which can be generally dismissed. For this reason it will be stated for each kind of lighting under which circumstances it can be recommended.

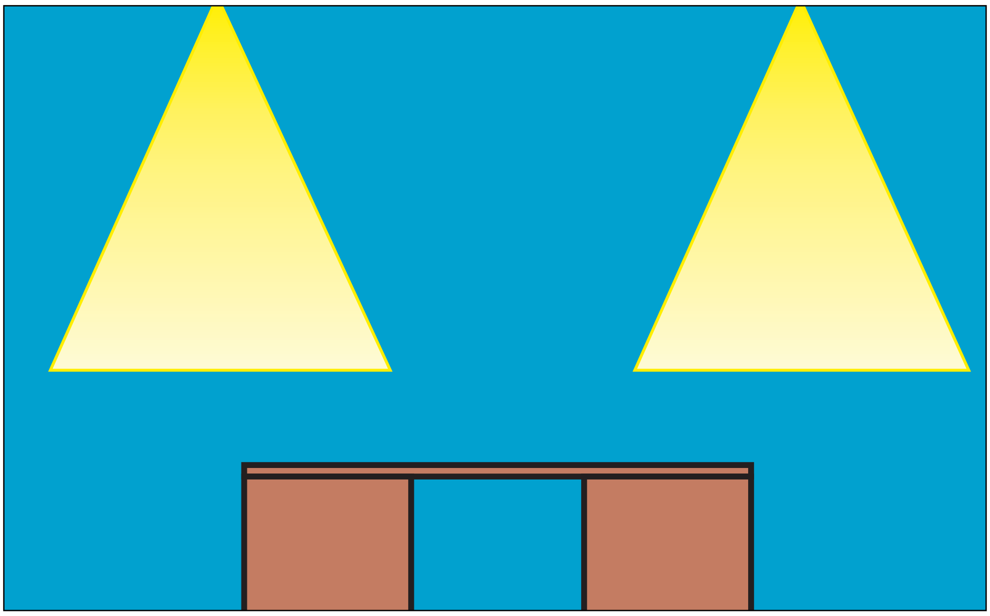
Ceiling Mounted Lighting with BAP Luminaires

This form of lighting uses luminaires with polished reflector grids and a narrow angle distribution characteristic; the luminaires approximately correspond to an elongated spotlight (seeFig. 11.1). This system is recommended for rooms with an internal height of over 3 m, where all working materials are matt and the workplaces can be arranged in a formation assumed by lighting planning.

The particular characteristics of this type of lighting are as follows:

+ limitation of direct glare
+ good illumination effect of the work surfaces
+ good illumination of office landscapes under high ceilings
- strongly directed light, uniformity strongly dependent on the height of the room
- room divisions partly too dark because of large distances between luminaires
- low luminance values in the areas of walls and ceilings
- marks of light distribution curves on the walls
- visual disturbances when glossy working materials are to be used
- glare on glossy working materials
- high planning investment
- lack of flexibility, i.e. limited possibilities for the positioning of workplaces and especially
- adaptability to individual sight difficult or impossible

Fig. 11.1 Schematic representation of illumination with BAP luminaires. The entire luminous flux emitted by the luminaire is directed onto the working surface.



(2) "Semi-direct lighting"

This form of lighting uses reflector grid luminaires with narrow angle characteristics in the lower hemisphere, and wide angle characteristics in the upper (see Fig. 11.2.

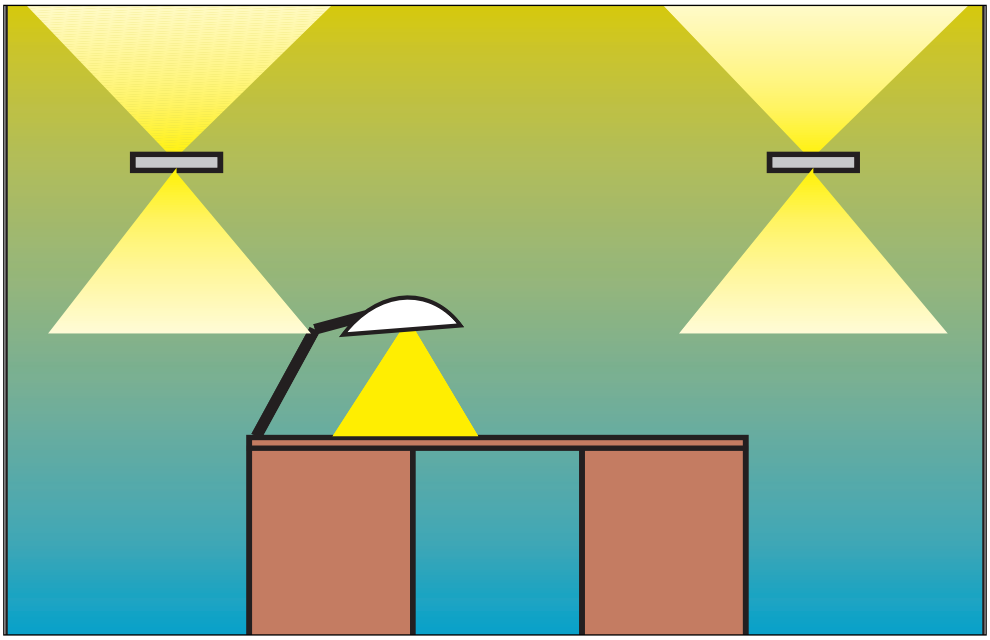
This system is recommended when

- the entire room is to be lit "evenly";
- there is no necessity for individual control of a second component (at the workplace);
- the suspension length (distance between the ceiling and luminaire) can be selected for adequate diffusing of the incident light and creating acceptable luminance values on the ceiling

The particular characteristics of this type of lighting are as follows:

+ good illumination of shelf surfaces and cabinets
+ good limitation of direct glare
+ reduced glare disturbances
- limited flexibility
- reduced interior room height

Fig. 11.2 Principle of semi-direct lighting. Some proportion (< 30%) of the luminous flux is radiated towards the ceiling yielding a proportion of 20% diffuse illuminance. (The task lighting is optional and is not part of the concept)



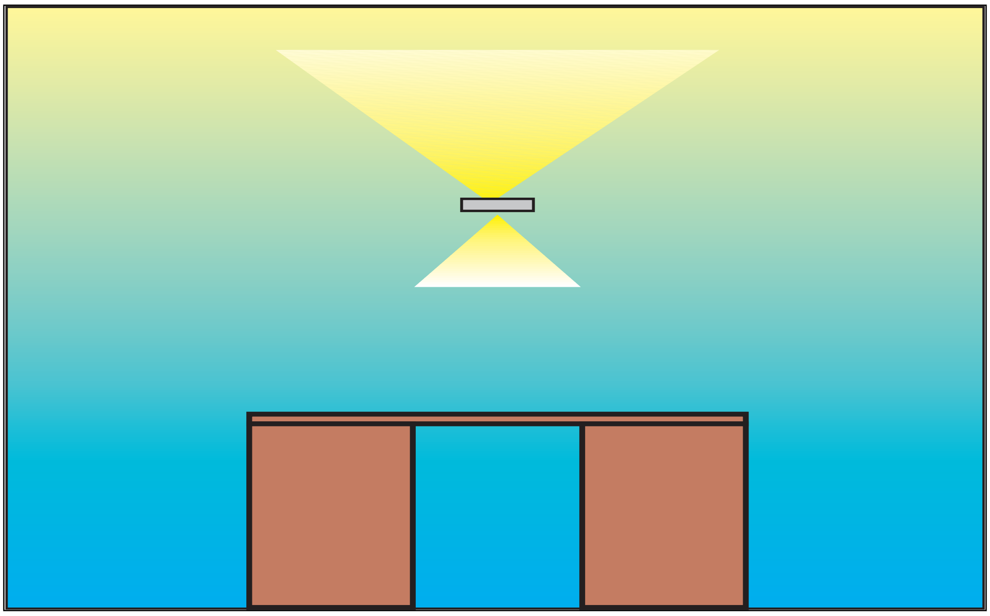
(3) "Semi-indirect lighting"

In this form of illumination, luminaires which have an indirect luminous flux of more than 50%, are mounted on the ceiling or at the workplace (Fig. 11.3). The direct component is produced by the same luminaire, however the luminance is reduced by the correct optical measures until no direct glare, disturbance from glare by reflection or reduction of contrast occurs - even if the luminaire is over the workplace. The luminaires can be mounted on the ceiling, on work orientated furniture or on stands. With some products the indirect / direct ratio can be adjusted or controlled individually.

This kind of illumination is necessary for a great many purposes. Its special characteristics are:

+ good zonal illumination for rooms the purpose of which is known beforehand, practical for cellular offices.
+ relatively independent of ceiling height and room dimensions
+ good contrast over the entire working surface
+ glare and reflection are avoided on screens and horizontal lying objects
+ even luminance on vertical surfaces
+ flexibility in terms of rearrangement of workplaces
+ high acceptance
- bright and solid ceiling necessary

Fig. 11.3 Principle of indirect-direct lighting with CRF luminaires. More than 60% of the luminous flux is emitted indirectly.



(4) “2C-opt.” - Two-Component-Lighting” Ceiling, Wall and Workplace mounted as well as Free-standing

For this purpose, indirect radiating luminaires and localized lighting are used; both components can be mounted at the workplace, although this need not be the case.

This system (see Fig. 11.4) is recommended when

- a system is desired which can be adapted to different work tasks and to individual preferences;
- lighting is to be adjustable by individual workers according to their needs;
- there are always some workplaces which are not in use due to the absence of certain workers;
- economic viability is required;
- luminaires are to be (and can be) integrated into the furniture
- a high degree of acceptance is desired.

This lighting has the following characteristics:

+ Lighting can be coordinated according to the respective activities (zone lighting at different illuminance levels)
+ avoidance of glare and reflections on screens and horizontally placed objects
+ balanced luminance on all vertical surfaces
+ flexibility for changes in size and / or orientation of workplaces
+ well-lit wall surfaces for the use of wall shelves and containers
+ high acceptance
+ easy replacement of the entire lighting system
+ easy hook-up in floor- or furniture sockets
+ easily adjusted to the visual ability of the individual
- requires bright, solid ceilings

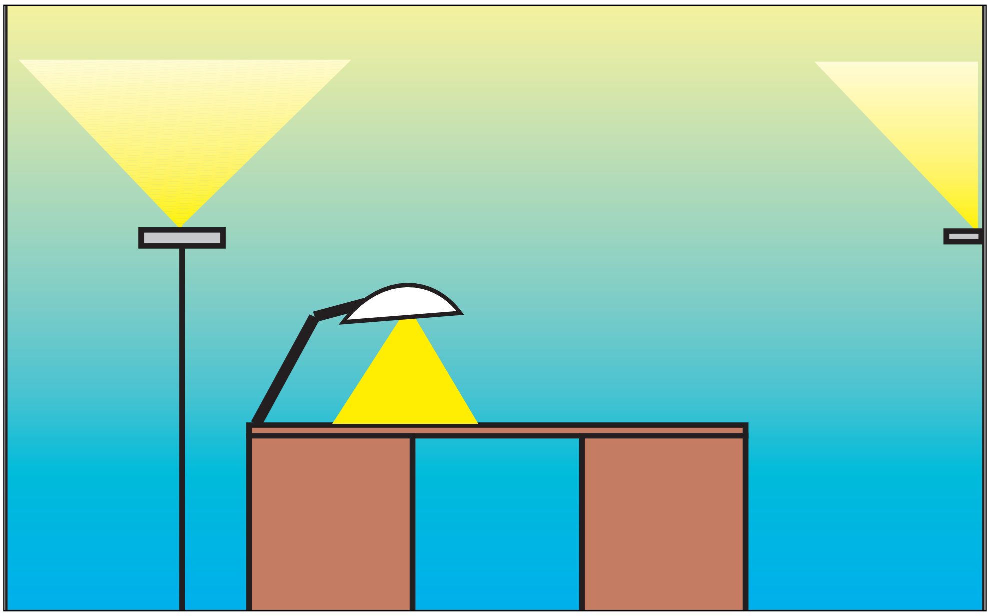
(5) “Indirect Lighting” Ceiling, Wall and Workplace Mounted

This form of lighting uses indirect radiating luminaires, which are directed towards the ceiling or towards the walls. This system is recommended especially when shadowiness should or must be reduced, e.g. for highly glossy objects.

This lighting has the following characteristics:

+ diffuse light, hence no glare disturbances
+ no direct glare as long as the ceiling luminance is not too high (i.e. over 1000 cd / m^2)

Fig. 11.4 Principle of two-component lighting with separate luminaires for direct and indirect illumination. Task light is part of the concept.



- illumination with few shadows, due to the absence of a second component emitting direct light.
- high luminance at the ceiling if a high illuminance level is needed
- adjustment to individual visual ability possible but complicated
- relatively high wattage, and hence increased temperatures in the room.

11.2.3 Technical Investigations

Measurement of Illuminance

The measurements for the lighting installations were carried out according to DIN 5035, part 6. For practical reasons, this norm indicates two different measurement procedures for empty and for furnished rooms, respectively. Empty rooms, or sections of rooms, are to be measured according to a definite measuring grid (DIN 5035, part 6, fig. 2). In rooms with tall articles of furniture, however, such a measurement would not give any usable results. For this reason the measurements should be made in selected places, for example workplaces. According to the Workplace Ordinance 7/ 3 the measurement should be made at the place of activity; in the case of a desk this is where writing takes place. This method is also used by State Inspectors of Safety.

Since the investigation alone was not sufficient for the evaluation of the existing workplaces in respect to the norms and rules, measurements were made in all positions that they would be, if one takes the norms and regulations as a basis. The measurements were made in by dividing the room into a grid of 1x1m and measuring in each square and at the workplace (each time at three different points). If the measurement at a certain point was unreliable due to the shadow cast by a high article of furniture it was not taken into consideration when calculating the mean value.

All kinds of lighting (with the exception of those belonging to the concept of task lighting) can be sensibly measured in this way. The illuminance given off by task lighting could not be determined by earlier measurements. This has been possible since May 1994 when the norm DIN 5035 Part 8 gave a measuring order. These correspond to the recommendations contained in research report of the Federal Institute for Work Safety: "Recommendations for Measurement of Lighting Installations" (see Krochmann and Lindemuth 1989), where the basis for measuring task lighting was also established. The illuminance measured in this way is not, however added to the value of nominal illuminance, as a universally accepted method for calculation does not yet exist.

The measurements were carried out with an illuminance meter from PRC Krochmann Lichtmesstechnik Berlin. The measuring instrument was calibrated for these measurements by the producer.

Measurement of Degrees of Reflectance

The degrees of reflectance of the wall and ceiling surfaces, and of the furniture were measured by means of a reflectance measuring sphere produced by LMT, Berlin. It is possible to calculate the degree of reflectance of surfaces to within a 2% margin with this special instrument.

Measurement of "Cylindrical" Illuminance

The measurement of this value serves the purpose of determining shadowiness. The measuring surface for this value is not even but rather corresponds to the curved surface of an (imaginary) cylinder - hence the name. The idea of this measurement is that the vertical illuminance is measured all the way around a certain point which is then put into ratio to the horizontal illuminance at the same point. From this, a measure of shadowiness can be obtained, which can then be used as a measure for modeling objects - such a faces. From this value it is possible to roughly estimate how great the contrast rendering factor is at a certain point. This quantity itself can only be accurately measured in a laboratory.

The measurements were carried out by means of an illuminance meter with a special measuring head from LMT, Berlin and corresponds to DIN 5035, part 6.

Measurement of Luminance

The measurements of luminance were carried out according to DIN 5035, part 6, which stipulates that representative workplaces and the direction they are facing must be determined. The measurements must be made at the position of an imaginary eye. This point was laid down as 500 mm above the edge of the desk (the eye level of the theoretically smallest person in an upright position).

For this study, workplaces at each end of the respective rooms were selected, and from here the following luminance values were measured:

- visual object (white sheet of paper in the middle of the desk)
- maximal and minimal luminance of the ceiling
- ditto for the walls in the main line of sight
- ditto for the visible parts of the floor.

The luminance measurements were made with a Topcon luminance meter.

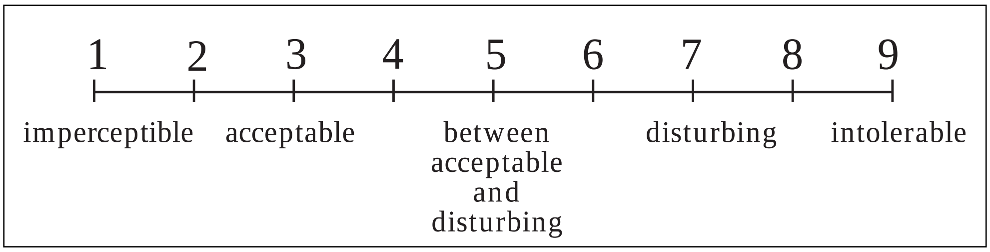
11.2.4 Questioning

The questioning was carried out in the users' workrooms during working hours with the help of the same questionnaire as in phase 2 of the project. The instructions of the questionnaire were modified where necessary after consultation with the respective company.

In one part of the project it was possible to obtain not only evaluations from the users of the room, but also from other company employees who were able to briefly acquaint themselves with the particular lighting. They were only asked to assess the pleasantness of the illumination and the sensation of disturbance as these were the only values they could judge reliably, but not to indicate potential consequences for their well-being.

The subjects were also asked to rate discomfort glare according to a scale which has been in use in lighting technology for a very long time. (Fig. 11.5, Çakir, 1975).The rating on discomfort glare took place during dark hours in winter avoiding an influence of the daylight.

Fig. 11.5 Scale for rating discomfort glare (Çakir, 1975)



11.3 Comparative Evaluation of Optimized 2C-Lighting and Overhead-Lighting with BAP luminaires

11.3.1 Objects of Comparison

The objects of comparison belong to the *“direct lighting” with BAP luminaires* type (Object 1) and to the *“2C-opt.”* type (Object 2). *“Object 1"* consists of four slightly different installations, which were equipped with VDT luminaires. The rooms were small (less than 10 persons each). All rooms had windows. The individual evaluations of these lighting systems showed no significant differences, which legitimizes considering them together. Evaluations from a total of 80 subjects were taken into consideration for “Object 1".

“Object 2", by contrast, consists of two identical systems, which had been installed in two equally large rooms of one and the same company. The number of subjects here was 28.

