AN EVALUATION METHODOLOGY FOR ASSESSING ARTIFICIAL LIGHTING QUALITY IN ARCHITECTURE:
THE CASE OF APIKAM

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ABSTRACT

AN EVALUATION METHODOLOGY FOR ASSESSING ARTIFICIAL LIGHTING QUALITY IN ARCHITECTURE: THE CASE OF APIKAM

The aim of this dissertation is to design a qualitative evaluation methodology for artificial lighting. There is a problem in the general characteristics of lighting industry, deriving from its technical vocabulary which is mainly based on quantitative parameters, values, and systems which in some ways are neglecting the main ingredient of architecture: the user.

The evaluation methodology that is subject of this dissertation was considered as a qualitative approach to lighting quality. The study benefited from the knowledge of environmental psychology, concerning the effect of lighting on behaviors and tried to integrate it to the process of assessing lighting quality. The methodology depends on data collection by various means such as surveys, measurements, and computer simulations.

To test the qualitative evaluation methodology, a case study was designed in the exhibition hall of the Ahmet Piriştina City Archive and Museum (APIKAM) in İzmir. The evaluation methodology was successfully operated and made a detailed evaluation possible on the two lighting systems in the exhibition hall of APIKAM. Both lighting systems failed in functional aspects, because of the high intensity of light they produce, the emission of UV and IR wavelengths, and glare problems. They are simply not appropriate for the selected environment, where organic – based materials are exhibited. Recessed fluorescent lighting system failed in physiological aspects as it triggers less arousal than halogen spotlighting system. Both lighting systems have failed in attention scale under psychological aspects, because none of them supply continuity in the order of visual clues that match with the sequential order of the exhibition. For aesthetic and environmental judgments, the results of the survey showed that halogen lighting system was the preferred one by the subjects. For the sub-part of feelings, recessed fluorescent lighting systems failed, because it influenced generally negative feelings, while positive feelings are generally influenced by halogen spotlighting system.

ÖZET

MİMARLIKTA YAPAY AYDINLATMA NİTELİĞİNİ BELİRLEMEK İÇİN BİR DEĞERLENDİRME YÖNTEMİ: APIKAM ÖRNEĞİ

Bu tezin amacı yapay aydınlatma kalitesini belirlemeye yönelik niteliksel bir değerlendirme metodolojisi geliştirmektir. Aydınlatma endüstrisinin temel problemi niceliksel parametreler ve sistemler üzerinde yükselen teknik yapısıyla mimarlığın temel bileşenlerinden biri olan insan faktörünü gözardı eden bir kurguya sahip olmasıdır.

Değerlendirme metodolojisi, aydınlatma aracılığı ile oluşan mekansal dinamikler üzerinde etkisi olduğu düşünülen tüm değişkenleri gözeten niteliksel bir yaklaşım olarak gözetilmiştir. Aydınlatmanın davranış üzerindeki etkilerini de gözeten bu çalışma bilgi alanı olarak çevre psikolojisinden yararlanmış ve bu davranışsal etkileri aydınlatma kalitesinin belirlenme sürecine dahil etmeyi amaçlamıştır. Veri toplamak amacıyla anketlerden, manuel ölçümlerden ve bilgisayar simulasyonlarından yararlanılmıştır.

Değerlendirme metodolojisini test etmek amacıyla, İzmir Ahmet Piriştina Kent Arşivi ve Müzesi (APIKAM) sergi salonunda bir çalışma alanı oluşturulmuştur. Geliştirilen metodoloji, APIKAM sergi salonunda mevcut iki aydınlatma sistemine ilişkin olarak detaylı bir değerlendirmeyi mümkün kılmıştır. Her iki aydınlatma sistemi de, ürettikleri ışığın yüksek yoğunlukta olması, UV ve IR dalgaboylarını ışımaları, ve de yarattıkları kamaşma problemleri nedeniyle fonksiyonel değerlendirmeler özelinde başarısız olmuştur. Her iki sistem de organik kökenli malzemelerin sergilendiği bir ortamın aydınlatılması için uygun değildir. Fizyolojik değerlendirmede, florasan sistem, halojen sisteme oranla daha az uyarıcı etkiye sahip olduğu için başarısız olmuştur. Psikolojik değerlendirmede, her iki aydınlatma sistemi de dikkat ölçeği özelinde, mekan hiyerarşisi ile çakışan bir görsel izlek oluşturamadıkları için başarısız olmuşlardır. Anket sonuçları, estetik ve mekansal yargılar ölçeğinde, tercih edilen aydınlatmanın halojen sistem olduğunu göstermektedir. Duygusal tepkiler özelinde, florasan aydınlatma sistemi, genel olarak olumsuz duygulanımları tetiklediği için başarısız olmuştur.

To my family

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CHAPTER 1

INTRODUCTION

Artificial lighting has been one of the important basics of architecture, since it provides possibility to all kinds of activities especially at night, when the natural source of illumination –the sun- is not available. The invention of electricity at the end of the nineteenth century initiated a new era for architecture, where electric lighting became a crucial component for spatial quality. As Mies van der Rohe stated, the history of architecture is the history of man's struggle for light (Trauthwein 2003). Light plays a central role in the design of a visual environment. The architecture, users, and objects are all made visible by the lighting. However, light is no longer just an essential element that is needed when it is dark. Moreover it is an effective instrument influencing our perception of architecture, consequently our appreciation of spatial quality.

Architecture is a multi-layered profession interrelated with varying disciplines such as art, engineering, psychology, sociology, philosophy, etc. Each of these varying disciplines has its own unique terminology, regulations, and ways of manipulating problems. When "quality" is at stake; all these varying disciplines would define and judge from different perspectives. Thus "spatial quality" should be assumed as a summary of all these perspectives.

1.1. Definition of the Problem

During the twentieth century electric lighting became the subject of a profession with its own enormous terminology and conventions. The most important innovation was the appearance of lighting engineering in the light of the idea that artificial lighting was a technical theme. This evolution was the natural result of a belief that lighting comprised a science and solving lighting problems needed a technical and scientific formation. There is nothing unusual or wrong about this belief. Actually it may be seen as a necessity for this profession to be able to improve in the world of technology and rationality, where specialization is fundamental. Thus the new profession soon established its own sphere of terminology which was mostly defined by engineers and technical specialists. Architects and lighting engineers established a collaboration from the start and together determined the night-time look of cities. This co-operation, however, did not last long, since lighting engineering soon became the one and only profession with its large supporting technical background and technical vocabulary that enabled deciding the night-time look of cities (Jones 1983).

The problem here lies in the general characteristics of this technical vocabulary which is mainly based on quantitative parameters, values, and systems which in some ways neglect the main ingredient of architecture: the user.

The other problem is the light engineers' understanding and treatment of quality which perhaps unconsciously separates "lighting quality" and "spatial quality" from each other. This judgment could be seen as too harsh, but then, what could be the explanation for the absence of the major peculiarities of "spatial quality" in the definition of good lighting criteria? The British Lighting Council (1962) defines good lighting as follows:

> …What then, is good lighting? It is not just good lamps, or good fittings, or plenty of light, or lack of glare, or suitable color or a workmanlike installation, or lighting well maintained. It isn't either daylighting or electric lighting. It is all these things put together in such a way that people can get on with it safely, quickly, certainly, and easily; and all at a reasonable cost in relation to other essential costs.

It is remarkable that all mentioned criteria are related to visual ability, safety, and economics. It is important to recognize that the focus of lighting researchers has been the optimization of visual performance. Their investigations concern the characteristics of lighting and tasks that make details easy to see and that would enable safety in spaces. Non-visual aspects of the lighting-space relationship, such as motivation, subjective impressions of the illumination, behavioral outcomes, and physiological effects have been clearly of secondary interest.

According to lighting engineering good lighting is related to the supplied visual abilities, illuminance levels, and uniform distribution of light. Throughout the twentieth century several models had been developed to measure and predict lighting quality, such as Visibility Level Model (VL), Equivalent Sphere Illuminance (ESI), Visual Comfort Probability (VCP), and Relative Visual Performance (RVP). Most of these models are still in use today and mostly deal with the issue of visual abilities and disabilities in space. There are some other models which are concerned with economics and energy consumption.