Differences between the objects which are relevant from the point of view of lighting technology consist in the mean illuminance in the rooms, the distribution of luminance in the visual field, shadowiness, reflected glare, and others.

On average, “Object 1" produces higher illuminance values (> 500 lx) than “Object 2" (appr. 400 lx). The differences of luminance in the visual field consist especially in the fact that due to system characteristics, the ceiling luminance lies at maximally 30 cd/m^2 for Object 1, and at less than 400 cd/m^2 for Object 2. Shadowiness, calculated from the relation of cylindrical illuminance to horizontal illuminance, lies at less than 0.30 at every second workplace in Object 1, averaging appr. 0.3, whereas in Object 2 shadowiness is always more than 0.40, and 0.45 on the average. From this last figure it can be seen that the range of values was very narrow.

Furthermore, the latter value shows that common expert opinion, claiming that indirect lighting leads to entirely shadowless lighting and hence to an unpleasant working situation is not applicable.

With respect to “discomfort glare”, which was measured according to applicable norms, both systems were identical, since by definition they were supposed to cause no discomfort glare at all. For Object 1, the rooms would have been too small for discomfort glare to arise even if luminaires with inferior shields had been used. In the case of Object 2, all visible surfaces lay below a maximal value of 500 cd / m^2, thus making glare highly improbable.

According to applicable norms, “Object 1" should represent the most favorable lighting for VDT-workplaces. It produces higher illuminance values (in any case if the task light for Object 2 is not included) and the luminance of the ceiling, which could be reflected on the screen, is less. In addition to this, no task lighting, which was considered problematical for VDT-workplaces, was installed. The only advantage that could be expected from Object 2 was a better ratio of cylindrical illumination to horizontal and a better contrast factor. The latter is irrelevant if all the working material is matt.

11.3.2 Results of the Investigation

The results of the investigation are in clear contradiction to the theoretical expectations which one would develop on the basis of expert opinion: Object 1 (direct lighting) is neither more pleasant, nor does it cause fewer sensations of disturbance. Instead, it turns out that the evaluation of a lighting installation by the users runs counter to expectations: to a statistically significant extent, “2C-lighting” is not just more pleasant than Object 1, but was evaluated as pleasant in itself and this did not depend if the questionees worked in a conventional office or at a VDT workstation (see Fig. 11.6 and Fig. 11.7). The same holds true for sensation of disturbance (see Fig. 11.8 and Fig. 11.9).

Fig. 11.6 Comparative assessment of pleasantness of direct lighting and “2C-lighting” at VDT workplaces

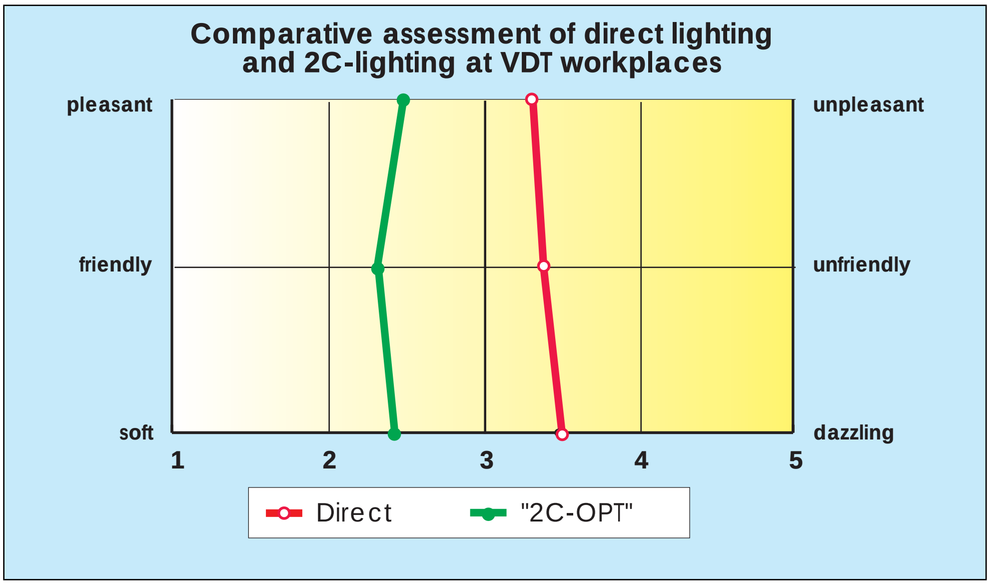


Fig. 11.7 Comparative assessment of pleasantness of direct lighting and “2C-lighting” at conventional office workplaces

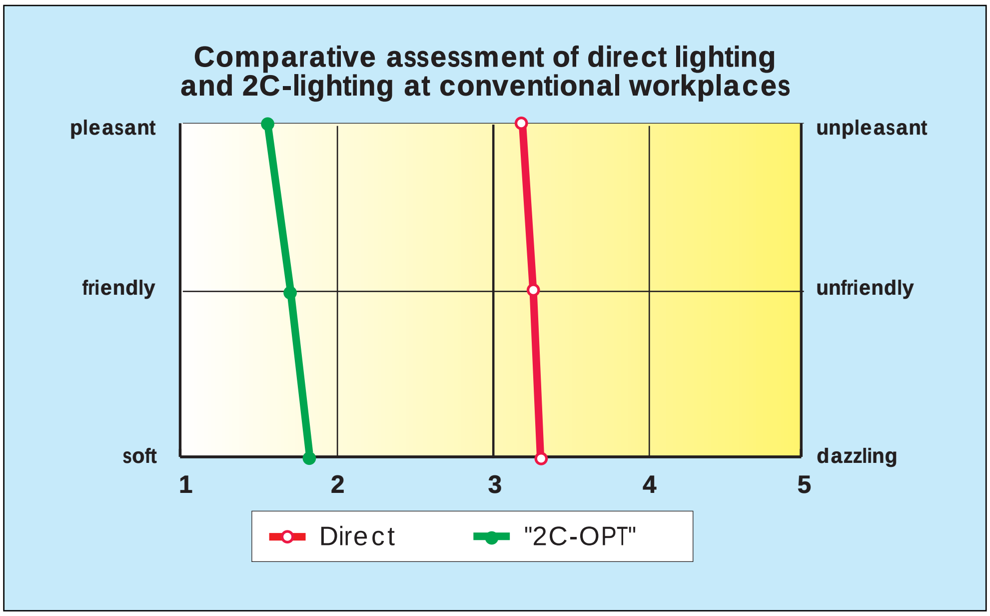


Fig. 11.8 Comparative assessment of disturbance caused by direct lighting and “2C-lighting” at VDT workplaces

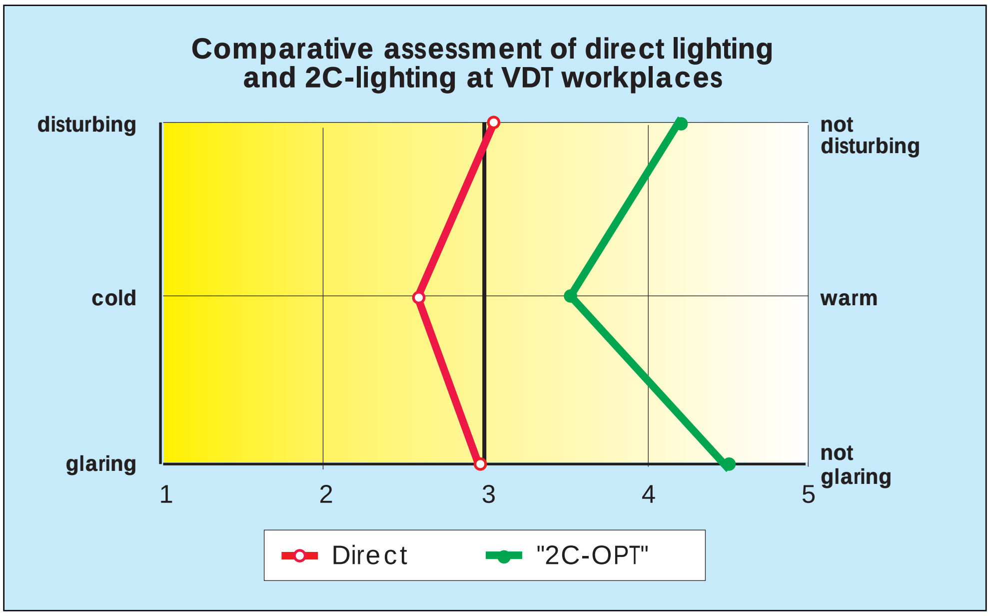
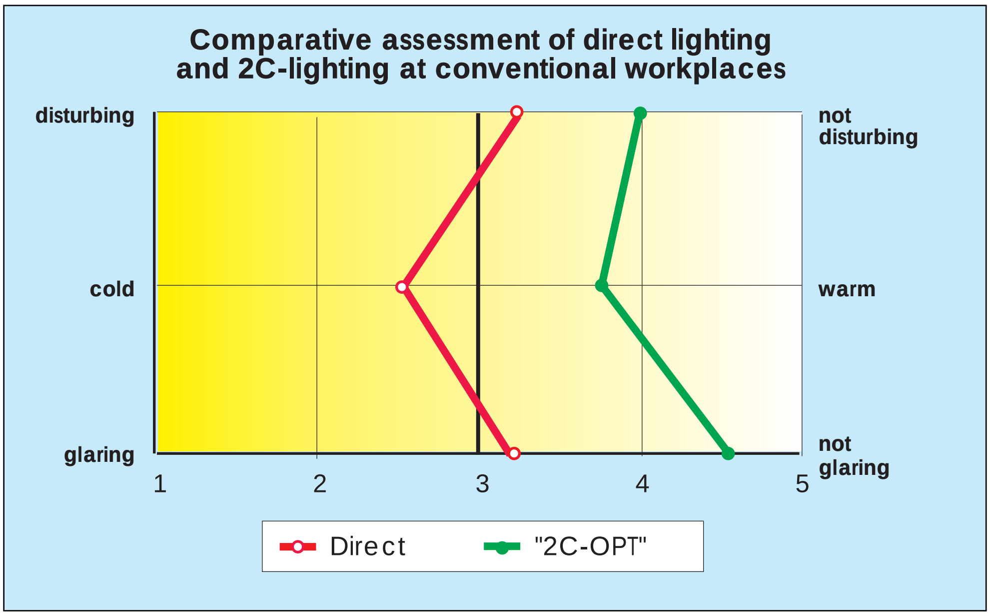


Fig. 11.9 Comparative assessment of disturbance caused by direct lighting and “2C-lighting” at conventional office workplaces



As far as subjective evaluation of the lighting situation is concerned, “2C-lighting” is far superior to the object of comparison. The question arises, however, whether this preference is also reflected in the strain caused to the users. This is by no means self-evident, given the results of phase 2 of the project, where the table lamp, which was felt to be the “*most pleasant*” type, also turned out to cause the most strain in any case the users had more health complaints than any of the other subjects.

In this case, however, the evaluation of the “*pleasantness*” and the “*sensation of disturbance*” caused by a type of lighting tends to correspond to the latter's effect on health and well-being (seeFig. 11.10). Fig. 11.10 shows the result of this investigation compared to the result of phase two of the project for unspecified overhead lighting. The evaluation of VDT-lighting tends to be better than for conventional overhead lighting. The optimized 2C-lighting is significantly better than “VDT-lighting” in seven out of eight criteria.

The difference between the 2C lighting in part 2 - a combination of ceiling mounted lighting and the optimized 2C lighting is shown in Fig. 11.11. Health impairments with one exception (irritability) are less. In the case of six health complaints they are less to a significantly significant extent. This difference would have certainly been much greater if there had not been so many VDT operators (70% instead of 30%) in the sample group for 2C OPT.

This part of the study is significant in two respects. The first being, that one kind of artificial lighting which is in fact cheaper can reduce health complaints greatly. The VDT operators, whose visual load was always regarded as high, experienced less health impairments than those people working at a conventional office workplaces who were working under ceiling mounted general lighting. The second respect is that some complaints (for example “sudden fatigue“) were reduced so greatly that it is hardly possible to obtain better results in a questionnaire. This means that the criticisms levelled at florescent lamps are probably rooted in the lighting concept and not in the characteristics of the lamps themselves.

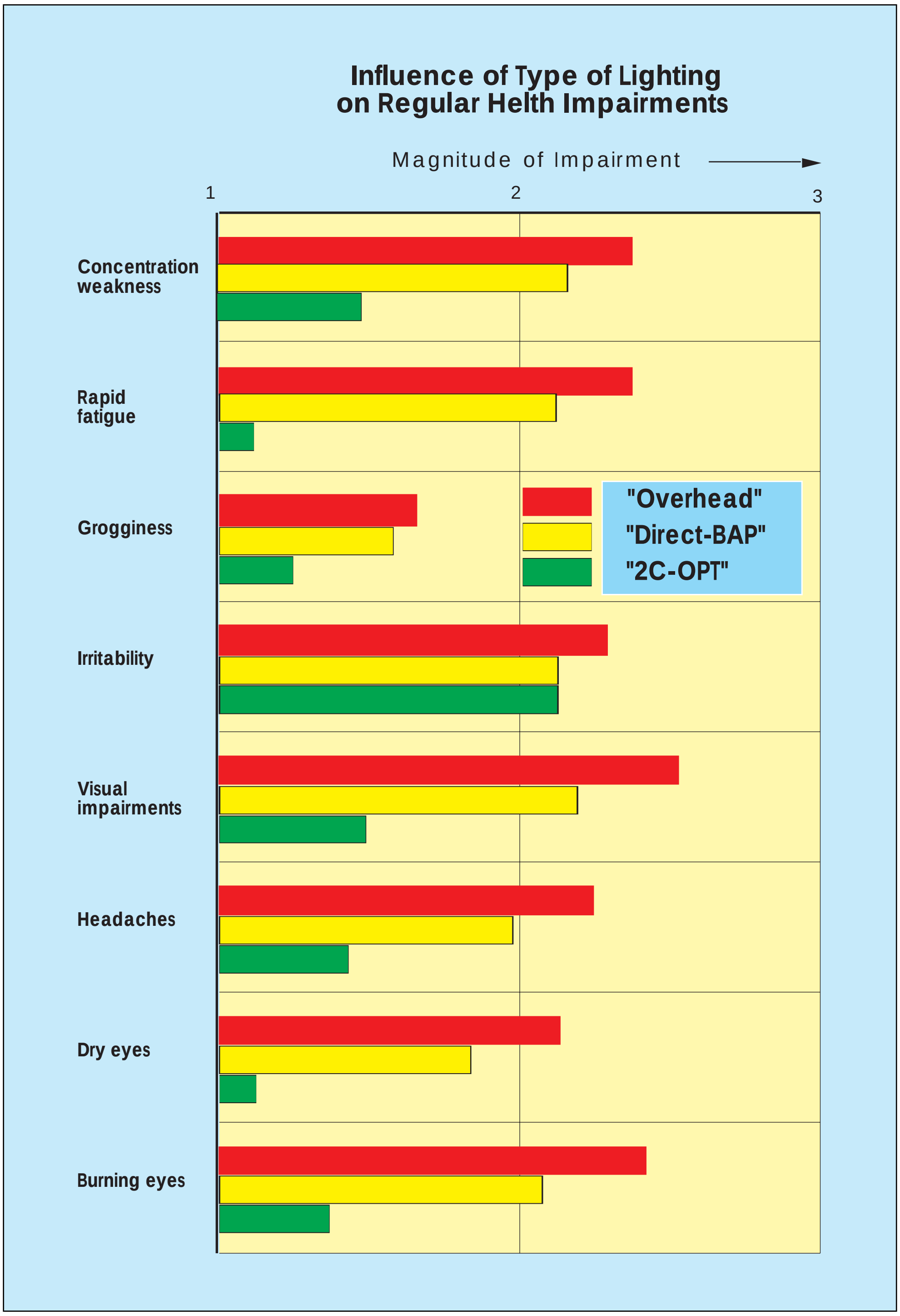
11.4 Comparative Study of Five Lighting Concepts

11.4.1 Objects of Comparison

The following concepts were realized:

15 general lighting from ceiling-mounted lamps with cut-off angles at 50° in connection with a maximum luminance of 200 cd/m^2 (“VDT-lighting”), two rooms (three installations).

Fig. 11.10 Reduction of health impairment through suitable type of lighting



16 same as 1., with an additional indirect component (“semi-indirect lighting”), five rooms.

17 workplace-oriented lighting with features for the maximization of the “contrast rendering factor”, so-called “CRF-luminaires” (“semi-indirect lighting”), two rooms.

18 Indirect lighting, two rooms.

19 Indirect lighting with task lighting - a concept with an indirect component in the form of general lighting, and a direct component in the form of task lighting. This type of lighting is characterized as “2C-Opt.” because it represents an optimized version of the 2C-type; one room.

The five objects of comparison correspond to the lighting types described in section 11.2. We studied 13 lighting systems which were installed in cellular offices with the same qualities in one building. The potentially important difference among the cellular offices consisted only in their widths and the number of workplaces. The systems were planned by different companies who were given instructions to install a lighting system in compliance with the norms of DIN 5035.

Since the investigation was carried out in furnished rooms, we had to work with some restrictions, the most important of which was the somewhat low degree of reflectance of the ceilings (approximately 0,7). This represented a handicap for those types of lighting which included a relevant proportion of indirect light. These installations would have attained a better evaluation with a brighter ceiling.

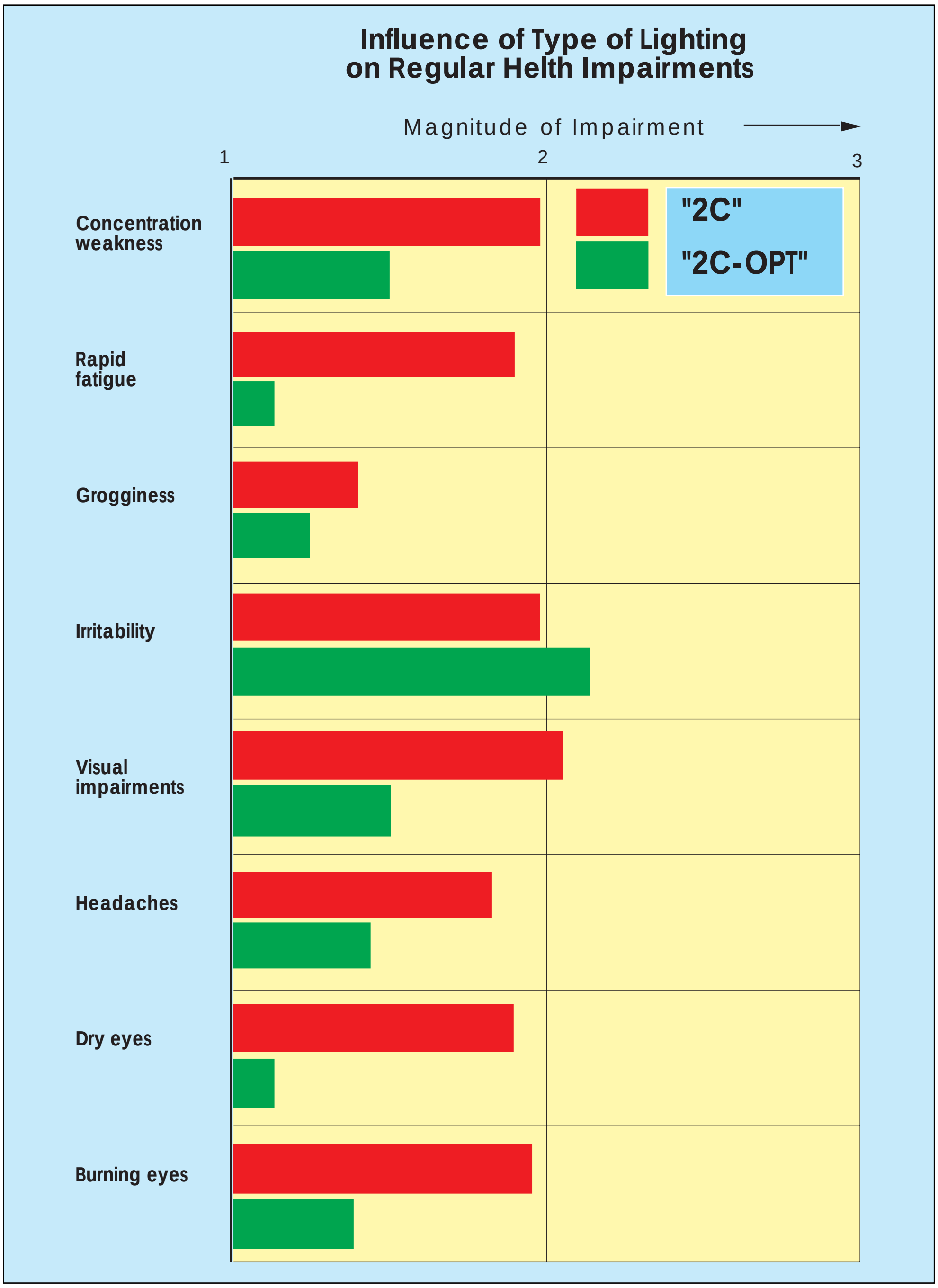
11.4.2 Results of the Technical Investigations

The results of the technical investigations are represented here inasmuch as they are relevant to the results of the study that are described below.

Illuminance

As can be seen in Table 11.1, only two of the lighting installations fulfilled the requirements for mean illuminance which, according to DIN 5035, part 2, must lie at >625 lx for the newly installed system. This value is derived from a target value of 500 lx, to which one must add a supplementary 25% (design factor). Even in the case of these two installations, the illuminance was not sufficient at the workplace as the illuminance was not only unevenly but also nonsensically distributed. As shown in fig. 11.12. The illuminance values were largely determined in parts of the room where no workplace should be placed. Further to this, in the positions where the workplaces should be placed according to the norms the illuminances were only 300 lx when the installations were new and this is reduced to 240 lx through ageing.

Fig. 11.11 Improvements through the optimization of a type of lighting



If we were to wait until the installation is only operating at 80% of the nominal illuminance the illuminance at the workplace would have sunk below 200 lx.

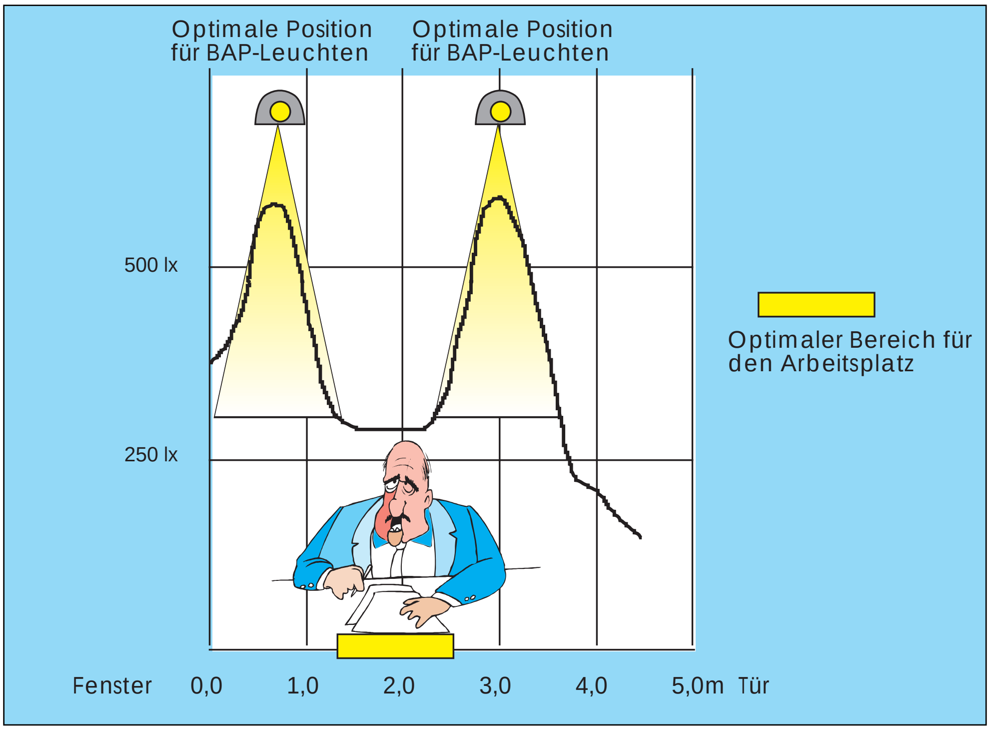
Tab. 11. 7 Average illuminance, uniformity of illuminance, and shadowiness for different lighting types

Type of Lighting	Illuminance (lx)	Uniformity	Shadowiness
VDT(1)	625	low	poor
VDT(1)	570	high	partly poor
VDT(1)	490	very low	acceptable
Semi-direct(2)	560	low	acceptable
Semi-direct(2)	590	low	partly poor
Semi-direct(2)	640	low	acceptable
Semi-direct(2)	480	very low	partly poor
Semi-direct(2)	433	very low	partly poor
Semi-indirect(3)	410	medium	good
Semi-indirect(3)	330	high	good
Indirect(4)	330	high	acceptable
Indirect(4)	225	medium	acceptable
“2C-OPT”(5)	240	very high	very good

It was established that even within the scope of one type of lighting, extremely different values of illuminance, distribution of illuminance etc. occur even when all of the designers had been instructed to comply with a certain norm. Although the aim of the concept of general lighting is to create the same visual conditions in all parts of the room the planners could not once manage to keep to the nominal illuminance in the course of this project. In one particularly notable example, the illuminance of the desk was 300 lx where the planned illuminance had been 500 lx.

The study also showed that determining the nominal illumination by calculation has very little to do with the illuminance found at workplaces in reality. The average value for concept 3 (CRF luminaires) is 410 lx or 330 lx (see table 11.1) The illuminance at the workplace was the highest with this concept and the effective illumination at the workplace was greatly higher than the illuminance attained with concept 1 where the average illuminance, determined by calculation, was between 490 and 625 lx.

Fig. 11.12 Distribution of illumination in the work room. The main part of luminous flux goes into room areas where according to DIN 5035 workplaces should not be placed.



By measuring throughout the whole room and neglecting the illuminance of the workplace concept 5 was put at a disadvantage. An additional value of approximately 700 lx must be added to the value of 240 lx already given, if a value of effective illumination is to be established, as the task lights could create up to a further 700 lx over a surface of 600mm x 600mm according to how they were set up.

The investigations of this part of the study back up one of the central statements of Chapter 10, namely that even the illuminance is not properly taken into consideration during planning. The fact that only two installations examined in this study reached a comparative ratio better than 1:1,5 (minimal value to mean value) speaks for itself. This is by no means merely coincidental to this project. It is possible to calculate, just from the manufacturer's information and taking the height of the room into consideration, that the necessary uniformity cannot be achieved in most rooms because they are too low. This leads us to the assumption that it was not a coincidence that the uniformity ratio of illuminance is no longer included in the norms of lighting technology.

(*Note Uniformity ratio of illumination should be reintroduced by the future European norm on lighting, but only within a certain zone and not for an entire room.)*

Shadowiness

Shadowiness, measured as the relationship between the cylindrical illuminance and the horizontal was very good with 2C OPT (type 5) and was good with indirect / direct luminaires. Surprisingly both of the installations with indirect luminaires (type 4) had unfavorable values that were no better than those of an installation with BAP luminaires. The semi-direct illumination did not show any better results than narrow angle BAP illumination.

The surprising result of indirect illumination can be traced to the fact that when it comes to real installations, there is only a small number of luminaires which can be installed in a room and in addition to this it is not always possible to arrange them correctly. The picture of shadowless indirect lighting which removes the plastic effect of objects and makes peoples' faces appear flat probably has its origins in theory.

Luminance Ratios

As mentioned in Chapter 9 luminance and its proportions are the most important values from the point of view of vision, while illuminance and reflectance are rather to be considered as values that aid planning. What results are obtained when an installation is commissioned which complies to all the norms and is supposed to create good conditions?

As can be seen in table 11.2 the values obtained were highly different. For example the luminance of a sheet of paper in the middle of the desk, i.e. where documents are usually read, can vary between 45 and 225 cd / m2, when speaking about all the installations in general. Even inside one room, the luminance can vary from workplace to workplace by a ratio of 1:3. In addition to this, luminance values which vary by a factor of three, can be obtained at the same place depending on the position of the reading material. All in all this reflects badly on the designers as luminance of reading material is the most important measure in respect to legibility.

Luminance in visible ceiling areas (measured from the habitual working positions between the horizontal and 60° above) ranged between 10 cd / m^2 and 1,400 cd / m^2, with the greatest irregularity found in one ceiling being in ratio 1:70 between lowest and highest luminance, the second highest value being 1:53. Interestingly enough, the former relation was measured for "semi-direct" lighting where the lowest ratio of 1:6 was also recorded; whereas the second was measured for an "indirect" type of lighting.

Tab. 11. 8 Luminance distribution in the visual field (Luminance 1= white paper in center of work area, L2= ceiling or visible parts of the luminaires, L3= walls)

Type of Lighting	Luminance 1 (cd/m^2)	Luminance 2 (cd/m^2)	Luminance 3 (cd/m^2)
VDT(1)	150 / 255	12 / 580	20 / 80
VDT(1)	78 / 217	20 / 700	20 / 100
VDT(1)	100 / 110	60 / 460	50 / 120
Semi-direct(2)	119 / 165	30 / 290	70 / 80
Semi-direct(2)	134 / 148	20 / 1400	60 / 110
Semi-direct(2)	138 / 235	30 / 350	30 / 350
Semi-direct(2)	140 / 170	50 / 280	30 / 150
Semi-direct(2)	175 / 180	20 / 300	30 / 75
Semi-indirect(3)	120 / 130	30 / 500	20 / 50
Semi-indirect(3)	65 / 80	30 / 300	15 / 100
Indirect(4)	75 / 88	10 / 530	13 / 40
Indirect(4)	--	--	--
“2C-OPT”(5)	25 / 60	30 / 420	30 / 55
VDT(1)	150 / 255	12 / 580	20 / 80
VDT(1)	78 / 217	20 / 700	20 / 100
VDT(1)	100 / 110	60 / 460	50 / 120

This implies that one should take great care in making judgements since lighting installations which are based on one and the same concept can apparently vary quite substantially in reality.

Luminance was more regular in the wall areas than at the ceiling; the most unfavorable relation lay at 1:12, the most favorable almost at 1:1, i.e. the whole wall had practically the same luminance.

Note: The measured results briefly mentioned here, as well as the usual pictures provided by the manufacturer, which originate from the planning programs were discussed in another form at various conferences. Lighting technicians who were present did not even want to believe that the were real. In one case the development director of a supplier dismissed one plan from his own company as nonsense.

11.4.3 Results of the Questioning of Room Users

Fig. 11.13 shows the evaluation of lighting types, representing the summarized assessments for *"pleasantness"* (scales of *"pleasant", "friendly"*, and *"soft")* and for *"sensation of disturbance"* (scales for *"disturbing", "cold"*, and *"glaring")*. The two curves are almost mirror images with respect to the middle evaluative position, i.e. the more pleasant a type of lighting is felt to be, the lower its disturbing effects. This nexus does not necessarily always exist; rather, it occurs when the disturbing effects of a given lighting installation are strong enough (see Çakir, 1975). Where disturbing effects are low, on the other hand, these two criteria represent independent dimensions.

With respect to the two evaluative criteria, the order of preference is as follows:

1. "2C-opt."
2. Indirect
3. Semi-indirect
4. VDT
5. Semi-direct

(**Note.**: *the evaluation of semi indirect lighting with CRF luminaires can be much better in practice as in this experiment, the luminaires used in this experiment have since been replaced by technically improved solutions. Nevertheless, this type of lighting received a notably positive evaluation when in spite of the technical deficiencies it still had at that time. (See case study 6 in Chapter 10).*

As far as the effects on health are concerned, the order of preference is slightly different, as can be seen in Fig. 11.14; it runs as follows:

1. "2C-opt"
2. Semi-indirect
3. Semi-direct
4. Indirect
5. VDT

This tendency is not just valid for the health disturbances (sudden fatigue and visual complaints) shown in fig 11.14 but is generally true.

Fig. 11.13 The evaluation of the five types of illumination based on “*pleasantness*“ and sensation of “*disturbance*“

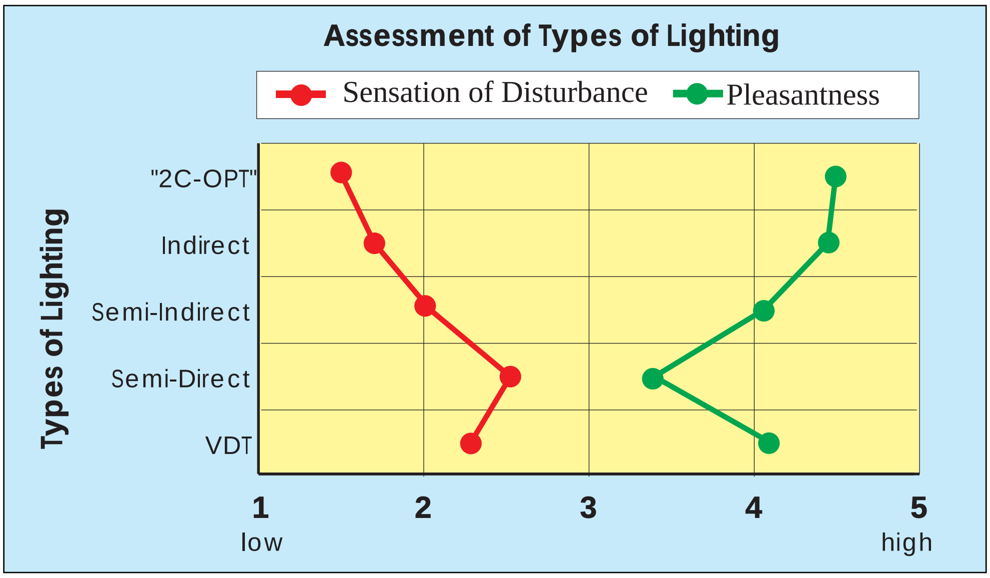
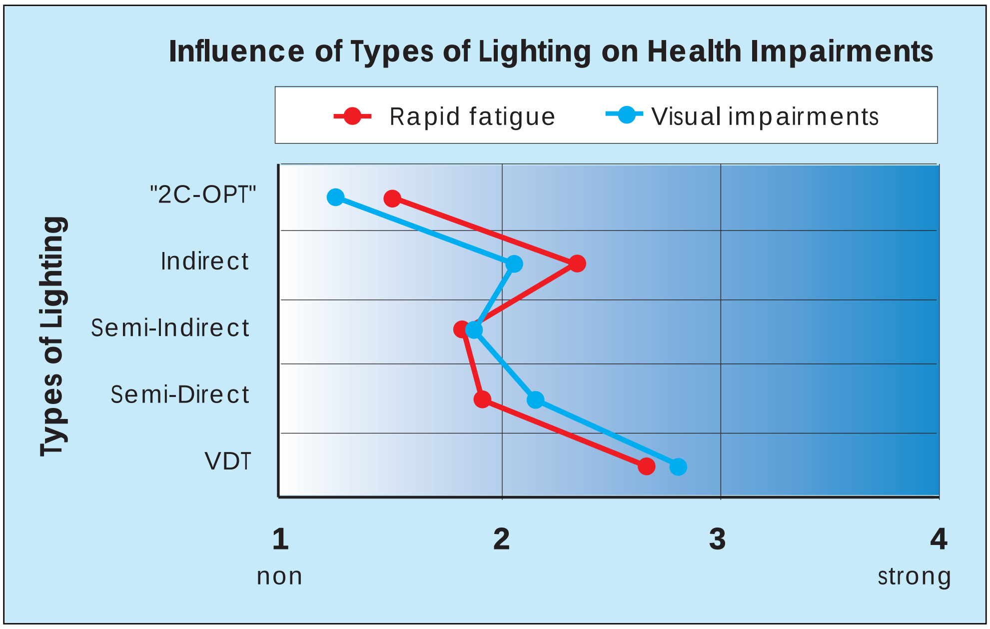


Fig. 11.14 The evaluation of “*sudden fatigue*“ and “*visual impairment*“



11.4.4 Results of the Questioning of Employees Previously Unacquainted with the Room

The same lighting installations were used in a further survey of another 68 employees of the same company who were not yet acquainted with the installations. As has already been mentioned as these subjects were not asked about health impairments as the result would have been speculative. For this reason they were only asked about "*pleasantness*", "*sensation of disturbance*", and "*glare*". This part of the investigation corresponds to the short timespan experiments in laboratories, with the one difference, however, that the illumination they found best would probably be installed at their workplaces at a later date.