Supplying visual ability and achieving required illuminance levels do not necessarily ensure good lighting quality. The quality as well as the quantity of illuminance is important in producing a comfortable, productive, aesthetically pleasing lighted environment and achieving “quality” in lighting needs to take users into consideration with all the requirements without limiting it to visual ability alone. Today, our most comfortable, pleasant spaces are those in which designers and users have retained control over the lighting: spaces such as museums, cinemas, and restaurants, in which objects of interest are correctly emphasized by the luminous environment. The lighting in private homes is generally satisfactory and pleasant for the same reason, because it has usually been designed and adjusted by the users to suit their specific needs for visual information, not to achieve some mandatory prescribed amount of light.

Various researches have demonstrated that light has a profound impact on people, which should be studied under varying criteria such as spatial aesthetics, psychology, physiology, etc. While fulfilling the visual needs, lighting engineering does not pay much attention to physiological and psychological comfort and spatial aesthetics.

Light is a visual phenomenon which can affect motivation and performance levels. Light also affects our biological clocks in the following manner: It is well known that circadian rhythms, such as sleeping or waking cycles, are influenced by light. Many business travelers use melatonin tablets to help them maintain their work efficiency and performance when they travel to locations in different time zones. What many people do not realize is that simply increasing their exposure to light could also help them naturally alter their melatonin levels (Steelcase 1999).

Lighting on the other hand has a strong psychological effect on people. It has many emotional qualities that can considerably change people's moods. Light influences our well-being, the aesthetic effect and the mood of a room or area. Phototropism is another psychological effect of light. Since lighting is always a part of our physical environment, it is not much to say that we are constantly manipulated by lighting.

Lighting quality should be redefined as the degree to which a lighting installation fulfils all the requirements of user needs, which have been summed up under three main headings as physiological, functional, and psychological in this dissertation. Moreover, good lighting should also consider spatial aesthetics, economics, and energy consumption. Technical know-how is sine-qua-non for lighting. However, concepts of lighting quality could be enhanced in order to serve spatial quality determined as in architecture. It is certain that lighting is a science and will remain so. However, being so much related to architecture and being so much active in the creation of spaces, it is believed that the lighting industry should be open to some further concepts from other disciplines such as architecture, art, and psychology.

1.2. Background

> I believe in an emotional architecture. It is very important for humankind that architecture should move by its beauty: if there are many equally valid technical solutions to a problem, the one which offers the user a message of beauty and emotion, that one is architecture.
>
> Luis Barragan (Ambasz 1976)

Lighting can be used to modify spaces in many different ways. It can reveal or conceal surfaces, heighten or diminish spaces. The theatrical lighting designer and the artist have often exploited lighting in this way, and there is much that the architect and lighting engineer can learn from them (Hopkinson 1969).

According to Millet (1996) our experience of light is connected to specific places where light contributes to the identification of *genius loci*, the peculiar character of a place as it is impressed upon our minds. She also adds that ideally, light not only fulfills its function of providing illumination for visual activities but does so in a way that enriches our experience.

It is useful to discuss the lighting problem from another aspect, which is beyond the purely “lighting function” which will depend upon the physiological needs of those using the space. It is the architectural function relating lighting needs to all other design considerations that must form part of the architectural compromise (Philips 1989).

Lam (1992) discusses the quality problem in lighting as follows: “A comfortable, pleasing, relevant environment is as important as visual performance determined by the conditions of good lighting” . Quality, rather than quantity, is the key to good lighting. A small improvement in the quality of the luminous environment produces better visual performance than a large increase in intensity. Lam (1992) adds that lacking an understanding of the basic principles involved, the technicians who now control our luminous environments have reduced the criteria for illumination to simple numbers, which are basically unrelated to vision, perception, comfort, or pleasure.

Lechner (1990) demonstrates that lighting is considered only as a problem in quantity and not as a problem of quality which must be integrated with architecture. Ignoring quality has always been at the expense of visual performance. The change in the atmosphere of a space denotes a qualitative chance in which quantity of light is of only secondary importance (Von Meiss 1990).

The appropriate quantity of light contributes to the achievement of good quality, but is not its sole determinant. Other dimensions, including illuminance uniformity, luminance distributions, spectral power distribution, and glare are potential contributors to overall lighting quality (Miller 1994). What is "appropriate" depends on the setting, activities, aesthetics, and other user needs in the space. Furthermore, the characteristics of the people who will use or experience the space also influence whether or not the lighting installation will achieve good quality (Boyce 1981).

Flynn et al. (1992) noted that lighting, in addition to providing task visibility, also influences motivation, orientation, mood, social interaction and well-being.

A large number of research projects that compare the effects on health, well-being and alertness as a result of people working under different lighting conditions have been carried out. The results show that good lighting indeed has important beneficial effects, not only visually but also biologically. Bommel and Beld (2003) stated that, on the basis of research on the biological effects of lighting, it is evident that the rules governing the design of good and healthy lighting installations are, to a certain degree, different from the conventionally held rules. Not only the light cast on the visual task, but also light that enters the eye determines the overall quality of lighting.

The standard design process, fostered by the Illuminating Engineering Society (IES), is obviously unsuited to produce a high-quality fit between needs and luminous environment, nor was it ever intended to produce such a fit (Lam 1992). A lighting concept should be derived from the set of programmed activities and biological needs, so that the definition of the luminous environment will complement and reinforce the general architectural concepts; then - only then – should details and hardware be selected to execute the concept (Lam 1992). Lam continues to argue that this is the diametric opposite of the typical "engineered" approach, which starts with the selection of light fixtures and then, taking them as givens, places them in patterns to achieve predetermined illumination levels. Veitch and Newsham (1996) have argued about lighting quality as follows:

> The failure to reach agreement about lighting quality has been seriously impeded by the failure to recognize the question as one part of the larger attempt to determine the nature of environmental quality, provided to support human activity. The outcomes that benefit from good lighting quality are behavioral outcomes. Behavioral scientists have been remiss in not looking to the lighting literature for a different perspective. Lighting researchers have been remiss in not following the behavioral literature, and in particular its standards for research design, methods, statistical analysis, and reporting. In consequence, we know less about lighting quality than we should after more than a century of lighting practice and ninety years of its professional organizations.

1.3. Objectives

In this dissertation light is examined as a creative design tool not only with its ability to supply visual communication in space, but also in terms of its contributions to space and spatial dynamics in various degrees and its effects on users on both physiological and psychological scales. The aim of this dissertation is to design a qualitative evaluation methodology for artificial lighting, which will help criticize and judge the quality of a pre-installed artificial lighting system by forming criteria related to visual and non-visual effects of light. The secondary intention is to carry out the main concepts and the in-between parts of lighting and space relationship and to fill the gaps in illumination techniques under the guidance of spatial quality concepts.