The tendencies more or less correspond to the results obtained from the other employees (see Fig. 11.15). Occasionally the subjects felt some of the differences between the types of lighting to be greater. This may be due to the short time the questionees had to look at the installations, whereas employees, who have had more time to get used to the particular type of lighting, judge it more according to the visual conditions it facilitates. In this survey the 2C OPt was favored most and VDT the least.

The questions as to discomfort glare should have brought about the same results on the glare evaluation curves in use at that time - none at all. If differences were to occur, then VDT lighting should be significantly preferred. However, these expectations were all proved incorrect: the glare effect of the various installations was indeed different and VDT lighting was not rated the best but the worst. The installations are listed in order of preference below (see also Fig. 11.15):

1. "2C-opt."

2. Indirect

3. Semi-indirect

4. Semi-direct

5. VDT

Fig. 11.15 The evaluation of five types of illumination for pleasantness and sensation of disturbance as given by subjects previously unacquainted with the room

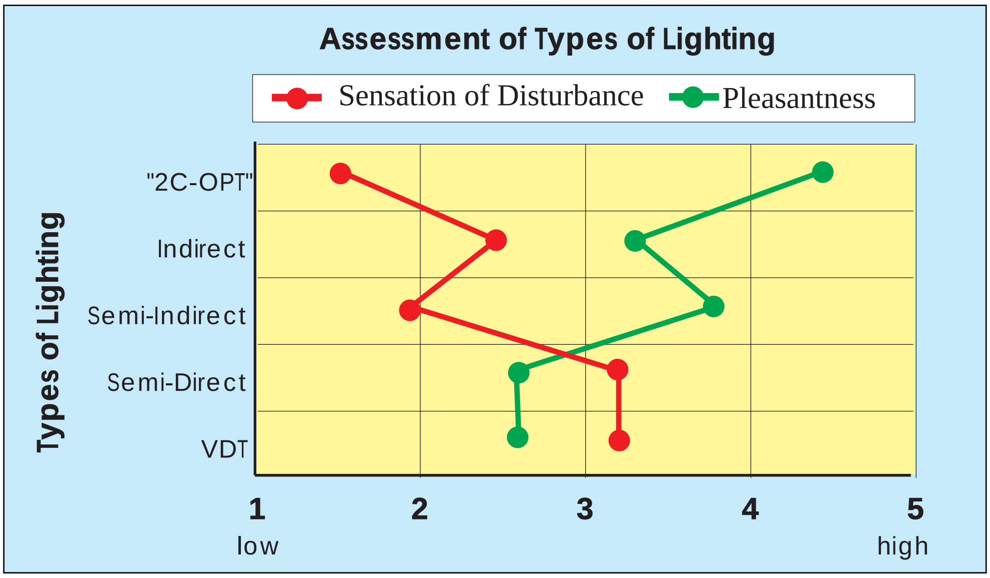
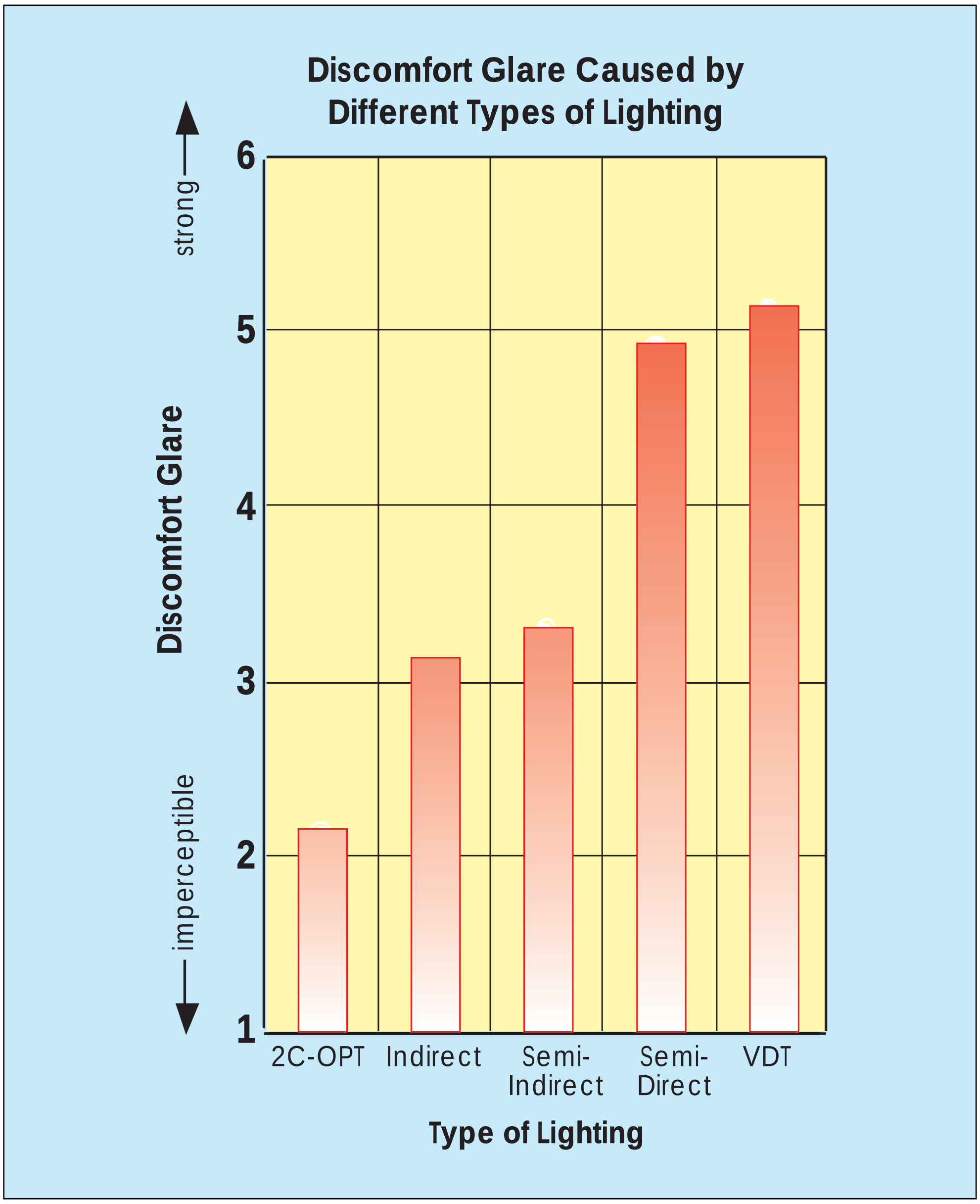


Fig. 11.16 Comparative assessment of discomfort glare under five different types of lighting



11.5 Conclusions

The comparative investigations which have been described led to the following conclusions in 1994

- Artificial lighting does not necessarily cause an impairment to health; it can even be beneficial to health and well-being.
- The type of narrow angle lighting with BAP luminaires propagated for the illumination of VDT workplaces does not solve visual problems, either at these workplaces or at others. This type of lighting should rather be seen as the cause of impairments to health and well-being.

The form of lighting which is most favorable from the point of view of the users consists of indirect general lighting with an additional component, which the users can use at their own discretion. (*Note: a vital precondition for this is that it does not disturb others in rooms with multiple workplaces.)*

- Direct angle ceiling luminaires equipped with modern fluorescent lamps with high luminance values do not find user acceptance, even when supplemented by an indirect component.
- The three parts of the investigation carried out so far have shown the most important characteristic of a lighting system from the point of view of the users to be its adaptability and adjustability to individual needs, i.e. its flexibility.

The investigations carried out since the 1994 edition of this report have shown that the above mentioned conclusions hold to be generally true. In addition there are other studies, entirely independent from our own, which have yielded results along the same lines. (See 11.7 Comparisons with Other Studies).

The latter study was not able to show whether or not the quality criteria for lighting are adequate for designing acceptable lighting or for use as evaluative criteria for good illumination. The basic reason for this is that up until not no designer has been able to fulfill all the criteria. From this the question arises if it is at all possible to fulfill all the criteria required by the norm.

11.6 Checking the Reliability of the Results

11.6.1 Methodological Reasons for Checking

In an investigation which has been conducted over a long period of time it is sensible to check at the end if the result obtained are reliable. For example a change in the intensity of work at VDTs which has, without doubt, occurred during the course of this study can have led to the situation, where the frequency of complaints (e.g. the frequency of headaches) has stayed the same but the effect of the lighting has decreased whereas the effect of the screens concerned has increased. It is feasible and according to an investigation conducted by Östberg (Östberg 1979) probable, that impediments to visual conditions bring about a less favorable evaluation of the lighting.

For the reasons stated above, the results of an investigation from 1996 are being included at this point. In this study the following question were put in the foreground

- To what degree of precision will the results coincide if the survey for a certain type of lighting were repeated with a different group of users (Test-retest reliability)?
- Is it possible to make generalizations as to the positive effect of task lighting?

11.6.2 Methods

A company using open-plan offices was selected, where the conditions and lighting were basically the same as in the study from 1976 as described in Chapter 10. 120 people were questioned, over a third of whom worked at VDTs for between 4-6 hours every day and were to a large extent doing the same tasks as those questioned in 1976. The remaining two thirds worked exclusively with VDTs. Their visual task was denoted as significantly more difficult due to the greater use of VDTs.

The judgements ascertained previously were only marginally different to the later evaluation. For this reason we have summarized the evaluations of 450 people working in similar organizations and doing comparable tasks from the same branch as a sample for comparison. Although the rooms varied drastically (from 2 person cellular offices to open plan offices) the lighting was judged uniformly. Only the lighting was in common to all.

The evaluation of the lighting that we received in this manner was then compared with another new investigation.

The second investigation was carried out in a company where many different types of illumination had been installed. The assortment ranged from direct illumination to indirect illumination with wall mounted luminaires as general lighting where many workplaces were also equipped with supplementary task lighting and others were not. under these conditions it was especially good to investigate the influence of task lighting. 250 office employees took part in this study.

11.6.3 The Reliability of the Evaluation of Lighting

The evaluation from 1976 does not even marginally differ from that of 1996 (see Fig. 11.17). There evaluations of the two groups from 1996 differed slightly but not to a statistically significant extent. This occurred where intensive work at a VDT, which was assessed as being a more difficult visual task, seemed to slightly worsen the evaluation of the lighting. This difference was so slight however, that it should not be interpreted.

It has been shown that the subjective judgement on illumination is nearly completely dependent on the type of lighting itself. The user questionnaire has therefore, a very high test-retest reliability.

The evaluation of lighting in our study only differs on the comparable scales “lighting is glaring“ “lighting is pleasant“ and “lighting is disturbing“ in small detail from the evaluation of direct illumination with narrow angle luminaires that was carried out at Cornell University. (See 11.7 Comparisons with Other Reports).

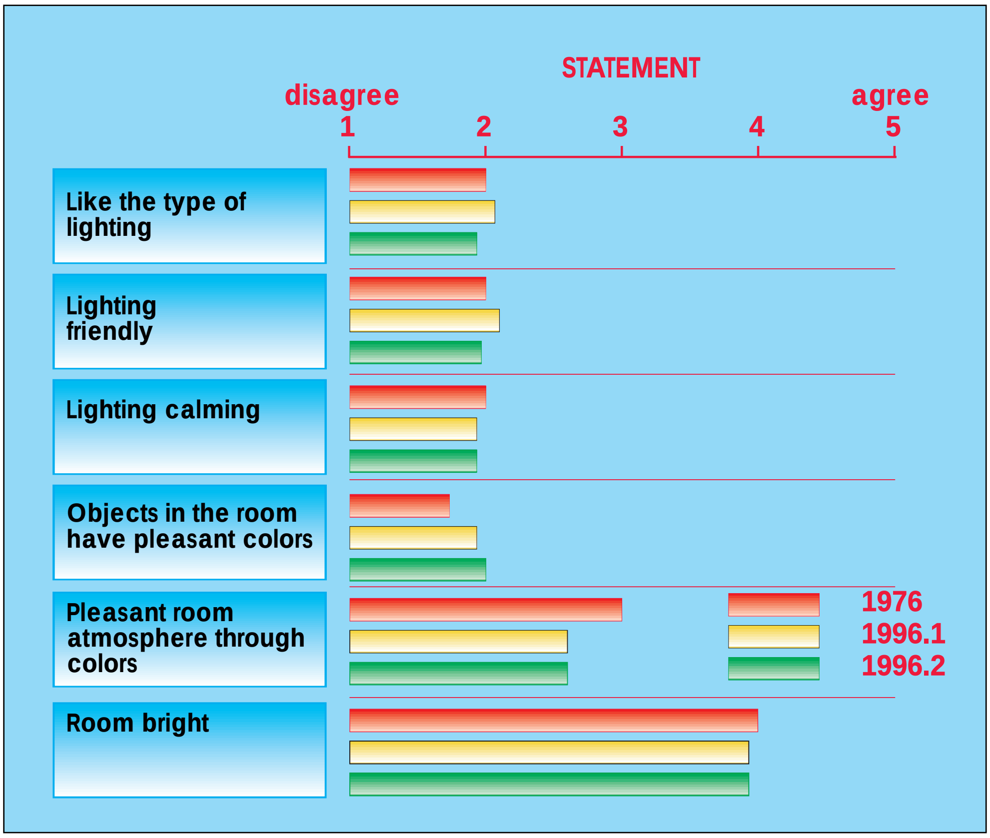
11.6.4 Is it Possible to Generalize about the Effects of Task Lighting?

Theoretically the positive effects of “table lamps“ can be linked to the general lighting. Even if we cannot make any statement as to its quality, it was so disliked that the users preferred the table lamps out of necessity. Such an assumption is by no means unfounded as for example the users of film production rooms prefer one particularly questionable kind of lighting as they have to work with extremely glossy working material; otherwise they would have to cope with lighting conditions that were even less satisfactory. For this reason it is necessary to prove if a positive influence of task lighting can also be established when the general lighting has been installed correctly according to the standard of lighting technology. We had the opportunity to examine this in the second of the above mentioned investigations, where general lighting with direct luminaires was installed in similar rooms but in some cases there was additional task lighting.

The results of the investigation are shown in Fig. 11.19: It is also possible to prove that the acceptance of a certain type of illumination rises when it is used together with additional task lighting.

This statement does not necessarily mean that the real cause for this is the task lighting. As has already been shown in this chapter the reason may simply be that individual needs are better catered for. In this case, this means that other measures,

Fig. 11.17 Comparative assessment of direct lighting under similar working conditions in the years 1976 and 1996 (1996.1 = control group, 1996.2 control group with more difficult visual tasks)



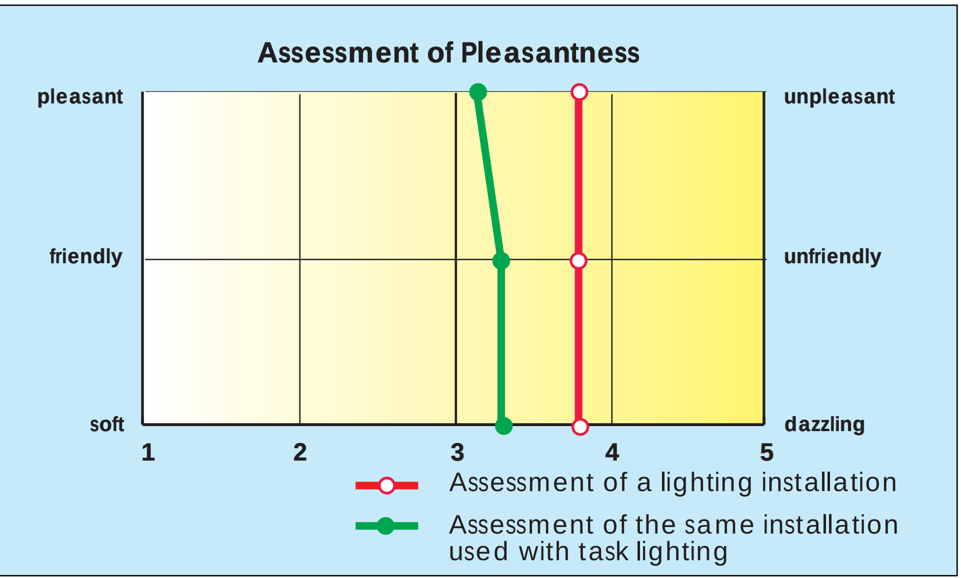
which help to adjust the lighting according to personal needs, could be just as effective.

11.7 Comparison with Other Studies

In the last few years, several projects on the subjective evaluation of artificial illumination have been carried out. In the following section, the results of the four most important tests will be presented:

- The study conducted at Cornell University (Hedge et al)
- The study conducted at Karlsruhe University (Bodmann et al)
- The study conducted at Giessen College of Further Education (Lorenz)
- The study conducted at the Technical University of Ilmenau (Gall et al)

Fig. 11.18 Changes in the evaluation of direct illumination by the use of task lighting.



11.7.1 The Cornell-University Study

This investigation was carried out between 1988 and 1990 in the USA by a scientist (Hedge et al 1990) who took part into the most extensive project to date on the so-called sick building syndrome. The author has proved in his earlier studies that lighting is one of the most important causes of "sick building syndrome." The study was brought about by investigations carried out in several different locations, the most important results of which were as follows:

- The American society of Interior Designers had found out that 68% of office workers complained about the lighting at their workplaces.
- A study in California had shown that 79% of VDT users wished for a better lighting.
- A study by Louis Harris had shown that office workers rated visual load as the biggest hazard, even ahead of radiation and asbestos.

(Information summarized in the report)

The investigation was carried out in large scale office rooms which were sub-divided into small cells. The objects for comparison were indirect illumination and narrow angle direct illumination (similar to VDT lighting). Around half of the 200 participants, all of whom were VDT operators, received indirect lighting. The investigation was repeated a year later to examine the habituation effect.

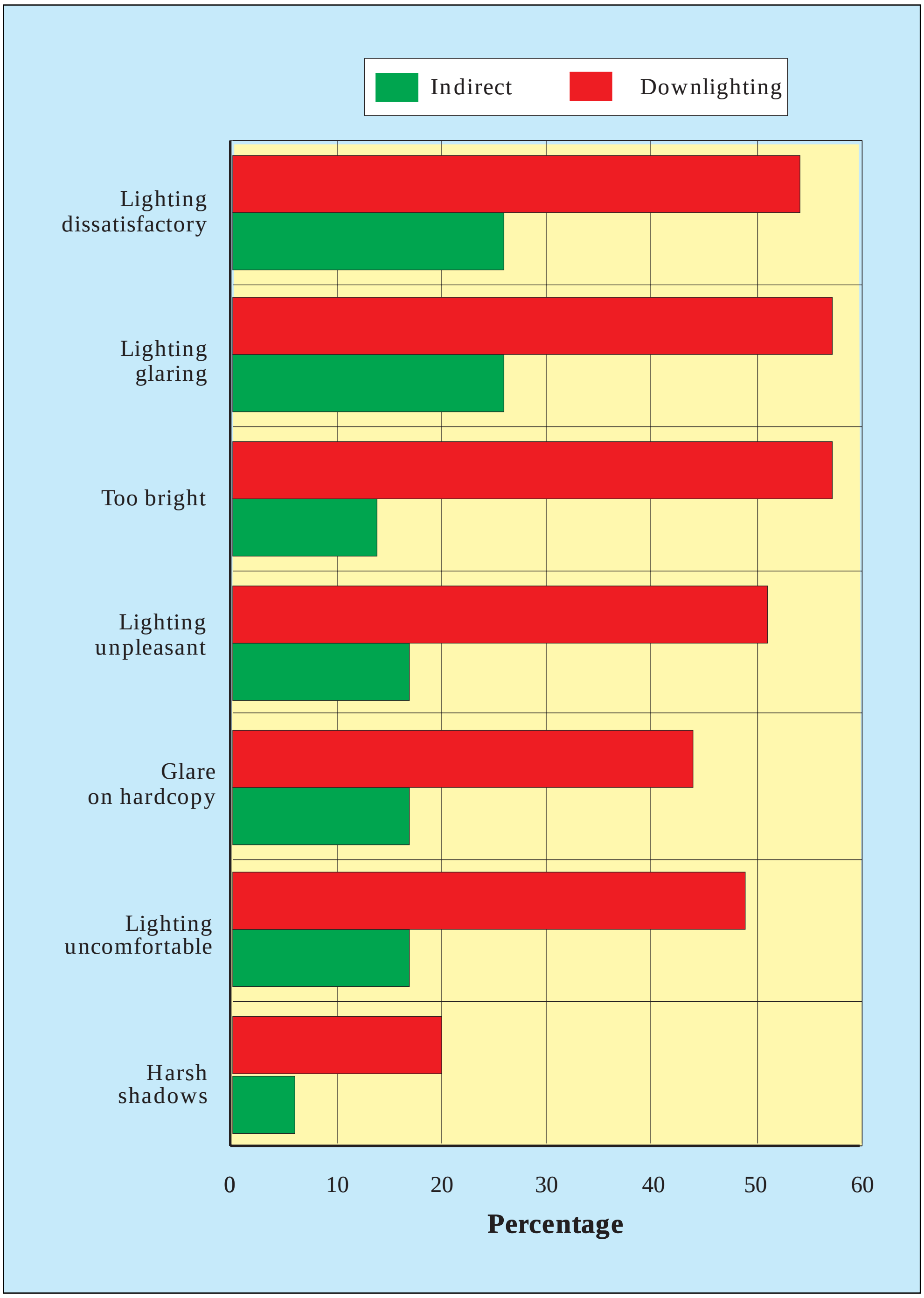
At the beginning of the study 79% of those working under indirect lighting preferred it and only 2% preferred direct lighting. In the group working under direct lighting 48% preferred indirect lighting and 28% direct lighting. One year later the first groups acceptance of indirect lighting had shrunk to 70% whereas the second group's preference for this kind of lighting had grown to 75%.

At the end of the study the subjects had a vote on the various possible problems of the lighting which is illustrated in Fig. 11.20 (all data: Hedge; every difference is statistically significant). In the case of every problem discussed direct lighting attains a statistically significant worse evaluation. The percentage of those dissatisfied with direct lighting as higher by a factor of between 2 to 4.

It is not just the results of the study which confirm our own outcome. Even the measures taken by the users in order to improve their visual environment correspond to those which were presented in Chapter 10 (see table 11.3) In addition, much similar information can be found in the literature (e.g. Çakir et al 1978).

As a final point - it is not really necessary to turn to the literature to find a picture of the situations described here; this can be done simply by looking round the door of any average office.

Fig. 11.19 Problems experienced daily with illumination by direct narrow angle lighting and by indirect lighting (Hedge 1992)

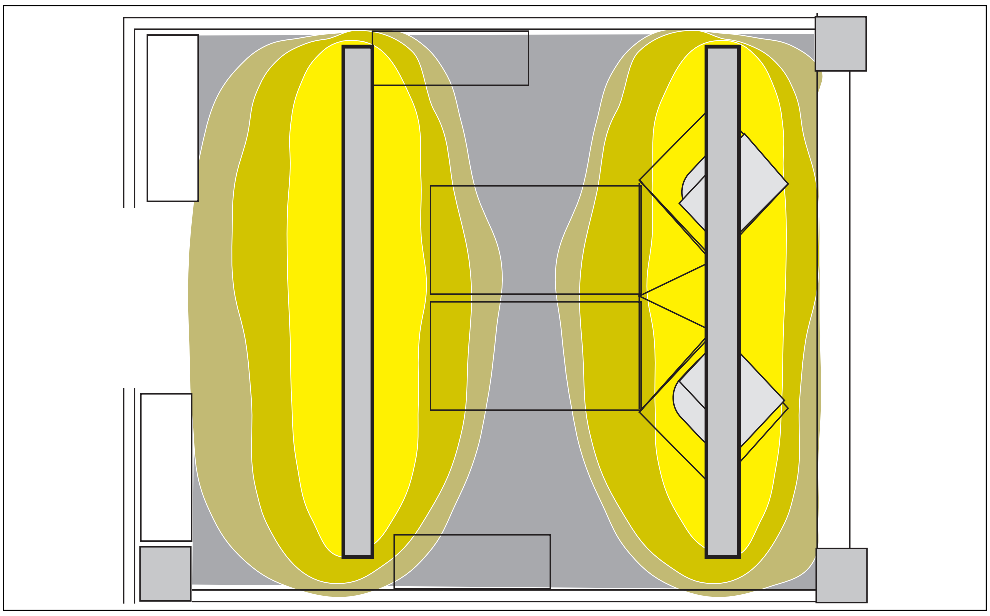


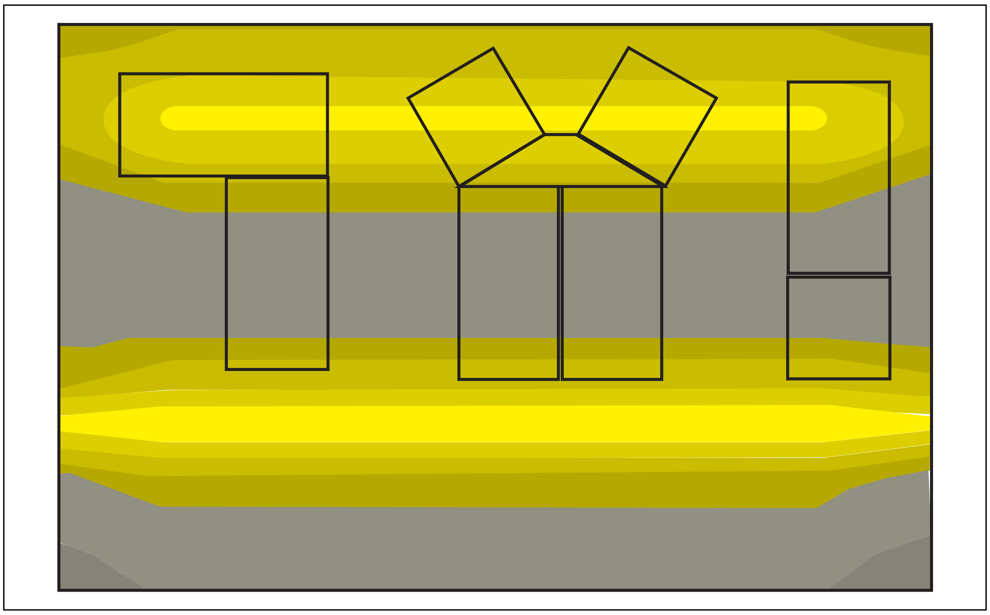
Tab. 11. 9 Measures initiated by the users in order to improve their visual environment

User actions	Indirect-Lighting	Direct-Lighting
Lamps removed to get less light	15%	66%
Lamps removed to reduce glare by reflections on the visual displays	12%	55%
Computer rearranged to reduce glare by reflections on the visual displays	34%	72%
Desk moved away to get less light	10%	24%
Lighting switched off most of the time to reduce glare by reflections on the visual displays	10%	39%

The reasons for moving the furniture to and fro can be seen in Fig. 11.21 which shows the distribution of illuminance in two rooms and the position of the workplaces: in the places where the highest levels of illuminance are needed (on the desk) the lowest values can be found, the luminaires are not hanging over the VDT desks so that these can benefit the highest illuminance nor is the floor in the corridor illuminated: all in all, it would be very difficult to attempt to explain the sense behind this lighting to those who have to use it.

Fig. 11.20 Distribution of illuminance in two cellular offices with VDT luminaires (for a comparison see also Fig. 11.12). The luminous strips predominantly illuminate the VDT desks whereas those on the door side predominantly illuminate the floor while the writing desks stay relatively dark.





11.7.2 Study Conducted at the University of Karlsruhe

This study was carried out as a laboratory experiment to determine the acceptance of new lighting systems (Bodmann et al 1995). Eight lighting installations were investigated:

(1) Direct lighting, ceiling mounted luminaires with white louvers

(2) Direct lighting, ceiling mounted luminaires with parabolic reflecting louvers, highly glossy with 60 degree glare reduction

(3) The same as above but with a matt gloss reflector

(4) Semi-direct lighting, suspended luminaires with parabolic reflecting louvers, matt

(5) Indirect lighting, free standing luminaires with metal halogen high intensity lamps.

(6) Semi indirect lighting with free standing luminaires and desk luminaires with compact florescent lamps (corresponds to the principle of “2C OPT“)

(7) Direct lighting, ceiling mounted luminaires with covered lamps and a matt white reflector equipped with compact florescent lamps (corresponds to the principle of secondary illumination)

(8) Direct direct lighting, ceiling mounted luminaires as in (7) and desk luminaires as in (6).

At this point only part of the results will be introduced. The rating according to glare evaluation was in order of preference:

1. Objects (5) and (6) with indirect lighting

2. Objects (7) and (8) (however far behind)

3. Objects (4) and (2) (semi direct lighting with matt reflecting louvers and direct lighting with highly reflecting mirrored louvers)

4. Objects (1) and (3) (direct lighting with white louvers and matt gloss reflecting louvers)

In general it has been shown that indirectly emitting lighting installations are more widely accepted than directly emitting (Bodmann et al 1993).

According to the results printed above, this study arrived at the same order of preference for evaluation as we did in our comparable studies, which have been described in this report.

Although this was a laboratory study, where it was not possibly to establish any important effects on health, 20% of the participants complained of dry and burning eyes. These complaints were significantly less for indirect lighting installations combined with desk luminaires.

The following data was established for other impairments to well-being:

Lack of concentration : the lighting installations equipped with desk luminaires (6) and (8) as well as the indirect lighting installations (5) caused less disturbance than the direct lighting installations (1),(2) and (3) as well as the semi indirect lighting(4).

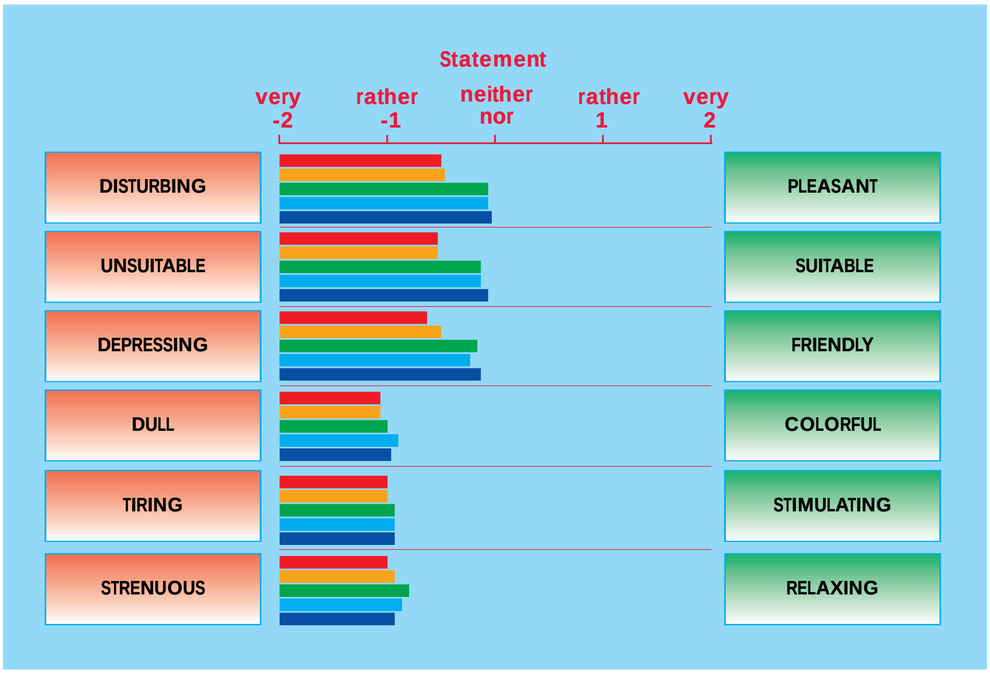
Sudden fatigue : Installations (1) to (4) caused more impairment than (5) to (8).

Irritability and Nervousness : For installations (5) and (6) no disturbances were recorded. the worst rating was received by (1).

Headaches : Installations (1) and (2) were rated as the worst while the best results were attained by (8).

The subjective evaluation of the various types of illumination was partly very unfavorable (see Fig. 11.22, from Bodmann et al). Some evaluations that are not included here are significantly better than in our investigations, however, the judgements illustrated below are to a great extent worse than in our investigations (more oppressive than friendly, more unsuitable than purpose suited, more tiring and straining than invigorating and relaxing.)

Fig. 11.21 Some evaluation of types of lighting (in the following order: (2) VDT, (4) semi direct, (5) indirect, (6) semi indirect with task lighting, (8) Total direct with task lighting



11.7.3 Analysis of Use for Lighting Installations

An analysis of use for different types of lighting was made at the Giessen College of Further Education (Lorenz,1993). The basis for the evaluation of the following criteria and weights was established (see Tab. 11.10).

Tab. 11. 10 Criteria and weights for the analysis of use.

%	Target criteria	%	Single criteria
25	Functionality	10	Uniformity of illuminance
		10	Luminance ratio task / surrounding
		20	Avoidance of direct glare
		15	Avoidance of glare by reflection
		25	Shadowiness
		20	Avoidance of gloss
5	Concept	100	Simplicity of the concept
25	Flexibility	50	Adaptability to new workplace requirements
		10	Suitability for different room heights
		10	Adaptability for different needs
		15	Adaptability for different reflectances
		15	Ease of replacement of the entire system
20	Costs	20	Acquisition
		20	Installation
		15	Maintenance
		45	Energy efficiency
5	Maintenance	60	Maintenance intervals
		40	Required qualification of maintenance personnel
20	Subjective criteria	45	Adaptability for different needs, age
		45	Acceptance by users
		10	Luminous color

The objects for comparison were:

(1) Direct lighting with mirrored louvered luminaires

(2) As above but with additional task lighting

(3) Indirect illumination with free standing luminaires

(4) Indirect illumination with luminaires suspended from the ceiling

(5) Semi-direct illumination with luminaires suspended from the ceiling

(6) Direct illumination with ceiling luminaires, indirect illumination with free standing luminaires

(7) Indirect illumination with free standing luminaires direct illumination with task lighting (corresponds to 2C OPT).

Then results have been summarized and illustrated in Fig. 11.22

When looked at in this manner, indirect illumination with additional task lighting attains the best evaluation. The order of preference is as follows:

1. Concept (7): Indirect lighting with free standing luminaires direct illumination with task lighting (corresponds to 2C OPT).