1.4. Methodology

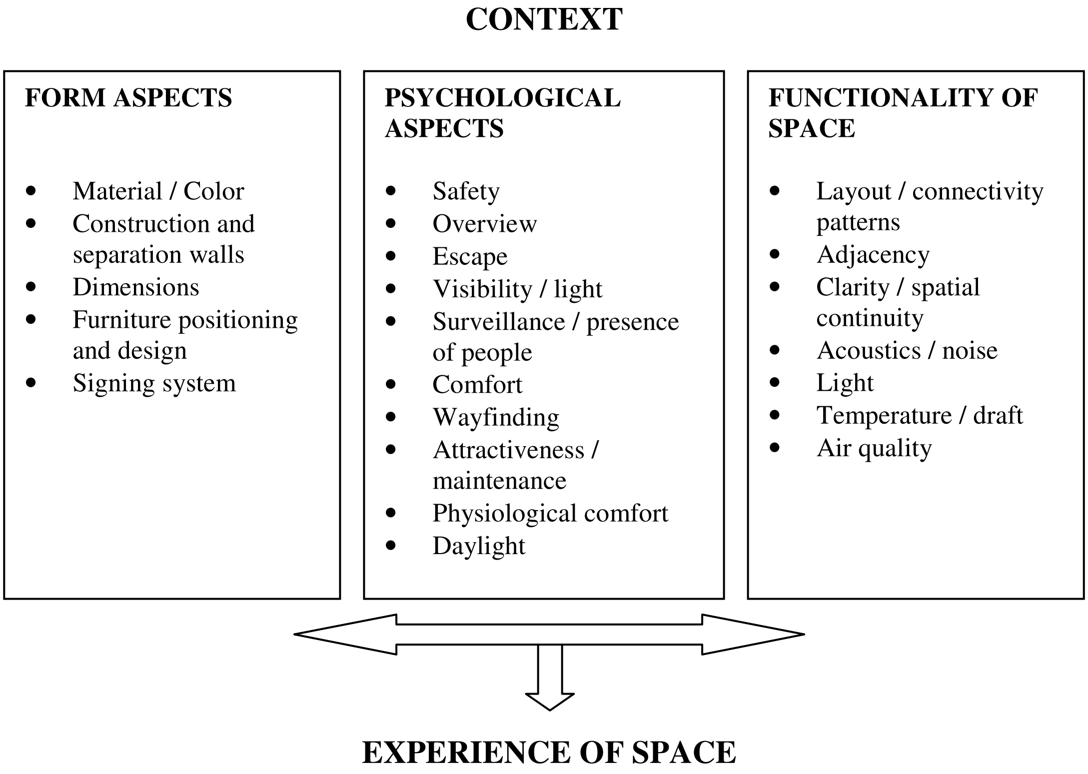
The evaluation methodology that is subject of this dissertation is considered as a qualitative approach to lighting quality as it tries to deal with all the variables which are thought to be effective in spatial dynamics created through lighting. Beyond lights' main (and mostly known) ability of setting up the required conditions in terms of seeing; its effects on the appearance and perception of the architectural body and architectural components; and its effects on users both in physiological and psychological scales have been taken into account. Lighting study so far has produced a large body of knowledge concerning the visual effects of light and created several models as well as regulations for controlling light for that purpose, with little attention to other consequences such as the architectural space itself, and behavioral outcomes. This study may be seen as a way of integrating the non-visual effects of light in the process of ascertaining lighting quality, without neglecting the visual parameters instead of feeding from them. In this framework, this study will attribute to the analysis of artificial lighting quality without reaching one unique numerical data, instead, an evaluation where numerical and non-numerical variables have been together interpreted. With an intention to cover all possible features in the lighting-space-user relationship, the evaluation methodology is structured as a combination of various aspects, as physiological, functional, and psychological respectively. Each of them works like a plug that includes several variables inspected under various lighting conditions such as illuminance (amount of light), luminance distribution, glare, lighting systems, and color. The evaluation methodology is subject to change in accordance with the architectural function, as each function has its own unique requirements in terms of lighting. As the structure of the evaluation methodology is formed of separate plugs, it is possible to add different aspects or remove some of them according to the intended function of space. This distinctive feature renders the constructed methodology valid for varying architectural functions upon little modification. Unlike the quantitative models developed by light engineers, in this qualitative approach, each part results in separate outcomes. These outcomes under three variables together form an answer for the quality of lighting in a space with detailed recommendations. Thus, without trying to reach a single magical number, all numerical and non-numerical factors were together evaluated to assess the quality of lighting.

Prior research about lighting from varying disciplines such as architecture, engineering, and environmental psychology were examined in order to reach the criteria in terms of architectural aesthetics, physiological, and psychological needs.

The main structure of the evaluation methodology is inspired from a study, done by Durmisevic and Sarıyıldız in 2001 in Delft University of Technology, which is a model for quality assessment of underground spaces-public transport stations. The main idea of that study was to deal with all the variables which were thought to be effective in terms of quality. Durmisevic and Sarıyıldız (2001) designed a conceptual framework (Figure 1.1); based on the idea that architecture integrates both function and form. According to them, through function and form, the psychological aspects are interwoven by having an influence on the experience of space in a given context. Only when both are together they give to each other a meaning and a quality. Under three main aspects as functional (Qf), psychological (Qp), and structural (Qs); 23 variables were examined in detail for quality assessment. The level of quality was determined as the sum of these three aspects (∑Q) (Figure 1.2). Thus, it is important that the design has an appropriate response for each variable.

Functional aspects comprise the functional requirements for an underground station, internal connections of the spaces and efficiency of movement. Psychological aspects are all aspects that are related to the user's experience of a space beginning with public safety on one side and comfort on the other. Structural aspects include the overall quality of the construction including its flexibility and possibility to change. In other words, the main technical requirement of a structure is sustainability.

This work of Durmisevic and Sarıyıldız has influenced this dissertations' methodology in a particular way, which is the idea of dealing with every variable that is thought to be effective in spatial quality. A conceptual framework was formed, which is peculiar to lighting-user-space relationship. Then each variable under the conceptual framework were inspected under various lighting conditions. This topic will be explained in detail in Chapter 3.



CONTEXT

FORM ASPECTS

- Material / Color
- Construction and separation walls
- Dimensions
- Furniture positioning and design
- Signing system

PSYCHOLOGICAL ASPECTS

- Safety
- Overview
- Escape
- Visibility / light
- Surveillance / presence of people
- Comfort
- Wayfinding
- Attractiveness / maintenance
- Physiological comfort
- Daylight

FUNCTIONALITY OF SPACE

- Layout / connectivity patterns
- Adjacency
- Clarity / spatial continuity
- Acoustics / noise
- Light
- Temperature / draft
- Air quality

EXPERIENCE OF SPACE

Figure 1.1. Conceptual Framework in Detail
(Source: Durmisevic and Sarıyıldız 2001)

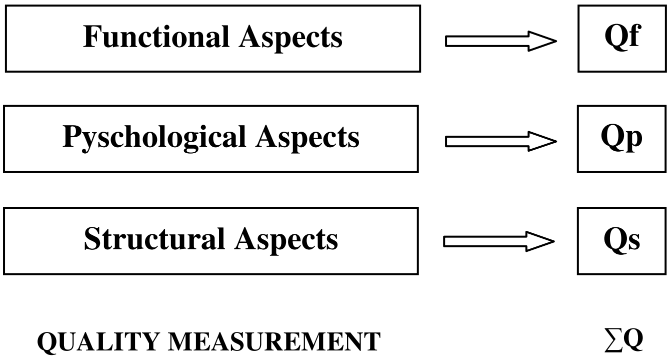


Figure 1.2. Determinants of Spatial Quality
(Source: Durmisevic and Sarıyıldız 2001)

1.4.1. Case Study

To test the qualitative evaluation methodology, a case study was designed in the exhibition hall of the Ahmet Piriştina City Archive and Museum (APIKAM) in İzmir, which was a fire station before the renovation done by the Municipality of İzmir between the years 2002 and 2004. The building is now used for cultural and educational purposes as the City Archive and Museum.

The main reason for choosing this space was that it is illuminated only by means of artificial light, which is made possible by two different lighting systems. The first one is a ceiling recessed fluorescent box system with a transparent methacrylate flat diffuser. Each box includes four fluorescent tubes with 5400 lm light output. 40 boxes with 216000 lm in total are used to illuminate the space. The second lighting system is a halogen spotlighting system which is mounted on tracks on the ceiling with four different suspension heights as 40, 60, 80, and 160 centimeters respectively. Each spot has 1279 lm light output at a 10.0° light angle. 217 spots with 277543 lm in total are used to illuminate the space. The two different lighting systems are not operated at the same time. There is not a distinct order known for the selection between them. Although the question was put, no satisfactory answer was obtained. It looks like it is a random choice mostly related to economical parameters, because the more preferred lighting system is the recessed fluorescent box system which is five times cheaper to operate. The lighting systems are assembled by an individual who owns a lighting store in Manisa. He mentioned that, his main aim when designing the lighting systems was to have a direct light on each task surface and create a dramatic effect in the exhibition. He added that the fluorescent lighting system was not his choice. He claimed that the fluorescent lighting system was demanded by the employer for supplying basic task lighting (visual access, safety) at times when no visitors are present in the exhibition.

The exhibition is mostly visited by students from high schools and universities, so the average user age range is between 15 and 30. Visits are made generally in groups under the supervision of an official guide, with a lecture about the history of İzmir. The exhibition includes three parts consisting of the headings; History of İzmir (3000 B.C. - 1933 A.C), City and Trade (1838-1933), and City and Fires. There is no real statistics available for the amount of visitors for this exhibition. The official guide claimed that the amount of visitors is up to the seasons. The added that in fall, winter, and spring, when the schools are open, they welcome group visitors at least two days in a week in general. He mentioned an approximate number of 150 visitors per week for high season. In summer the exhibition welcomes a small amount of individual visits.

The exhibition hall is rectangular in shape and formed by three rectangles attached to each other side by side without any auxiliary spaces in the places of transition (Figure 1.3). It has an area of 436.93 square meters.

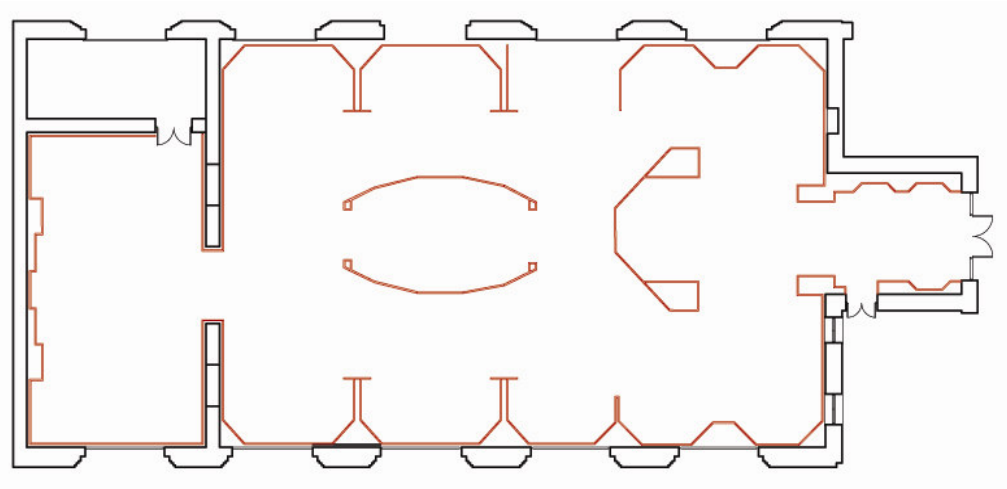


Figure 1.3. Plan of the Exhibition Hall in APIKAM

The walls in the exhibition are smoothly plastered and colored with a water-based very light matte yellow paint which has a reflectance factor of 0,70. The suspended ceiling is matte white and has a reflectance factor of 0,78. The shiny granite floor receive direct light from both of the lighting systems and has a reflectance factor of 0,68. The task surfaces are of laminated wood in matte white and have a reflectance factor of 0,65.

1.4.2. Survey

A survey was carried out to assess user evaluations related to the two lighting systems of the exhibition hall in APIKAM. The survey included five sections which deal with different dimensions of the lighting-user-space relationship, as personal information, lighting and task, aesthetic and environmental judgments, feelings, and perceptual preferences.

The first section includes four questions related to sex, age, job, and visual disabilities. The second section includes four questions too which ask subjects to critic their visual abilities within the space according to lighting systems. The third section includes eleven questions to help subjects judge the lighting systems within aesthetical and environmental scales.

The fourth section is a P.A.D. scale seeking for emotional outcomes related to lighting with fourteen pairs of adjectives. P.A.D. is a three dimensional temperament model developed by Mehrabian (1976). The latter theorized that one can describe any emotion with these three dimensions: pleasure-displeasure (P), arousal-nonarousal (A), and dominance-submissiveness (D). “P” signifies that one experiences more pleasure than displeasure. It relates positively to extraversion, affiliation, nurturance, empathy, and achievement, and negatively to neuroticism, hostility, and depression. “A” signifies that one responds strongly to unusual, complex, or changing situations. It relates to emotionality, neuroticism, sensitivity, introversion, schizophrenia, heart disease, eating disorders, etc. “D” signifies that one feels in control over his/her life. It relates positively to extraversion, assertiveness, competitiveness, affiliation, social skills, and nurturance, and negatively to neuroticism, tension, anxiety, introversion, conformity, and depression.

The fifth section includes two questions for assessing perceptual preferences and attention levels according to the lighting systems.

Each subject filled the survey twice, once for the ceiling recessed fluorescent lighting system and once for the halogen spotlighting system. Before filling the surveys they were explained clearly what to do and were asked freely to visit the exhibition for five minutes under each lighting system. Most of the questions included a likert scale from 1 to 5. Subjects checked a number which was closer to their opinion. 67 subjects participated in a time span of three days. The amount of subjects covers the two thirds of the amount of visitors for three days. The general profile of the subjects in terms of age, sex, job, and visual disabilities is given in Table 1.1.

The data collected through surveys is evaluated with the software named "Analyze It for Excel" which includes Anova, Manova, Chi Square, and other tools to obtain the correlations among different variables. The collected data is exposed to four different tests with the help of this software. The first test is a categorical summary which finds the mean and standard deviation of the selections. The second test is the t-test with a hypothesis that Ceiling Mounted Fluorescent Lighting System ≠ Halogen Spotlighting System. It checks whether there is a distinct variance between the two lighting systems related to the selected parameter or not. The third and fourth tests seek the variance related to sexual preferences and age differences respectively.

Table 1.1. General characteristics of subjects participated in survey

Sex	Female	38
	Male	29
Age	20-30	39
	30-35	17
	35-40	8
	40-50	3
Job	Student	39
	Public Officer	8
	Officer	13
	Freelance	7
Visual Disabilities [corrected]	Longsighted	14
	Shortsighted	4
	Astigmatic	5

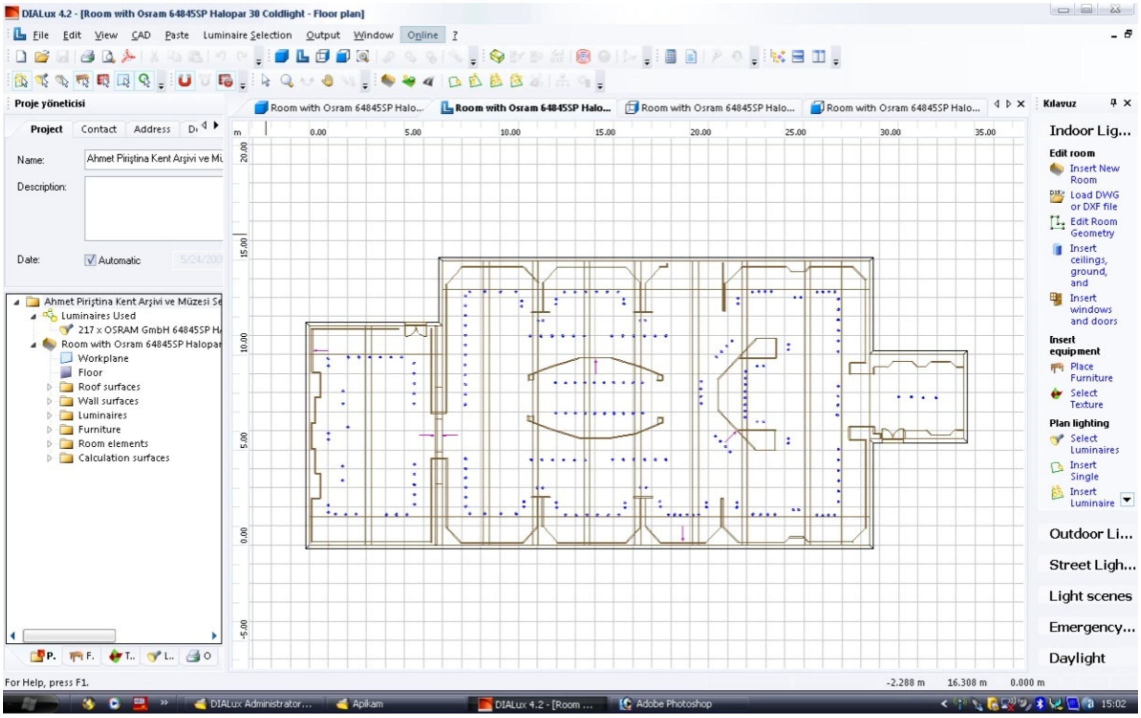
1.4.3. Photometric Calculations

All photometric calculations which cover the structural and spatial components and furnishing are made through the lighting software Dialux (Version 4.2.0.5) in very accurate mode. Dialux is an open-source program for calculation and visualization of indoor and outdoor lighting systems. The main advantage of the program is its accuracy in calculation and its ability to work with almost all widely known lighting manufacturers through software plugs, which means that it is possible to make calculations concerning almost any lighting systems of any brand. The user interface of the software is shown in Figure 1.4 and Figure 1.5.