2. Concept (3): Indirect lighting with free standing luminaires

3. Concept (6): Direct lighting with ceiling luminaires indirect illumination with free standing luminaires

4. Concept (2): Direct lighting with mirrored louvered luminaires with additional task lighting

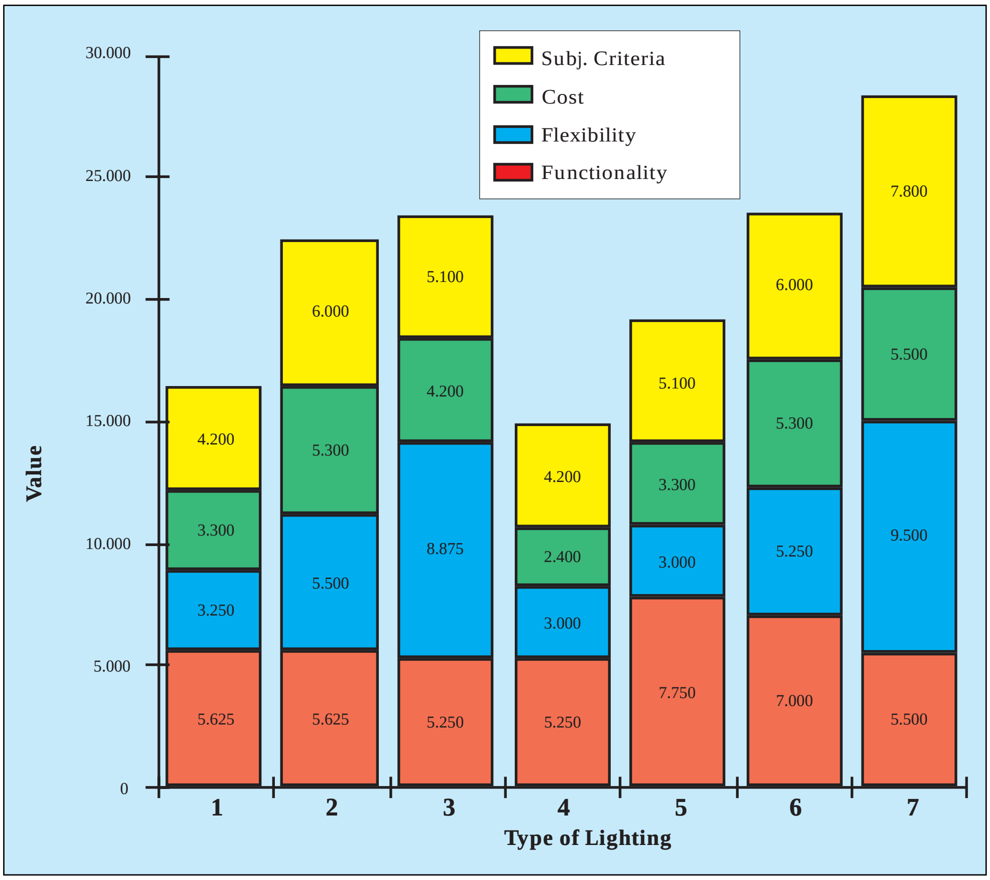
5. Concept (5): Semi-direct lighting with luminaires suspended from the ceiling

6. Concept (1): Direct lighting with mirrored louvered luminaires

7. Concept (4): Indirect lighting with luminaires suspended from the ceiling.

Direct illumination with mirrored louvers (concept (1)) finishes second to bottom on the scale of use. The author's opinion on this and concepts (4) and (5) is "*The poor results attained by the other types of illumination shows conclusively that they are only suitable for solving lighting problems under exceptional circumstances.*" *As mentioned in Chapter 9 this had already been said in 1975 in the "Illumination Handbook."*

Fig. 11.22 Calculated use value for seven types of lighting



11.7.4 Study Conducted at the Technical University of Ilmenau

This study which was commissioned by the Federal Institute of Work Safety and Occupational Medicine was published at the end of 1996. Individual aspects of single place illumination and general lighting were investigated under laboratory conditions and in field studies. Consequently some interesting findings from the research report were cited. Further details could be found in the report. There are also many papers and dissertations on single aspects which can be obtained from the Technical University of Ilmenau

The study puts forward the conclusion that single place illumination is not just being used more but is also preferred: “*as this lighting system has so many advantages its acceptance by the user is very high. This investigation and others... have conclusively shown this to be the case.*“ This statement must be supplemented by the condition that the result is only valid if room lighting is also present.

How High Should the General Level of Illuminance Be?

The study arrives at the result that it is not necessary for general lighting to keep to the nominal illuminance as put down in DIN 5035 Part 2. Rather a level of 250 lx is sufficient. The reason for this value is not to do with visual performance but with the effect on the room on the one hand, and the relationship between general lighting and localized lighting on the other: “*...so that the room is bright and can be judged as a whole. This basic brightening is necessary anyway to achieve a good balance between general lighting and localized lighting.*“

How High Should the Total Level of Illuminance Be?

The total level of illuminance, i.e. the sum of the illuminance from general lighting and the illuminance from localized lighting, should be somewhere between 600 lx and 1000 lx. A large part of this should come from the task lighting as “*it is found more pleasant when the localized lighting stands out visibly from the rest of the room.*“

How High Should the Contribution of Task Lighting to the General Level of Illuminance Be?

Favorable values for task lighting lie between 500lx and 750 lx but this has, however, been judged independently of the general lighting. The optimum ratio of general illuminance to localized illuminance lies between 2:1 and 3:1.

Reasons for lighting measures

12 Reasons for lighting measures on the basis of new regulations for health and safety at work

12.1 Legal foundation

12.1.1 Current legal regulations for VDT workplaces

Up until now the lighting of workplaces has generally been regulated in regulations of differing legal importance, for example in the German Work Places Ordinance (Arbeitsstättenverordnung, ArbStättV), in the relevant work places guidelines (Arbeitsstättenrichtlinien, ASR) and in specific standards (e.g. DIN 5035). Here the ArbStättV provided the only legal provisions.

Due to the transposition of the EU framework Directive on safety and health at work and four of the related individual directives in German law which took place in 1996, both new national legislation have arisen and considerable changes in existing national regulations or for their application have resulted, as is also the case for the ArbStättV. In particular, a change has resulted for the artificial lighting of VDT workplaces for which there no specific legal provisions previously existed.

This has also lead to a new situation for the evaluation of artificial lighting with regard to safety and health at the workplace, particularly for the evaluation of the lighting of VDT workplaces.

The legal foundation for the directives of the EU for safety and health at work is Article 118a “Improvement of the Working Environment; Minimum Requirements” added to the EEC Treaty with the Single European Act. These directives do not address to the citizens of the member countries of the European Union, but instead to the respective country itself, which must transpose these directives to national law, i.e. “implement” them. The principle of the minimum requirements allows the countries to go beyond the level specified by the EEC and also to make specific definitions.

However, in no case may an EU member country come short of the level of health and safety protection at work specified in a directive. The totality of the changes in German legislation on occupational safety which have become necessary due to the EU legislation, and which even today, in 1997, have still not been completely implemented, is illustrated and commented on by Bücker, Feldhoff and Kohte in the work

"*Vom Arbeitsschutz zur Arbeitumwelt*" (From Labor Protection to the Working Environment) (see Bücker et al, 1994).

On the other hand, it is not necessary for a corresponding German law to be created for every EU directive. A member country can also provide for an implementation with reference to other regulations which takes the parts of a directive into consideration. This has occurred in Germany. The framework Directive *(Council Directive of 12 June 1989 on the introduction of measures to encourage improvements in the safety and health of workers (89/391/EEC)*) was implemented or integrated in national law in Germany with the

- Act for the implementation of the EU framework Directive on safety and health and other safety and health Directives

which took the parliamentary hurdles in July 1996 and became effective on 8/21/1996. Within the scope of this law both

- the Act on safety and health at work (Arbeitsschutzgesetz, ArbSchG) was passed
- and the Occupational safety act, the Work constitution act, the worker transfer act and the Industrial Code were modified.

The Act on safety and health at work includes a special authorization which enables the EC individual directives passed for the framework Directive to be implemented with ordinances in German law. The following two of these ordinances are of prime importance for the considerations on artificial lighting of VDT workplaces undertaken here:

- Ordinance on safety and health for work with display screen equipment (Bildschirmarbeitsverordnung, BildscharbV)

This is primarily concerned with an implementation of the display screen directive (Council Directive of 29 May 1990 on the minimum health and safety requirements for work with display screen equipment (90/270/EEC)) with the same content. However, as parts of this directive were already integrated in existing laws (Works Constitution Act, Act on safety and health at work), several requirements of the directive were not covered in the German BildscharbV to prevent double regulations, but rather in exactly these other laws. Although this is wise for legislative reasons, it complicates application.

- **Ordinance for changing the Work Places Ordinance (ArbStättV)**

Here a special situation exists, i.e. in Germany an Work Places Ordinance has already existed for many years. It became effective in 1975, long before the development of the concept of the EU for safety and health in working environment. Its regulations were now adapted with the Ordinance to the Directive "Council Directive of 30 November 1989 concerning the minimum safety and health requirements for the workplace (89/654/EEC)".

12.1.2 Requirements of the previous legal regulation for artificial lighting of VDT workplaces

For the general lighting of workplaces, the ArbStättV was and is of major importance. In § 7 it specified for artificial lighting:

"*Lighting equipment in work rooms and traffic routes are to be arranged and designed so that no accident and health risks can result for the worker from the type of lighting. The lighting must be based on the type of visual task. The intensity of the general lighting must be at least 15 lux.*"

Specific requirements for certain activities are not contained in the ArbStättV itself, and this also includes work at a visual display screen.

12.1.3 Requirements of the new legal regulation with regard to the artificial lighting of VDT workplaces

The new acts on safety and health at work assume, as do the EC Directives on health and safety in working environment on which they are based, a comprehensive understanding of health and safety at work. The title of the framework Directive already clearly shows the legislators' intentions: "Council Directive of 12 June 1989 on the introduction of measures to encourage improvements in the safety and health of workers at work..."

Requirements relevant for the illumination of display workstations are contained

- in the Act on health and safety at work
- in the Work Places Ordinance
- and in the Ordinance on Safety and Health for Work with Display Screen Equipment

The most important, because basic, changes which were introduced with the new Directives on safety and health in working environment are contained in the Act on health and safety at work. The requirements specified there also always apply to the subordinately assigned ordinances, i.e. the ordinances must always be considered in conjunction with the Act on health and safety at work. (Note: With some ordinances this already results for the reason that in these ordinances specific reference is made to the Act on health and safety at work, as is also the case with the amended Work Places Ordinance and the Ordinance on safety and health for work with display screen equipment.)

12.1.4 Requirements of the Act on health and safety at work (ArbSchG)

The ArbSchG specifies the relevant duties of the employer as follows:

- Basic obligations of employers (ArbSchG § 3 (1)):
  “The employer is obligated to take the necessary work health and safety measures under consideration of the conditions which influence the safety and health of the workers at work. She/he must check the measures for their effectiveness and adapt them to changing conditions if necessary. In the process, she/he must strive for an improvement of safety and health of the workers at work.”

- General principles (ArbSchG § 4)

  "1. *the work must be structured so that a risk for life and health is prevented wherever possible and the remaining risks are kept as low as possible;*

  2. risks must be combatted at their source;

  3. the state-of-the-art in technology, occupational medicine and hygiene and other established scientific knowledge on work must be taken into consideration for the measures;

  4. …

  5. individual protective measures are subordinate to other measures;

  6. ...”

- Obligation to Evaluate Working Conditions (ArbSchG § 5)
  “(1) The employer must determine which protective measures for safety and health at work are required by evaluation the risks to the safety and health of workers
  (2) ….
  (3) A risk may in particular result from

  1. the design and equipment of the workplace,
  2. physical, chemical and biological influences,
  3. the design, selection and use of work equipment, particularly of working substances, machines, devices and systems and their use
  4. …”

12.1.5 Requirements of the Ordinance on safety and health for work with display screen equipment

The Ordinance on safety and health for work with display screen equipment is divided

- into a more general part with basic requirements for the working conditions, the design of the workplace, the organization of the daily work procedure and an eye and eyesight test
- and in an annex on the requirements to be placed on workstations.

With regard to lighting, the following regulations are of importance:

"*§ 3 Evaluation of working conditions*

When evaluating working conditions in accordance with § 5 of the Act on safety and health at work, the employer must determine and evaluate the safety and health conditions of workstations, in particular with regard to a possible risk to eyesight, physical problems and mental stress."

"§ 4 Design requirements

(1) The employer must take appropriate measures so that the workstations meet the requirements of the annex and other legal regulations."

In the annex under the category "work environment" the following is required for lighting:

"*15. The lighting must correspond to the type of visual task and be adapted to the eyesight of the user; in the course of this, a suitable contrast between the screen and the work environment must be ensured. Disturbing glare or reflections on the screen and other working equipment shall be prevented by the design of the workstation and the layout and arrangement of lighting.*"

When interpreting these regulations, it is advisable to also make use of the EU Directive 90/270/EEC itself, as the German implementation expresses the requirements of the directive less clearly. The directive specifies the following for lighting in the Annex with the minimum regulations under "*2. Environment*":

"(*b*) *Room lighting and/or the spot lighting (work lamps) shall ensure satisfactory lighting conditions and an appropriate contrast between the screen and the background environment, taking into account to type of work and the users vision requirements*

Possible disturbing glare and reflections on the screen and other equipment shall be prevented by coordinating workplace and workstation layout with the positioning and technical characteristics of the artificial light sources."

The first paragraph requires, to a greater degree than the ArbStättV, not only the adaptation of the lighting to the visual tasks (type of work), but also to the users vision requirements and / or the eyesight of the user. This requirement represents a novelty in the regulations on lighting; neither in the ArbStättV nor in the German lighting standards have individual needs of the user been explicitly taken into consideration up until now. The additional requirement must be appropriately taken into account, since the BildscharbV is the relevant specific legal basis and the minimum requirements for the design of the working environment are specified in its annex.

Note: *The new requirement is also of major importance for the planning of lighting systems. Therefore, it must be checked whether changes will have to be made to the regulations valid up to this point for this reason.*

Another novelty is the fact that, in contrast to previous regulations (standards and safety rules), the lighting is referred to in a combination of “general lighting and / or special lighting (work lamps)”, and that thus the special lighting, which is to be viewed as “single-workplace lighting” (German term for localized lighting) or individual lighting, is given a new ranking. This is all the more important, as according to some former regulations individual workplace lighting was to be avoided up until now.

The second paragraph requires that annoying disturbing glare and reflections on screens and other visible objects, e.g. keyboards, manuscripts etc. are to be avoided. The equipment named also includes at least all working equipment listed in the definition of the VDT workstation which may be present (optional additional devices, system elements including floppy disk drive, telephone, modem, printer, manuscript holder, desk etc.) (see BildscharbV § 2 Concept Definitions). The means with which the employer achieves the specified goal of preventing disturbances as the result of disturbing glare and reflections is not specified. On the contrary, she / he may select an appropriate arrangement of the workplace in question or of the screen set up there with reference to the room, an appropriate arrangement of the lighting equipment or an appropriate technical design of luminaires or any combination thereof. As a result, the regulation speaks of a coordination, the goal of which is achieved when disturbing glare and reflected images are no longer noticeable as disturbing. For good reasons, it does not indicate which measure is to be given preference.

12.1.6 Requirements of the Work Places Ordinance

The wording of the regulation of the ArbStättV for artificial lighting of workplaces has remained unchanged. For reasons of completeness, it is included once again below.

"*Lighting equipment in work rooms and traffic routes are to be arranged and designed so that no accident and health risks can result for the worker from the type of lighting. The lighting must be based on the type of visual task. The general lighting must be at least 15 lux.*"

12.1.7 Special aspects

All three regulations specify goals for the avoidance or reduction of a health risk for the workers during work.

However, assistance in achieving these goals are currently only provided in the Work Places Ordinance with the assigned work places guidelines. In the case of artificial lighting, this is the work places guideline ASR 7/3 which, however, does not represent an established law, as does the ArbStättV.

The ASR 7/3 does not prefer any certain type of lighting as long as the parts of the lighting standards listed in the guideline are fulfilled. No specific statements on the lighting of rooms with VDT workplaces are made, as well.

However, the work places guidelines in turn refer to relevant lighting standards. For the planning of lighting equipment, these are the parts 1, 2, 6 and 7 of the standard DIN 5035. And here the only reference is made to the fact that special planning is required for VDT workplaces by referring to DIN 5035, Part 7 "*Artificial lighting of interiors; lighting with display work stations and with work stations with display support*".

Although the lighting standards specified in ASR 7/3 (e.g. DIN 5035, Parts 1, 2, 6 and 7) are themselves not legal norms, but rather "Rules of Technology", however, the knowledge cited and taken into consideration in them are obligatory for the employer, the addressee of the regulations for safety and health at work, when reference is made to them in established laws and a de facto reliability is thus created.

This kind of assignment of standards is not present in and also not planned for the Act on safety and health at work and the Ordinance on safety and health at work with display screen equipment.

> **Conclusion:** Regardless of the question of whether or not this kind of assignment is appropriate, the situation results today, in 1998, that two legal regulations, the ArbStättV and the BildscharbV, contain regulations on the artificial lighting of VDT workstations, and that in one of these regulations, the ArbStättV, de facto assignments to standards have been created.

However, this raises the question of whether the requirements and recommendations of these standards match the requirements of the BildscharbV for lighting.

12.2 Possible health hazards due to artificial lighting at the display workstation

The three legal regulations listed all have the goal of preventing risks to the health of the workers or of keeping it as low as possible, and thus also includes a risk to the workers presented by the artificial lighting at the display workstation. The ArbStättV even requires the unlimited prevention of health risks posed by artificial lighting. In this context the question arises as to the what the nature of these risks or hazards posed by artificial lighting at the display workstation may be and what is meant by these terms.

12.2.1 Explanation of the relevant terms

In legislation, ergonomics and safety engineering some terms are being used in different meanings. Moreover, one term may be used differently within the same domain, e.g. the term risk in ergonomics. Unfortunately, some other factors go even beyond the negative effects of these undesirable ambiguities. One of these factors is ambiguous use of the term "risk" in the European legal provisions in addition to the simultaneous use of "risk" and "hazard" in the same meaning. If these provisions are translated into another European language and back the resulting text may sound similar but implicate very different measures.

To avoid difficulties associated with language problems, the terms "hazard" and "threat" will be used in this chapter as defined in safety engineering:

- A "**hazard**" is any possible influence on human beings with an undesirable effect without consideration of the actual occurrence of injuries. For example, electricity is a hazard.
- A "***threat***" is understood as the meeting of a human being and a hazard, whereby this term is approximately equivalent to the term "**risk**". The threat to the human being posed by electricity can, for example, probably be expressed as injury or death caused by the hazard.

Using electrical power means a hazard to almost all people in a country, while the threat or risk is about 50 lethal accidents for 80 million German citizens per year.

The principle of "**combating the risks at source**" cited in the Act on safety and health at work means that hazards in themselves must be kept away from the workplace. As this is not possible for a number of hazards, e.g. electricity, it is specified that the threat (i.e. the risk) is to be kept as small as possible. Therefore, for example, electrical accidents in Germany are largely prevented with a broad range of technical and organizational measures.

For the other statements it is also necessary to consider the term “health”. Due to the particular importance of this term, several statements from Chapter 7 will be cited again in the following.

Working conditions experienced as disturbances are not necessarily also a factor in health impairment. However, what can be defined as a health impairment at all? First of all this is explained using the definition of the term “health”.

- The most comprehensive definition of “health” is that of the WHO (World Health Organization), which states that health represents a condition of well-being and not of absence of illness. (Note: In contrast to the term “health”, there is no definition for the term “illness”.)

It is true the definition of health as per the WHO is comprehensive, but it is designated as hardly practicable (see Bücker et al, 1994). For this reason, the following somewhat restricted term was proposed by the International Labor Organization (ILO) and definitively specified in “Agreement No. 155".

- According to this, **health** in conjunction with work **not only means being free of illness or disease, but also includes the physical and mental factors which affect health and are directly connect with safety and health during work. ”** (Bieneck, BABl 10/1984, 5, 7; quoted from Bücker et al, 1994)

This agreement has played a major role in the preparation of the EU directives. According to the court decisions of the European Court of Justice, the resolutions of the ILO are to be used for the interpretation of Community law terms, including for the term “health”. In the following observations “health” is understood as defined in this agreement.