The calculations of Dialux are compared with the results obtained through an exposure meter manually (Gossen Variosix F2). An exposure meter is a device used generally by photographers to measure light intensity. However the measurements of this device are shown as film exposure and F-stop setting rather than in luxes. The exposure indicator of an exposure meter is in seconds, to be more precise in fractions of a second. That means when an exposure meter shows 125, it actually indicates 1/125 of a second. F-stop value indicates the amount of light allowed through the lens by the iris opening. A third indicator is the Ev value, which is obtained by summing up the reference numbers of the exposure and the F-stop (RNt and RNf). As lighting calculations require measurements in lux, the EV values obtained by exposure meter need to be converted to lux through the following formula:

$$\mathbf{I_{lux}=2.5 \times 2^{(RNt+RNf)}=2.5 \times 2^{EV}}$$

The measurements are made on the floor and on task surfaces for both lighting systems. Eleven points on floor and four points on four different task surfaces at a height of eighty centimeters are used for manual measurements. The amount of the calculation surfaces derives from the variety of the horizontal illuminance levels supplied by the lighting systems, which means all photometric results for bright, semi-bright, and dark surfaces are included in the comparison process. After the comparison a difference of only 2 lm was detected on floor measurements. As this is a negligible amount of deviation, no calibration was made manually.



Name: Ahmet Piriştina Kent Arşivi ve Mü

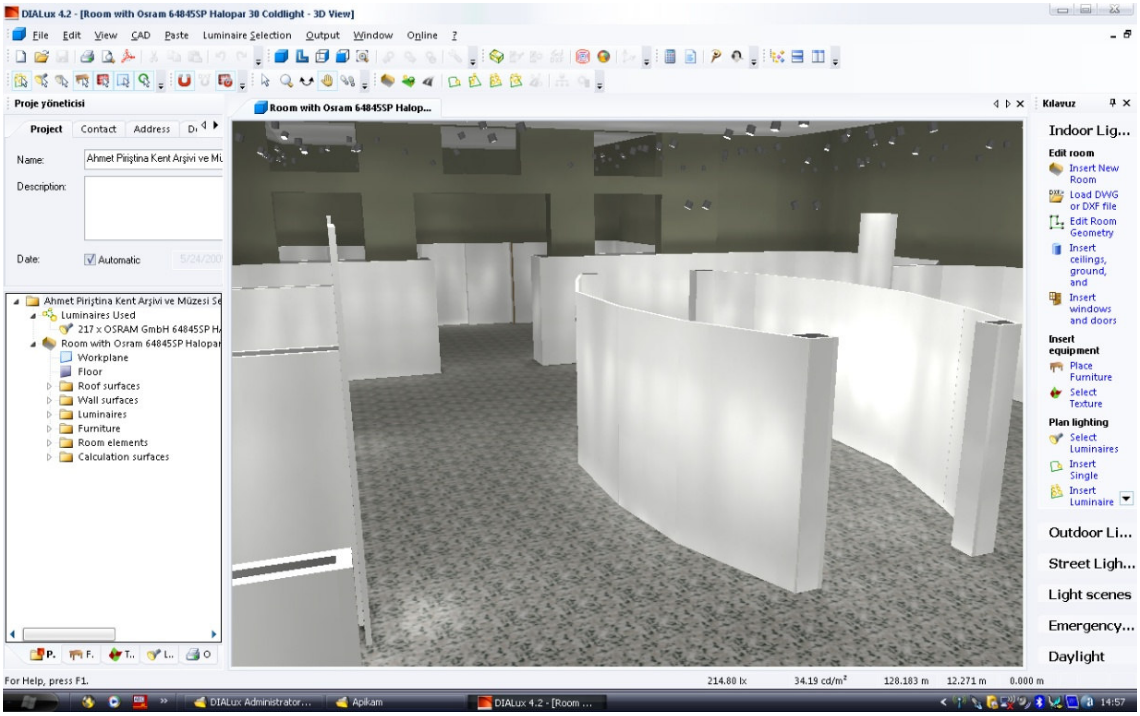
Description:

Date: ☑ Automatic

- Ahmet Piriştina Kent Arşivi ve Müzesi Se
  - Luminaires Used
    - 217 x OSRAM GmbH 64845SP H
  - Room with Osram 64845SP Halopar
    - Workplane
    - Floor
    - Roof surfaces
    - Wall surfaces
    - Luminaires
    - Furniture
    - Room elements
    - Calculation surfaces

-2.288 m 16.308 m 0.000 m

Figure 1.4. User interface of Dialux 4.2.0.5 (plan view)



Name: Ahmet Piriştina Kent Arşivi ve Mü

Description:

Date: ☑ Automatic

- Ahmet Piriştina Kent Arşivi ve Müzesi Se
  - Luminaires Used
    - 217 x OSRAM GmbH 64845SP H
  - Room with Osram 64845SP Halopar
    - Workplane
    - Floor
    - Roof surfaces
    - Wall surfaces
    - Luminaires
    - Furniture
    - Room elements
    - Calculation surfaces

214.80 lx 34.19 cd/m² 128.183 m 12.271 m 0.000 m

Figure 1.5. User interface of Dialux 4.2.0.5 (3D view)

In the following chapter the quality concepts will be discussed with ideas from different disciplines, such as lighting engineering, urban design, and architecture. The third chapter will explain the detailed structure of the evaluation methodology for artificial lighting quality. Fourth chapter concerns with the field study of APIKAM. Last chapter includes the results of the field study, general conclusions, and recommendations for further research.

CHAPTER 2

A REVIEW OF QUALITY CONCEPTS IN LIGHTING

Discussions about quality are complicated because of its intangible nature. One cannot measure quality in the same way one measures length or weight. There are varying approaches to measure quality in various disciplines. The importance here lies in developing criteria which are suitable to cover all the requirements or necessities of the relevant function. The term “quality” deals with the essential or distinctive characteristics or properties of something by judging it according to how much closer it stands to a grade of excellence or perfection. Hence mentioning quality is implicitly tantamount to a mention of a bunch of criteria of perfection. This state of perfection varies in relation to the function, context, and the requirements and needs of the user.

There are many different definitions available to describe quality with an aim of developing strategies to measure it. For example Fox (1993) defines quality as the processes and activities that need to be carried out to enable the manufacture of a product that fully meets customer requirements. It is possible to encounter numerous arguments similar to Fox’s. Three of these definitions are noteworthy because of their detailed structure and because they led to a system called “Total Quality Management” used in varying disciplines to improve the quality of the end-product. Actually they are more than a definition as they are acting as a management philosophy or a theory of organization and social process (White and Wolf 1995).

These three different definitions of quality were developed by W. Edward Deming, Joseph M. Juran, and Philip Crosby at the beginning of the second half of the twentieth century. Deming[1] suggested that the goal of firms should be constantly to improve their services and products for the customers. Juran[2] defined quality as fitness for use or the ability of a service or product to satisfy a customers needs (Choi and

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[1] Deming describes quality departing from some concepts such as uniformity, dependability and preferentiality. He suggests 14 points for quality management, which could be constituted as the basis for transformation of the American industry. Deming (1986) mentioned that these 14 points could be applied anywhere, to small organizations as well as to large ones, to the service industry as well as to manufacturing..

[2] Juran (1964) says that techniques in controlling quality are far more developed than the ideas for managing the quality. He defines quality departing from two main points (Günaydın 2003):
Customer satisfaction
Elimination of defects

Eboch 1997). Crosby[3] defined quality in connection with the concept of “zero defect” . Except Crosby’s all the definitions are substantially connected to customer needs in several ways. It is therefore vital to understand “customer needs” in order to be able to develop strategies to fulfill them for reaching excellence and thus good quality for certain functions.

Within this framework of identifying “customer needs” or “user needs” the task of lighting seems to be a difficult one. It constitutes a theme of two varying disciplines such as engineering and architecture which have generally opposite perspectives in finding solutions for a specific problem. It is necessary to take a look at their respective ways of manipulating the quality issue in lighting to find out the deficiencies before setting up the required criteria. In the following section the development of artificial engineering and its ways of manipulating quality will be discussed.

2.1. The Development of Artificial Lighting in the Twentieth Century. Lighting Engineering and Its Quality Definitions

After the invention of the light bulb by Thomas Edison in 1879, a new era for architecture had begun. Architecture gained a new character through the rising use of artificial light. Architects were excited about the new technology and they were willing to learn and use the capabilities of lighting techniques in their works. Soon artificial light became one of the important mediums for architecture with its expanding market, which made many things possible for a city at night.