In Germany, the terms “rules of technology” and “established rules of technology” are widely used, also in legislation. A “rule of technology” can be any written or unwritten method or code to handle a certain problem, e.g., a standard on organizing an office workstation is a rule of technology. An example for an unwritten rule as a rule of technology is the capacity of the screen of a computer terminal with 25 lines with 80 characters each which has never been subject to a written standard.

Rules of technology are not always widely accepted, in some cases people may even refuse applying them. If, however, a certain proportion of the public interested in the matter uses them, they are considered “established rules of technology” with the consequence that violations of them may cause severe penalties even if the rule has never been written. E.g., supplying a customer with screens which are able to display 78 characters per line only will entitle her / him to refuse the delivery even if she / he has never specified the number of characters per line.

Existing lighting standards in Germany have started their life-cycle as “rules of technology”, they are “established rules of technology” now due to the fact that a substantial part of the public uses them. However, it must be noted that this fact does not mean a specific rule was true or false.

12.2.2 Possible risks from working at a display device

According to BildscharbV § 3, the specially emphasized risks at workplaces with display screen equipment are:

- Possible risks to eyesight
- Physical problems
- Problems of mental stress.

Whether and which risks, if any, can result from artificial lighting will be derived in the following sections. The emphasis in the law means that the legislator suspects particular hazards in such factors which can have an effect on the three aspects listed. However, the suspicion of hazards does not mean that these hazards will also be active at every workplace, i.e., constitute a threat or risk. On the contrary, the employer is obliged to evaluate workplaces to specifically determine which risks are present at the specific workplace. If the evaluation of the situation of workplaces shows that the potential hazards have been sufficiently taken into account, then the condition aimed for by the legislator prevails, i.e., there are hazards but no risk for safety and health of workers.

12.2.3 Conclusions from legal provisions and “established rules of technology”

One immediate way to recognize whether an object of consideration is to be classified as a hazard for safety and health at work, is the fact that there are applying legal provisions. This statement is contained in the reasons for the resolution of the 1st Senate of the German Federal Labor Court (BAG) of 4/2/1996 - 1ABR 47/95. The lawsuit was mainly concerned with the question disputed by the parties involved as to whether working with display screen equipment is actually linked to hazards to workers‘ health. In the opinion of the BAG, this question needs no response, as the measures and regulations demanded by the Council Directive on the minimum health and safety requirements for work with display screen equipment are exclusively used to protect the worker from hazards to life and health. The decision states the following on this: “*As a result, it is a binding requirement for the German legislator that hazards to the safety and health of the worker are posed by work with display screen equipment which necessitate the regulations provided for in the directive...*”. According to this, the objects of regulation covered in the Annex of the BildscharbV, and thus also the lighting, are accepted as hazards. According to the rationale of the opinion of the BAG, the facts concerned should not have been added to an established law for the protection of the worker against hazards to safety and health.

The Council Directive for workplaces also contains regulations which demonstrate a relationship between lighting and health. “*Workplaces must as far as possible receive sufficient natural light and* ***be equipped with artificial lighting adequate for the protection of workers´ safety and health.*** ” (Council Directive 89/654/EEC, Annex I, 8). And in the commentary to § 7 of the ArbStättV (lighting), Opfermann/Streit (Opfermann/Streit, 1997) emphasize the particular importance of lighting with the following introduction: “*One of the basic conditions for the prevention of accidents and work-related illnesses in the broadest sense is* ***lighting of the workplaces, working areas and the in-plant traffic routes*** *adapted to the working conditions and procedures.*” (Bold print used in original text).

It is also clear from the commentary on workplace guidelines (Opfermann/Streit) that lighting can represent a health hazard. In this context Opfermann/Streit even speak of health damage, “*... The strong radiation of heat of the luminaires (...) and excessive or insufficient lighting intensities can lead to health damage (e.g. headaches...).*” As a result, for example, the causing of headaches by lighting which, according to the observations in Chapter 7, is dependent on the type of lighting, would have to be classified as health damage and the factors possibly leading to this as hazards.

Although this already sufficiently proves the importance of lighting as a hazard, both with regard to safety and to health, it should also to be noted that the German standard DIN 5035 has pointed out the importance lighting for health and safety from its beginnings. As already shown in Chapter 9, the original version of the standard even declared health as the primary goal of design, *"The artificial lighting of inside rooms must comply with the requirements of health and beauty, and in the process be purposeful and economical."* (DIN 5035, Edition 11 / 1935). In the most recent version of the standard which meanwhile has several parts, Part 1 explains, *"The lighting influences (...) the visual performance, the activation, the occupational safety and the well-being of the human being with its quality."* (DIN 5035, Part 1, 1990) From the last statement it can be directly derived that the aspects named, including well-being, can also be negatively influenced by unsuitable lighting which, according to the definition of health of the WHO, already means a health impairment.

The belief that the WHO's definition of health forms the basis for the ideas behind the standard DIN 5035 can also be derived from the following observations of the former chairman of the responsible standards committee, *"A treatment of the interior lighting would be incomplete if it was only to be based on the visual performance and work related physiological requirements. Naturally, the hygienic importance of the light must be taken into account in the process; a quantity and a quality must be applied in such a manner that it is beneficial to health. Here health according to the well-known definition of the World Health Organization is not only to be understood as the freedom from illness, but also the complete physical and mental well-being of the human being."* (Hentschel, 1972, p. 258)

12.2.4 Conclusions from the literature on the "Sick Building Syndrome"

To clarify the question of whether the hazard of "lighting" assumed to be existent causes a methodically determinable health risk or, however, in contrast plays a more subordinate and negligible role, the research results on the Sick Building Syndrome (SBS) can be drawn upon. This is understood to be the occurrence of health impairments caused by the working environment (for detailed descriptions, see Çakir, 1993; Çakir, 1996). Although the phenomenon has been known since the turn of the century, it has only been systematically studied since the 1970's. In the following the results of several relevant publications on SBS are discussed.

- SBS formed the object of an EU project (COST, 1989), within the scope of which the relevant literature was also analyzed. Here it became apparent that no risk could be proven for a number of assumed hazards. This means that either the assumption of the hazard was incorrect or the actually existent affect could not be proven. In contrast to this, artificial lighting is named in as a proven cause of SBS. The questionnaire recommended for operational investigations names the lighting as an object of investigation.

The proof that artificial lighting presents a hazard has been provided with sufficient reliability in two studies (Hedge et al, 1989; Wilkins et al, 1988).

- In the first study, which covered 4,373 workplaces in 47 office buildings, it was established that the lighting represents a cause of Sick Building Syndrome. In this study is was also possible to develop a model for the influence mechanism of environmental factors.
- The second study only covers a sub-aspect, i.e. the affect of electronic ballasts on headaches and visual discomfort. In the process it was shown that, following the use of electronic ballasts which eliminate the cyclic variation of light output, the frequency of headaches and discomfort of the eyes decreased in 50% of the workers examined, i.e. the threat was demonstrably reduced.

There is very little proof of the importance of the lamp type (e.g. fluorescent lamp, incandescent lamp etc.) in the literature on SBS, although complaints on the light of fluorescent lamps are common in all countries since the introduction of these lamps. One reason for this may lie in the fact that it is virtually impossible to conduct a serious scientific study on this question, as virtually all workplaces accessible to a study are illuminated with fluorescent lamps. Nevertheless, two indirect proofs can be given on this question:

- The first results from a case study which was presented in Chapter 10 (Case Study 6). In this project lighting with existing incandescent lamps was replaced with a fluorescent lamp lighting system without additional complaints occurring. On the contrary, it was even possible to considerably reduce the complaints.
- In the second case study documented in this report, a certain type of lighting with fluorescent lamps was installed at four companies, after which it was also possible to considerably reduce the incidence of health impairments to such a degree that the tendency is that of a general satisfaction.

It must therefore be assumed that the disturbances caused by the lighting is more likely due to an incorrect use of the fluorescent lamps than their characteristics themselves. By the way, this realization corresponds to the argumentation of the lighting industry, which is nearly as old as the complaints on the fluorescent lamp.

In the literature on psychological aspects of work, in which publications on SBS can also be included, artificial lighting is frequently cited as a “stress factor”, i.e. as a type of mental stress. However, due to the ambiguity of the term “stress”, findings in this regard cannot necessarily always be linked to a negative effect.

12.3 Conclusion

Based on the regulations on protection of workers´ safety and health, measures against hazards must be provided, provided that these can cause risks at a certain workplace. Such hazards inarguably also include artificial lighting.

The protective measures taken up until now in the applicable regulations and possibly also implemented in practice might theoretically be sufficient, so that a hazard must be assumed, however no special measures need to be taken. However, this research report shows that, on the one hand, this is not the case and that, on the other hand, in accordance with the dictate of the Act on safety and health at work the hazard must already be eliminated at the source or, should this not be possible, then at least reduced. When doing so the employer must both taken the state-of-the-art technology into consideration and strive to improve safety and health.

For display screen equipment this means that all factors relevant for the following aspects, i.e.

- possible risks to eyesight
- physical problems
- problems of mental stress

must be taken into consideration. A minimization of hazards posed by lighting at these workplaces would call for the introduction of that type of lighting which, according to the remarks in Chapter 11, has performed best (an optimized 2-component lighting system), as it causes the least health impairments.

This type of procedure would certainly be advisable and realizable when planning new buildings, however, for example in the case of existing workplaces, would at times not be required and at times not be feasible, e.g. when the room conditions do not permit it. For each measure it must be considered that the goal of safety and health at work consists of protecting human beings to the greatest degree possible or required, and not of protecting them against the hazards of lighting regardless of other problems which might be caused by exactly this protection.

Based on the conditions described in Case Study 5 in Chapter 10, it can be said that even with the least favorable type of lighting, direct lighting, there is probably no need to take special measures, provided the general conditions and assumptions are fulfilled as described in DIN 5035, Part 7. This also includes the suitable placement of the workplace and that an adjustment to the eyesight of the user is not necessary, as the existing lighting has already been sufficiently adjusted.

The question of whether and which lighting measures, if any, are required can only be answered considering and evaluating the requirements of the individual workplace. However, such a statement is unacceptable for an office planner, as she / he does not plan for individual workplaces, but more for an entire building, and in extreme cases even for all office buildings of her / his corporation around the world. Finally, lighting adapted to the personal needs of the individual and her / his visual tasks would already fail in theory, because office personnel not only frequently change their workplace, but also their (visual) tasks - unless the technical solution is so flexible that an individual adaptation can be easily undertaken at any time. However, it would be even better if this kind of adaptation were only necessary in seldom cases or could be completely eliminated. The concept of general lighting in conjunction with requirements formulated as ***minimum*** requirements should actually serve exactly this purpose. Apparently it hardly comes close to reaching the established goals.

The possible and required procedure in practice can be illustrated using the concept of usability. This concept is a quality concept, i.e., it does not assume that an object of consideration may be suitable for use due to its characteristics per se, but instead based on the fulfillment of the requirements placed on it.

12.4 Usability of Lighting Concepts

12.4.1 Explanation of the Concept of Usability

Usability is defined in ISO 9241-11 as "*the extent to which a product can be used by specified users to achieve specified goals with effectiveness, efficiency and satisfaction in a specified context of use.*" While this definition was once specified with reference to software, usability can be generally applied to all products for which use is not exclusively determined by their own characteristics, but on the contrary only can be evaluated by the knowledge of the user, the conditions of use (context of use) and the goals connected with their use.

For example, lighting can be designed for children (schools), patients (hospitals), participants in celebrations (dance hall, disco) or for workplaces in which people of a certain age group pursue a certain activity. Lighting designed for a certain purpose will undoubtedly differ greatly from others without being able to say whether it is generally right or wrong. The correctness, i.e. the suitability of artificial lighting, is determined based on the context of use, which includes the intended users, their eyesight, their working equipment and the room architecture. It is not difficult to accept the importance of the context of use if this differs greatly - here a disco, there a hospital. Yet it is much more difficult to make finer distinctions, e.g. to accept different age groups of the users, different viewing tasks within the office area, different room shapes in office buildings etc. as an important difference in the context of use and to take these into account.

According to the concept of usability it is not necessarily important whether lighting is intended for a disco or a hospital, but instead only on whether its users achieve "certain goals" in accordance with the three criteria of effectiveness, efficiency and satisfaction:

- **effectiveness** (ISO 9241-11): The accuracy and completeness with which users achieve specified goals.
  For lighting it means, for example, that a user can read all her / his documents without error.
- **efficiency** (ISO 9241-11): The resources expended in relation to the accuracy and completeness with which users achieve goals.
  With regard to lighting, the efficiency can, for example, be measured on how quickly the user can read her / his documents without error, or on whether and, if applicable, on how great an effort she / he must make to do so.

Both of these - effectiveness and efficiency - are not sufficient to determine the usability. This includes

- **satisfaction** (ISO 9241-11): Freedom from discomfort and positive attitudes to the use of the product.
  It may be, for example, that although the user can read her / his documents without error and quickly enough without being satisfied with a lighting system, because it causes discomfort glare.

Therefore, the usability of an object describes its suitability with regard to the requirements placed on its **use**. The use in turn represents a part of all requirements placed on the product, as the object of consideration, such as lighting, must be planned, installed, maintained and then disposed of again at some point in time. The relevant requirements interest persons other than the users and their fulfillment calls for other quality characteristics than those taken into account in the usability. For this reason, the usability is **one** characteristic of quality, however does not describe the entire quality. This is defined as *"the totality of properties and characteristics of a product or an activity which refer to the suitability for the fulfillment of given requirements."* (DIN 55350, Part 1) The differentiation between the (total) quality and the usability is helpful in recognizing why different people in a company reach different results under the same circumstances. While for the user the important aspects of artificial lighting within the scope of the usability are meaningful, the planner must, for example, also take both these and the additional quality characteristics as well as the costs into account.

But what are “given requirements” and who defines them? With regard to the lighting of a workplace, this can only be the company which, on the one hand, is interested in the carrying out of the working tasks and, on the other hand, must adhere to the regulations for safety and health at work. This is the reason why the new regulations for safety and health at work in particular, and above all the Act on safety and health at work, assume a “company orientation”, which in plain English means that the company knows its problems best, and is therefore more capable than other instances of finding their solutions. The totality of the requirements of a company for lighting concern its “quality”, of which the usability only represents one part, albeit a very important one.

The company orientation of measures, i.e. the breaking down of the evaluation of work tools, equipment and conditions, has two advantages - one for the company and one for the worker. The advantage for the company lies in the fact that, with a factual, company-oriented weighing of the situation, solutions can be found which, similar to a custom tailored suit, fit better than those though out uniformly in advance for an entire industry or even for a union of countries. The advantage for the workers results from the fact that general regulations must take the financially weakest companies or the least favorable general conditions into account. However, by definition, the majority of the companies are not included among the financially weakest and also not among those with the least favorable conditions. As a result, they can generally realize a better situation than can generally be prescribed. And although companies really can be found which do not follow the rules here and there, companies can seldom be found which are generally and exclusively oriented only towards what they must fulfill.

Defining the quality of technical products from the user's standpoint undoubtedly means a new, unaccustomed way of thinking, as it has always been assumed that products possessed an ***inherent*** quality. However, there are only very few products which actually demonstrate a quality completely independent of the context of use. Even the universal means which has advanced our technical civilization like virtually no other, the wheel, is completely useless and at times even impeding, e.g. when a vehicle is to be moved over marshy ground. It is, of course, for this reason that the world has had to be paved with roads for several thousand years in order to produce the proper context of use of the wheel. Nevertheless, some wheels require iron rails in order to roll. They are neither correctly nor incorrectly designed, but rather are correct for railways and incorrect for roads.

12.4.2 The reference to the "objective" product quality?

The concept of the usability would be worthless without a counterpart which describes the product quality for the manufacturer, so to speak "objectively". Manufacturers are generally unable to design products if they assume only requirements set up later by the user, a situation comparable to pointing at running targets before they have become visible. On the contrary, the manufacturer must be able to predict the relevant requirements as well as possible. The planners are also in the same position of, for example, having or wanting to select a product for a number of plants or different contexts of use. For a long-term investment object such as lighting, it would also be impractical to orient themselves on the respective context of use, e.g. on the new owner of a workplace, who is considerably older or younger than her / his predecessor.

To be able to operate successfully, the manufacturer can select one of the following strategies:

- *Attempt to change the context of use in such a way that a given product quality will prove to be correct.*
  This is equivalent to the procedure of building a road or railway track so that the wheel functions.
- *To describe those contexts for use under which a given product can be properly used.*
  This corresponds to the procedure of specifying the "proper" use. Users who use the product for a different purpose cannot complain of defective product quality. The manufacturer will either offer a single product which is appropriate for a limited use or a diversity of single products each suitable for a certain context of use. An example for a single product for a specified use is the bicycle wheel for speed race.
- *Design the product so flexibly that it will probably be able to meet the requirements of the user even under unforeseeable operating conditions.*
  An example of this is dimmable lighting. However, for understandable reasons a manufacturer cannot generally be obligated to use such a strategy. It is a voluntary service.

According to the first strategy, a planner, who for whatever reasons wants to use a certain luminaire or type of lighting, can ensure that the office rooms are designed accordingly. This method was, for example, used in the construction of so-called "intelligent buildings" in which many conditions of the building were standardized worldwide. In the same way "standard rooms" were planned and realized when building the central administration of a large vehicle manufacturer.

On the other hand, those who realize products for the general market will frequently have to make use of the second strategy. This is, for example, what a luminaire manufacturer does in its catalog by indicating the spacing of luminaire rows which must be adhered to for each type of luminaire so that the desired uniformity of the lighting intensity can be maintained for a given room height. Other aspects which the user must consider are contained in the standards. As a result, the user is familiar with the proper or “intended” use of this manufacturer's products.

The last strategy, flexible product design, is pursued in a more or less pronounced manner for many technical objects, for example for bicycles on which the user can adjust the seat and handlebars to meet her / his needs. And the bicycle is even more flexibly designed with regard to the transmission of power. When her / his needs change (e.g. transition from level ground to a slope), the user can immediately adapt this by changing gears, while a bicycle equipped with an automatic gear shift is even more advantageous.