Around the time when artificial light -based on electricity- was born and became a widely used tool for architecture for several purposes; modernism was becoming popular standing on a strong background leaning back to 1750s. Artificial light and its abilities for architecture, especially the one, that supplemented visual ability at night, were highly overlapping with modern philosophy and the spirit of the time (*Zeitgeist*). Modern doctrine come to stand for an illuminated world. That is quite explicit in Paul Scheerbarts (1914) manifesto “Glass Architecture” . Scheerbart was suggesting an

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[3] According to Crosby (1980):

- Quality means conformance, not elegance
- There is no such thing as a quality problem
- There is no such thing as the economics of quality; it is always cheaper to do the job right the first time.
- The only performance measurement is the cost of quality
- The only performance standard is Zero Defects.

architecture of glass, which let the light of the sun penetrate deep into the interior space. There was also an informal forum, such as the “Crystal Chain” that believed in an architecture revealed by light (Thomsen 1994). Comprising important names such as Hans Schroun, Bruno Taut, Walter Gropius, Wenzel August Hablik and Paul Gösch; this forum was highly effective in introducing the new understanding of modernism about light and its effects in architecture.

The twenties witnessed important innovations in the lighting industry. First of all, artificial lighting became cheaper with the accelerated technology. New and powerful lamps and electromechanical systems were developed. The newly discovered capabilities of light, such as advertising and orientation, were the motivating factors for the lighting field for carrying its industry a step ahead each day (Rub 1986). Besides all of these innovations in the lighting field in the twenties, a new profession called lighting engineering appeared and established its own world of terminology, which was mostly defined by engineers and technical specialists.

Some attempts in the lighting field concerning public security were made in these years, such as the lighting of the streets and boulevards in big cities. These attempts are important for showing the general attitude of lighting engineers for determining their priorities to illuminate the city. Diggs (1933) pointed out that after San Francisco had increased lighting on Bay Shore Boulevard in 1933, the nighttime accident rate dropped by 40 percent in the first six months. Carr (1973) reported that after Gary, Indiana, upgraded its entire street lighting system, the number of reported criminal assaults declined by more than 70 percent.

Street lighting parameters were first established in 1914 by the National Electric Light Association and the Association of Edison Illuminating Companies in the United States. The primary purpose of lighting was to illuminate (Harrison et al. 1930). Another purpose of lighting was an orientation in order to serve for advertising needs (Rub 1986). In 1925, the Illuminating Engineering Society (IES), which is still the principal forum for setting lighting standards, set the scientific principals for street and highway lighting (Tien 1979). These standards derived from two main requirements as follows:

- To supply visual ability for basic activities at night
- To supply security in public areas

These were the first standardization attempts for lighting design and during the twentieth century they became more complex as the field grew larger. The main development in this approach at the end of the century is the fragmented characteristic of it. Lighting engineering today handles a city or a building complex in sub-categories deriving from the functional criteria, such as roads, walkways, trading areas, business areas, dwelling areas; or living rooms, bedrooms, study rooms, etc. It is possible to refer to a handbook for each varying functional area of a city or part of a building which suggests quantitative solutions for lighting problems. Table 2.1 shows the recommended light levels for varying functions.

Generally in the lighting engineering community, good lighting means a visual environment that enables peoples to see, to move safely and to perform visual tasks efficiently, accurately and without causing certain disabilities such as visual fatigue and glare. Although mentioning some quantitative aspects such as luminance distribution and color rendering; lighting engineering has a tendency to overcome the quality issue in a quantitative way through set of regulations.

Today each lighting problem reaches a solution through lighting master plans, prepared mostly by lighting engineers who respect the IES's regulations. The lighting or electrical engineer is given the responsibility for the lighting, and follows generally the lumen method for illuminating interior and exterior (Lam 1992). Kay (1996: pp. 71-72) discusses the steps in the lumen method as follows:

> From IES Handbook, from government codes, or from the client's specifications, determine the required average level of horizontal footcandles for the project. A single level may be specified for the entire building, or various levels may be established for different types of space: office, classroom, corridor, etc. Select a lighting fixture or fixtures suitable for mounting in the preselected ceiling system, which uses the most economical lamps available and has the highest fixture efficiency in terms of producing illumination on the horizontal plane at desk level. The shape of the fixture relative to that of the room is usually considered to be a secondary importance, if it is considered at all. Some consideration is given to quality of the lighting system by limiting direct glare, generally however, low-brightness fixtures will not be selected, if they cost more per footcandle delivered on the work plane. Calculate the number of fixtures required to achieve the average illumination level or level determined in step 1. Find a layout for the required number of fixtures which distributes the light uniformly over the room as measured at the work plane.

Table 2.1. Recommended Lighting Levels
(Source: WEB_1 2002)

Task Area	**Lighting Level [fc]**
Corridors/Stairways/Restrooms	10-20
Storage Rooms	10-50
Conference Rooms	20-50
General Offices	50-100
Drafting/Accounting	100-200
Areas with VDTs	75
Classrooms	50-75
Cafeterias	50
Gymnasiums	30-50
Merchandising	30-150
Manufacturing Assembly	50-500
Parking Areas (uncovered)	1-2

The Campus of the University of Iowa implemented a lighting master plan in 1996. Three main goals were described in the Campus Lighting Master Plan Strategy Book (1999):

- To provide sufficient levels of illumination at building entrances and along routes between campus buildings, parking lots, bike racks, bus stops, campus entrances, and isolated areas so that the pedestrians, drivers, bicyclists, and other users can travel safely at night.
- To balance energy efficiency and cost issues with other goals.
- To minimize the nuisance effects of light pollution.

Here, all goals are noteworthy as being entirely connected to quantitative basics as lighting levels, and cost issues.

Julian (1995) claims that the concept of quality in the field of lighting can be generally thought of as determined by three major aspects. In order of importance these are:

- Safeguard the safety of people in the interior.
- Facilitate the performance of visual tasks.
- Aid the creation of an appropriate visual environment.

According to Kampf (2005) successful lighting design is one which saves energy, saves money, improves visual comfort, decreases maintenance, and reduces waste. He adds that in order to reach good lighting solutions one should consider the budget, light levels, light sources, lighting controls, color rendering index, and color temperature.

Lighting engineering, as being the one and only authority in illumination decisions, also affected other disciplines in terms of lighting in theory and practice, such as urban design. This is remarkable because urban design has roots in the social sciences more than in engineering and thus bears a qualitative approach to research. Although there are some exceptions such as the ideas of Lynch (1960), who introduced the concepts of “variety in illumination” , “warmth achieved through illumination” , and “spatial mood created by illumination” urban design preferred to import the quantitative lighting vocabulary from lighting engineering. Urban designer Boduroğlu (2001), for example, points out that lighting should consider some basic criteria such as:

- Providing security.
- Providing easy access.
- Providing orientation.
- Providing minimum requirements for night-time activities such as sports, etc.

2.1.1. Models in Lighting Engineering Used to Define Quality of Lighting

As Boyce (1981) pointed out there have been two approaches to lighting research; practical study and the laboratory study. The laboratory studies have had greater effect on lighting practice because of their role in the establishment of lighting standards and codes. Field studies generally led to misinterpretations in the relationship between illumination and task performance. The best known study is the Hawthorne Experiment (1924-32), which demonstrates the difficulty in conducting field studies. The aim of these studies was to clarify the relationship between productivity and lighting as one of the environmental factors. The main conclusion was that there was no real connection between environmental factors and productivity, since productivity had been increased under all varying lighting installations. Later in the seventies, these studies were proved untrustable, because of the awareness of the participants that they were subject to a research. This phenomenon took its place in the literature of psychology as “Hawthorne Effect” .

Lighting engineering, especially in the last quarter of the twentieth century, attempted to develop some models in order to fill the gaps in their definitions of quality. Some, such as Visibility Level (VL), Comfort Satisfaction and Performance Index (CSP), Relative Visual Performance (RVP), Equivalent Sphere Illuminance (ESI), were primarily indices of quantity, rather than quality. Others, notably Visual Comfort Probability (VCP), addressed quality but in a limited way (Veitch and Newsham 1996).