It is also possible to demonstrate the disadvantage of flexibility using the last example. On the one hand, it generates costs and, on the other hand, must be provided with technical equipment which may be susceptible to breaking down. Therefore, flexibility is subject to certain limitations. It may even preclude itself if the user intended to profit from it tends to have problems with excessive flexibility, e.g. when a car is equipped with 21 gears for city driving, or even with an engine for each wheel. Such vehicles are only suitable for professionals who can make appropriate use of the given functionality. Other drivers are overtaxed by it.

In light of the above reasons, it makes sense to limit the normative regulations on the usability of products to defining the methodological procedure. The evaluation itself should be undertaken by the person familiar with the context of use. The manufacturer of a product must either design it for a context it describes (“intended” use) or, if possible, in such a way that the product can meet the requirements in any context (flexibility). The third possibility to change the conditions of use to match the existing product can only be considered if the product properties cannot be changed or are so useful that the user or operator also benefits from them (for example, the wheel).

12.5 Application of the usability concept to lighting

12.5.1 Specification of goals

The specification of the goals a company links with the design of a lighting system must take place on several levels in order to be able to identify any goal conflicts (Fig. 12.1). An example of this kind of conflict would be a type of lighting necessary for visual performance reasons which would place the room in an unpleasant “light”. This case occurs, for example, where a certain luminous color of the lamps is required to be able to distinguish color patterns well.

That level for which a properly acting user company does not discuss the meaning is the legal one. For ordinary workplaces it is formed by the Work Places Ordinance, and for work at display devices also by the Ordinance on safety and health at work with display screen equipment.

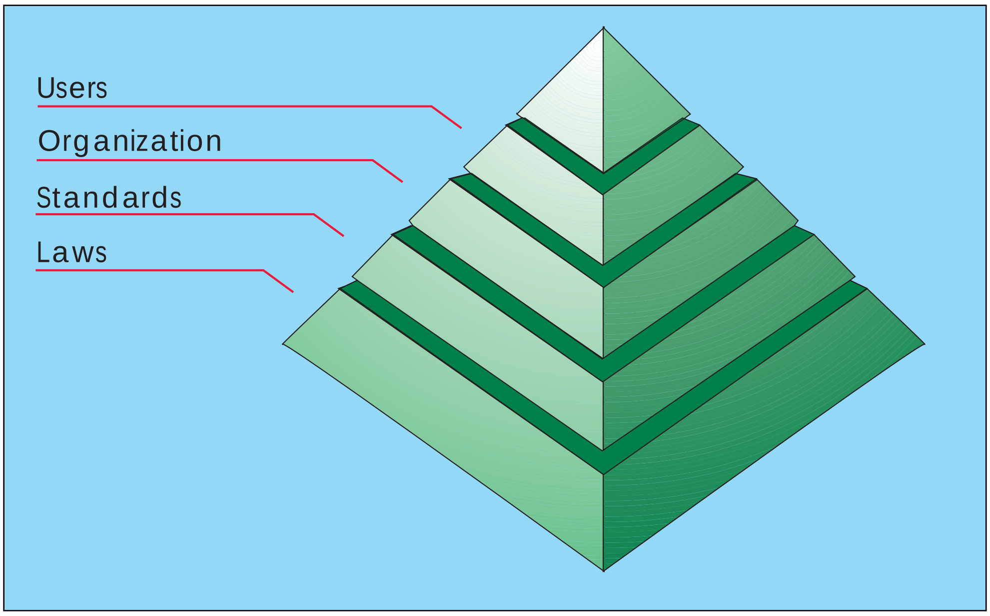
Another level is formed by the requirements of the standards which, however, must always be in agreement with the legal requirements. If a certain requirement of a standard contradicts the legal regulations, then the latter apply. Basically, a user can strive for a solution other than that described in the standard if she / he can fulfill the goals of the standard equally well or better with that solution. This principle not only applies with regard to standards, but for all regulations.

As standards and laws do not or may not describe all properties of a lighting system, the desired design is also determined on the next level, i.e. the company level. Here the work organizer is put forward as a representative for the company, because she / he is capable of formulating the requirements for use from the standpoint of work, even if she / he cannot be the sole decision-maker. On the contrary, she / he coordinates decision-making in cooperation with the committee for health and safety at work, the works council, building engineering, purchasing etc.

The top level of the concept is determined by the interests of the “people”, i.e. of the workers, because the object of the considerations is called improving of users safety and health at work. It must be noted, however, that the requirements resulting from the top level form a subset of the entirety of requirements.

This kind of procedure can easily be pursued in the office, however not everywhere. In work areas where lighting is not only working equipment, but, for example, serves decorative purposes, the interests between the user and other people (e.g. customer in business, visitors to a ballroom) must be weighed.

Fig. 12. 1 Arrangement of the levels of consideration of the usability in the form of an acceptance pyramid

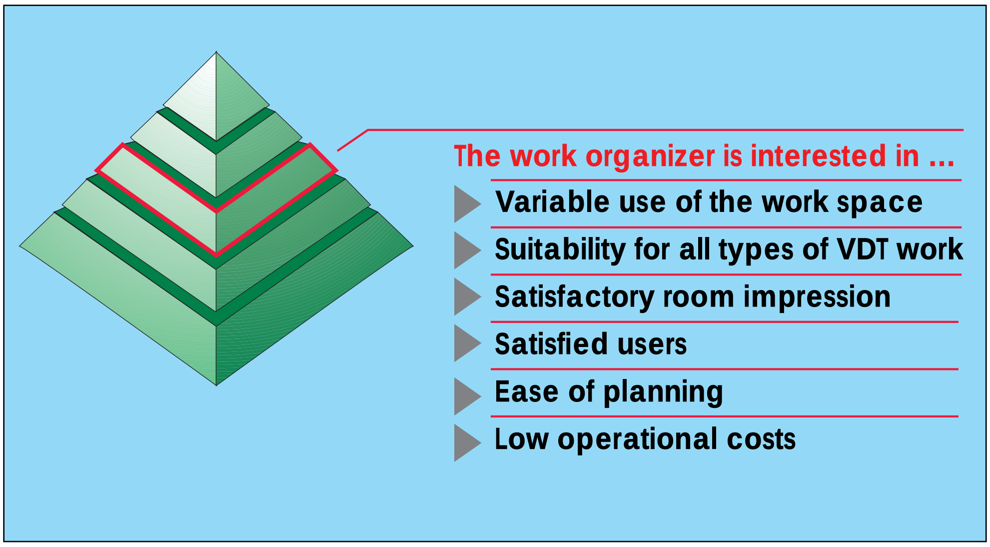


Good lighting should, in order to enjoy acceptance, match the two upper levels as well a possible and contradict the lower ones in as few points as possible. The latter statement does not mean that the provisions of laws and standards must be exactly adhered to, but instead the goals. Any technical design is permitted which achieves these goals equally as well as or better than the version which may be specified. *(Note: In more recent regulations, the realization of design criteria of products may no longer be specified anyway. For this reason, for example, a number of Accident prevention rules must be changed or withdrawn, because they contain so-called "construction and equipment regulations".)*

12.5.2 Requirements from the standpoint of the company

From the standpoint of the company, the important demands placed on an evaluation of the usability of a lighting system are based on the most universal use possible for every type of work at computerized workplaces, the fulfillment of the user requirements and, if possible, also of planning and low operating costs (Fig. 12.2)

Fig. 12. 2 Summary of the requirements of the work organizer for a lighting system



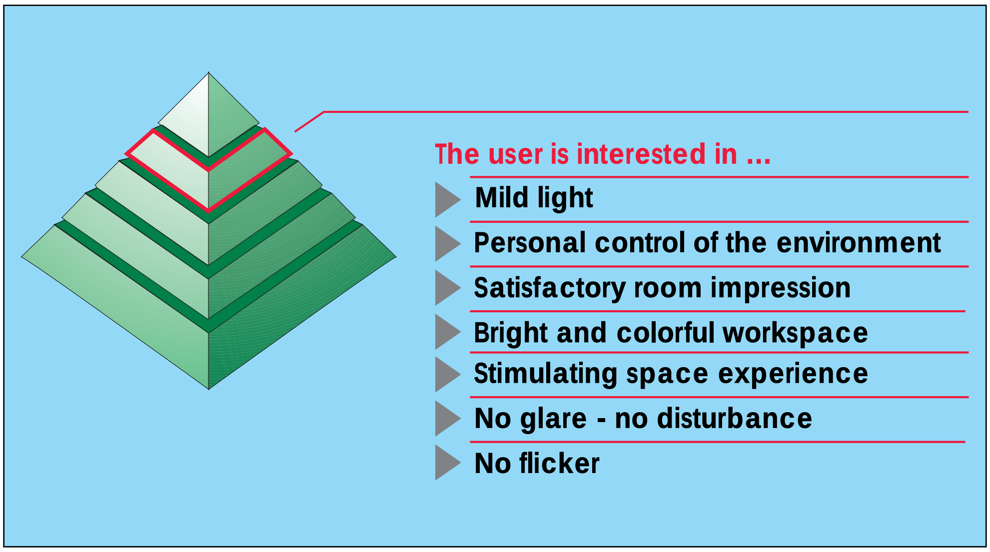
The order of listing approximately corresponds to the ranking of the considerations. The fact that the operating costs are listed last does not mean that they are unimportant. On the contrary, the order results from the logic of economy considerations - first the use, then the costs.

It can be seen from the diagram that two important points, i.e. optimum room impression and satisfied users, are also of interest to the users. The reasons for this are both the efforts of the organizer to create the most satisfactory and “pleasing to the eye” conditions and the programmed trouble with the users and / or their superiors if the result is not pleasing.

12.5.3 Requirements from the standpoint of the human being

For the user, the freedom from disturbances and acceptability of the lighting are of primary interest, whereby these are frequently first recognized as acceptable when an individual is able to exert a personal influence on her / his environment (Fig. 12.3)

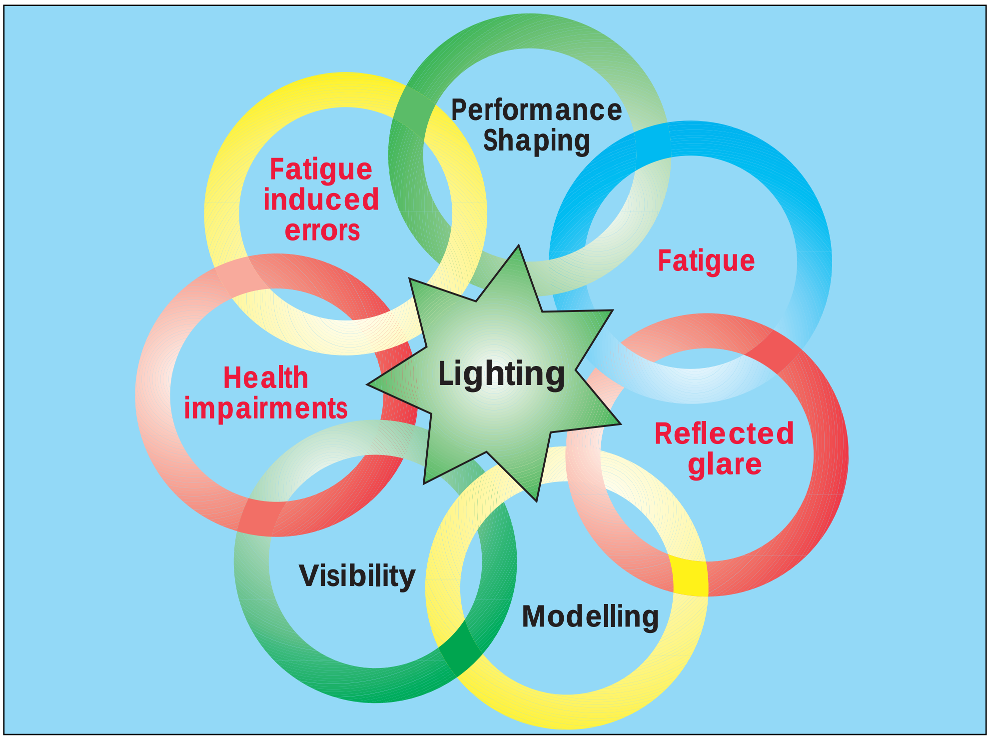
Fig. 12. 3 Summary of the user's requirements for a lighting system



The reason for the requirements put together above was derived from the knowledge described in this report, so that further explanation can be dispensed with at this point.

In general, the user's requirements result on the one hand from the room effect of the lighting, however on the other hand from the promotion of her/his efficiency through the lighting system, which may not be confused with the visual performance. The individual influencing factors are shown in Fig. 12.4. The black aspects shown in capital letters represent positive effects of the lighting system, while those in red show the negative ones (disturbances). A lighting system suitable for use maximizes the performance through a visual performance sufficient for the task, the emphasis of the corporeality of the viewing objects (modeling) and activates the organism with a bright and stimulating environment. The negative effects can be divided into direct (disturbing glare or poor contrast) and indirect (fatiguing, e.g. due to disturbing glare, fatigue-related errors and health impairments).

Fig. 12. 4 Positive and negative influences of lighting on the performance of human beings



This rather complicated picture is not intended to represent an incentive to conduct scientific studies, but rather to help find decision-making criteria for the specific case, as is shown in the following examples.

Example 1 *Working with primarily glossy documents (advertising agency, studying of magazines, working with films etc.).* Here it is particularly important to avoid disturbing glare. Indirect lighting is best suited for this purpose. By brightening up the room, it also makes a positive contribution to activation. However, to achieve a good room effect, the lighting should not be too diffuse. The lighting level is relatively meaningless, because the avoidance of disturbing glare has a considerably greater influence on the visual performance than, for example, a high level of illumination.

Example 2 *Working at a CAD system without paper documents:* The focus is on the visual performance at the display unit, frequently the recognition of colors on the screen. The antireflection coating of these screens is generally poorer than that of other office screens, as they are frequently operated in negative mode. A lighting system must be selected which does not lighten the room walls too strongly. In large rooms, where the reflections of the ceiling can also be seen on the screen, the luminance of the ceiling must be kept to a minimum. Suitable lighting types may be indirect lighting or CRF luminaires, preferably dimmable.

Regardless of which lighting system is given preference, it is important that the selected technology supports the feeling of brightness as well as possible, however produces the lowest illuminance on the visual display unit. The feeling of sitting in a bright room plays a special role in this work, because it is frequently carried out for longer periods at a time. Designers tend to work at certain times without taking working hours and breaks into consideration. In such cases a dark room feeling can lead to fatigue and errors by having a negative influence on activation.

Particular attention must also be directed at glare, as CAD work produces a much greater strain on the eyes than data or word processing

Example 3 *Mixed work:* The requirements for lighting vary from time to time, from workplace to workplace. For certain tasks the visual performance is the most important factor, and for others it is virtually irrelevant. The lighting should be designed with particular attention to the difference and incalculability of the visual tasks. For this purpose a lighting system with workplace luminaires provides the best conditions. As it is itself sufficient to produce a higher illuminance level than is even required for most visual tasks at the office, the importance of the remaining parts of the lighting lies in producing the room effect. Here indirect lighting, so-called “mild light“, CRF lighting are suitable.

12.5.4 Decision-making for the general case

If a decision is required for which a lighting design with a sure future without a differentiation of the individual tasks is important which, experience shows, is a frequent problem for the office planner, the future context of use should be estimated. This can be determined with sufficient accuracy from the development of office technology. This development will not only result in a further propagation of computer screens in general, but also to the increased introduction of so-called imaging systems, i.e. of computer applications where work is carried out with little or no use of paper. The required technology is already available and ready for use. The calculable (and tested) advantages for increasing productivity allow a relatively rapid propagation to be assumed. Currently the costs and the lack of knowledge of the proper organization are the only things which may be slowing the development of such systems.

We should not allow ourselves to be fooled by this, as was allowed to happen with the computer applications in the early 80's. At that time it was questioned whether “such a thing” was really needed and various ideas about the pro´s and con´s of computer usage were presented at conventions before an interested audience. Today these questions are no longer discussed, and it will probably be the same with imaging. As a result, anyone who is planning a lighting system today should also concern themselves with the related problems. These are in particular an oversized screen (today 21“), a quality of the scanned documents which tends to be poor and can at best be improved in the long term, and a light-sensitive screen of which an improvement will also be of a long-term nature. All in all not a matter gentle to the eyes!

While imaging represents **the** application of the future for companies such as insurance companies or banks, other companies will have to concern themselves with new computer applications which all operate with color on the screen, and this means an increased dependency on artificial light and controlling it than is common today - and also an increased strain on the eyes. The screens will also become larger.

We must prepare ourselves for both developments, as no user organization can afford to be scared off by the related disadvantages in view of the advantages of the new possibilities. A possible starting point for alleviation of today's and tomorrow's problems lies in the lighting systems.

One route to decision-making on the company level on the basis of the usability concept is shown in Fig. 12.5. This diagram illustrates the respective best solutions to the individual requirements. The requirements with regard to simple planning and the costs had to be left open. They must be checked in the individual case just as the overall conclusion must be checked. This should be drawn by the company in accordance with the procedure propagated in this report and no one else, provided it does not violate a legal regulations.

Before an overall conclusion is drawn, it should be considered in dependence on the possibilities of the company whether it wouldn't be appropriate then to convince one's self using actual examples. Large companies can organize test installations in their rooms in accordance to the model of the studies described in Chapter 11 for this purpose. Others can conduct an inspection of the work rooms of companies in their vicinity in which various lighting types are installed. Experience shows that the examination and the discussions with the users is more convincing than any scientific paper. In addition, the mental background of the new legal regulations lies, as already stated, in the decisions on the measures for safety and health at work becoming “company oriented”. This can certainly be better taken into account with this type of procedure than with any other.

Fig. 12. 5 The respective best fulfillment of the individual requirements for the lighting system

The user is interested in ...	best match offers ...
Mild light	Indirect lighting, CRF, "Mild light"
Personal control of the environment	Task luminaire
Satisfactory room impression	Indirect lighting, CRF
Bright and colorful workspace	Indirect lighting
Stimulating space experience	Balanced luminance distribution in space
No glare - no disturbance	Indirect lighting, task luminaire
No flicker	Elektronic ballast
The work organizer is interested in ...	
Variable use of the work space	Indirect lighting
Suitability for all types of VDT work	2 - Component lighting
Satisfactory room impression	Balanced luminance distribution in space
Satisfied users	2 - Component lighting
Ease of planning	Compare
Low operational costs	Compare

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