2.1.1.1. Visibility Level Model (Blackwell, 1959)

In an attempt to assess the level of visibility that an individual has for a specified target, Blackwell believed that a comparison was necessary between a predetermined standard and that of the individual perceiving the specified target (Torrez 2003). According to Blackwell, the visual difficulty of any task can be express as a single quantity, which he called visibility level (VL). In Blackwell's model each task was to be compared to a reference task to determine its visibility in terms of revealed contrast.[4] The reference task is the detection of a luminous disc, which is viewed for 0.2 seconds. Observers were initially required to view a uniform screen with a standardized level of illumination. At this point, the luminous disc was presented at the center of the screen in pulses of 0.2 sec and the observer was allowed to adjust the physical contrast of the disc until they perceive it as barely visible (Torrez 2003).

The standard curve used in the visibility model was constructed from a population of 20-30-year-olds with normal or corrected-to-normal vision, and the reference illumination is diffuse white light with color temperature of 2850 K. Visibility level was calculated as the ratio of the threshold contrast of the task to the threshold contrast of the standard luminous disc, which was determined using a special device, the visibility meter (Levy 1978).[5]

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4 According to Blackwell (1959), visual difficulty of any task can be express as a single quantity, which he described as Visibility Level (VL). VL=equivalent contrast/threshold contrast.

5 In calculating visibility level (VL), the researcher places the target (reading material or other task material) in to the visibility meter and sets the background luminance for the level under which the task is normally performed (C(Lt)). The observer then adjusts a knob that controls a mechanism to cast a veiling luminance (Lv) over the task until it is just barely visible. The target is then removed and the disk is presented. Under the same veiling luminance which is set before, the observer now changes the background luminance until the disk I just barely visible to give the equivalent contrast C(eq) . Visibility level is calculated using theformula: VL=C(eq)/C(Lt)

The model proposed by Blackwell was soon recognized for its insufficiency in forming response to a variety of tasks (Brass, 1982). The VL represents visibility under very special conditions that do not exist outside a visibility meter. The light was unpolarized, diffuse, of a particular color temperature, and produced with uniform luminance at all parts of the task (Veitch and Newsham, 1996). Additionally, the model of visibility level was judged for its lack of realism where under the controlled conditions it applied to only perceptible points of light, but did not encompass the complex, practical tasks that are involved in how and what we see (Brass 1982).

2.1.1.2. Equivalent Sphere Illuminance (ESI)

Sphere illumination is a standard reference condition with which the actual illumination can be compared. In sphere illumination the task receives light from a uniformly illuminated hemisphere. Since the task is illuminated from all directions, no veiling reflections can occur (Lechner 1991). Sphere illumination is such an exceedingly valuable concept not because it represents the best possible lighting, but because it is a very good reproducible standard with which any actual lighting system can be compared (Lechner 1991).

ESI was developed in the seventies and the goal was to develop a way to specify both quantity and quality using a single value to describe the lighting requirement for a given task. Generally ESI is the measure of visibility that takes both illuminance and contrast into account. This is useful in determining the effectiveness of controlling veiling reflections. The steps below describe, in general terms, how ESI can be measured in rooms (Egan 1983).

Step 1 (Figure 2.1):

Under a hemispherical source, measure brightness of task Lt and background Lb. Contrast C is related to task and background brightness as follows:

C= (Lt-Lb)/Lb

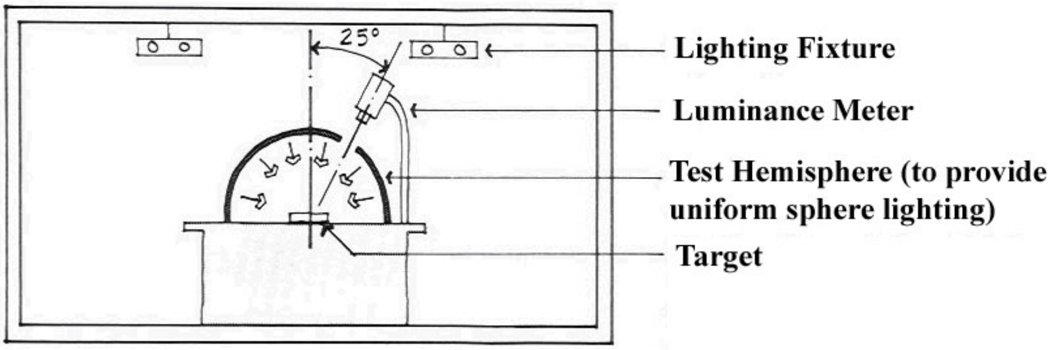

Figure 2.1. Measurement of ESI - Step 1
(Source: Egan M. D 1983)

Step 2 (Figure 2.2):

Under actual lighting conditions, again measure brightness of task and background to establish contrast.

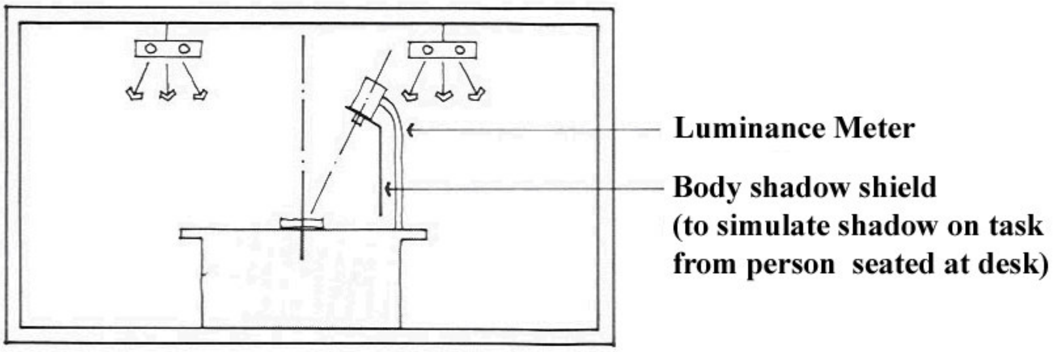

Figure 2.2. Measurement of ESI - Step 2
(Source: Egan M. D 1983)

Step 3:

The contrast rendition factor (CRF) is the ratio of contrasts found by steps 1 and 2. The ESI for a position in a room is determined by the CRF, the location, distribution, and the size of light sources; the room dimensions and reflectances; and the light distribution characteristics of the fixtures.

ESI footcandles can tell us how effective the illuminance in a room is. An actual lighting system that supplied an illumination of 250 footcandles might be no better than an equivalent spherical illumination of 50 ESI footcandles (Lechner 1991). That means that the quality of the actual system is so poor that 200 out 250 footcandles are noneffective for the task.

As a derived value, ESI had several drawbacks (Boyce, 1978). Although it was based upon visibility data, these data did not represent the visual tasks people typically perform. People generally look at objects with features from which the visual system constructs meaning (i.e., faces or letters), rather than luminous discs which do not carry any information. The calculation process depends on an assumption that all viewing is static and on-axis, whereas the human eye obtains much information from the periphery of the visual field, and often views moving objects (Boyce, 1978). Another problem, seldom mentioned in the literature, is the limited range of reference tasks for which CRF curves were developed. As a matter of fact, in ESI, CRF is specific to a given task, which is writing on paper with pencil. Further, CRF data for widespread applications to other kinds of tasks was never available.

2.1.1.3. Visual Comfort Probability (VCP)

While VL and ESI systems were based principally on visual performance, visual comfort probability (VCP) was developed to address discomfort glare. VCP is the probability that an observer will consider a given visual environment comfortable for performing a task. It can also be considered the percentage of observers who consider a visual environment comfortable in those conditions. A VCP rating of 75, for example, indicates that 75% of the observers in the poorest location would not be bothered by direct glare. A VCP of 70 percent is considered acceptable by IES Standards. The experimental work predicts discomfort glare ratings (DGR) from luminous conditions: source luminance, luminances in the field of view, the visual size of the glare source, and the location of the glare source in the field of view.[6]

Neither ESI nor VCP alone were developed as a complete specification of lighting quality: ESI addressed quantity and veiling reflections from a visibility standpoint, and VCP addressed discomfort glare. Herst and Ngai (1978) suggested that the two values could be combined to yield a value they called a Lighting Quality Index (LQI). The LQI was to be calculated on the basis of VCP and ESI maps of a space: LQI

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6 The method has been developed by Guth (1963) with this following formula:
Glare Sensation (M) = $0.5^* Ls^* Q / P^* F^{0.44}$
Ls is the luminance of the glare source (cd/m2),
P is an index of its position with respect to the line of sight,
F is the average luminance of the entire field of view including the glare source (cd/m2),
Q is a function of the solid angle ωs that subtends the source in the observer's eye:
$Q = 20.4\ \omega s + 1.52\ \omega s^{0.2} - 0.075$
To obtain the glare level for a number of glare sources in an installation the glare sensation values are summed using the following equation to obtain a value for the DGR. ($DGR = (\Sigma M)^{n\ -0.0914}$).
N is the number of glare sources in the visual field.

is the percentage of the space meeting the minimum criteria for both VCP and ESI. Although this approach was intuitively attractive to some, it never gained a wide following, probably because of the problems inherent in the ESI system (Veitch and Newsham 1996).

2.1.1.4. Comfort, Satisfaction, and Performance (CSP) Index

The CSP Index was developed by Bean and Bell (1992) to predict the probability that office workers will be satisfied with the visual environment provided for them. It is conceptually similar to the VCP system. However, its development followed a different path.

In this model, comfort index is based on glare index; satisfaction is predicted from cylindrical and horizontal illuminance. Performance is derived from horizontal and cylindrical illuminance, illuminance uniformity, and color rendering. All of them are equal in calculating the CSP index. Figure 2.3 shows the derivation of CSP.

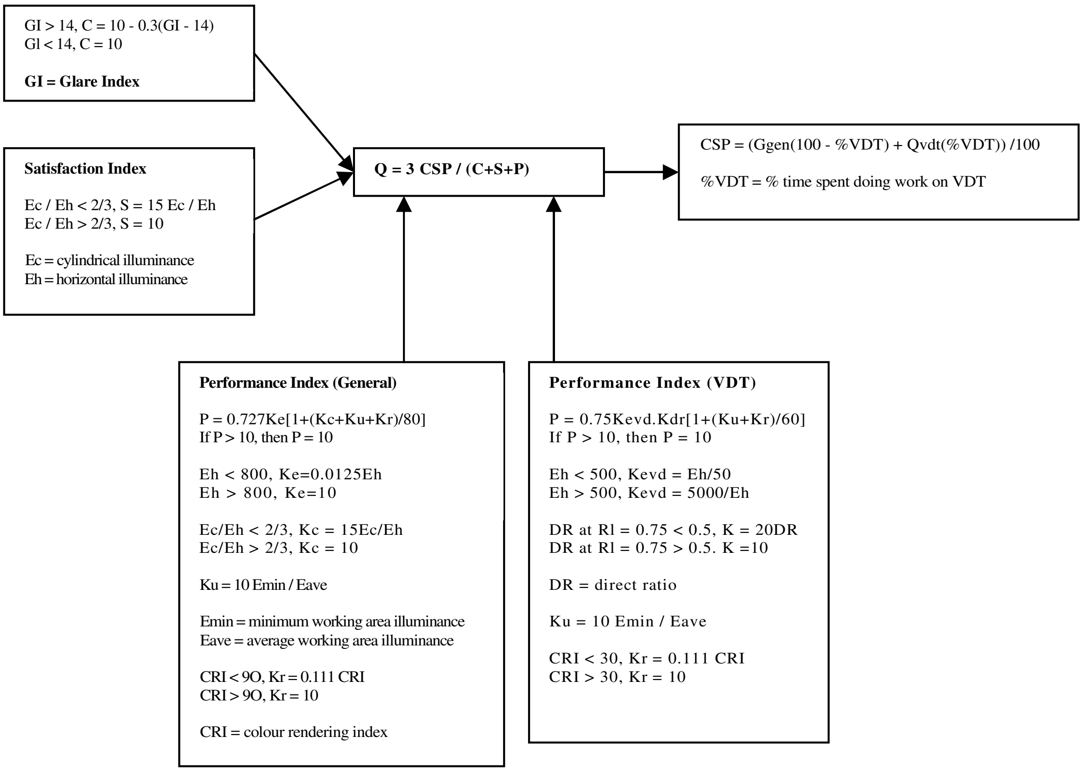

Figure 2.3. Derivation of CSP Index

(Source: Bean and Bell 1992)

2.1.1.5. Relative Visual Performance Model (RVP)

RVP is the percentage that an individual can perform for a given task with a particular lighting system. For a task of a particular size and type to be done by certain age individuals, both the background luminance and task contrast are taken into account. Two lighting systems can be compared by calculating the RVP for each with the same task and age of individual specified. The lighting system with the higher RVP percentage would provide better quality lighting for the given task.

RVP was developed by M. Rea and M. Ouelette, and mainly aimed at overcoming deficiencies in previous models such as Visibility Level of Blackwell. RVP describes visual performance in terms of target contrast, size, and adaptation luminance and includes modifiers for viewers of varying ages between 20 and 65 years (Veitch and Newsham 1996). Figure 2.4 is a graphic representation of RVP model.

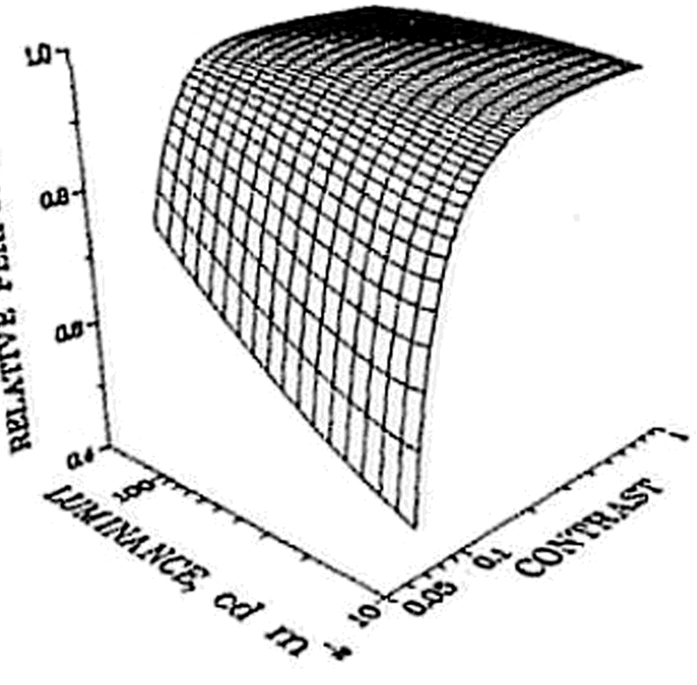

Figure 2.4. Graphic representation of the RVP Model
(Source: Rea and Ouellette 1991)

In this model observers are presented with two lists of five digit numbers that are arranged alongside the columns in a room. Then they are asked to identify any differences between the adjacent pairs and after recognition, they should mark their answers in response sheets. The contrast and background luminance of the test sheet was adjusted throughout the procedure, but the target size remained constant (Torrez 2003). In this study, the main element of mathematical measure for the development of the successive model was the speed and accuracy of recognition and detection. The model also included the issue of age. The neurological problems that occur with age were analyzed and considered in the creation of this model.

2.2. A Qualitative Way in Defining Quality in Lighting from the Architectural Point of View

The difference between positivist sciences and non-positivist sciences is in the methodology they use in research. Lighting engineering, as a positivist science, prefers a quantitative research methodology under a belief that anything could be measured, understood, and generalized about, while neglecting interpretation of non-numerical data, such as experience, feelings, and spatial dynamics with their relation to lighting properties.

The simplest way to define qualitative research is to propose that it is a type of research which includes interpreting non-numerical data. According to Gay and Airasian (1996), the underlying belief of qualitative research is that meaning is situated in a particular perspective or context, and, since different people and groups have different perspectives and contexts, there are many different meanings in the world, none of which is necessarily more valid or true than another. Chappell (WEB_2 2005) adds that a qualitative researcher, therefore, believes that the world cannot be pinned down to objective meanings, but that all variables must be taken into account when conducting research. Table 2.2 shows the differences between quantitative and qualitative research.

While the quantitative aspects of light are very well known (it has been the major determinant factor for lighting design), the qualitative aspects are not very well defined nor known. Besides supplying well defined visual abilities, lighting must also cover architectural requirements and create appropriate spatial dynamics in respect to human psychology. Lighting occurs and always should be integrated in an architectural context. High-quality lighting is responsive to the architectural form, composition, and style. The integration with the architecture conveys meaning and contributes to the observer's understanding of the space. It is light that first enables spatial perception.

Above and beyond this, our perception of architecture can also be influenced by light, as it expands and highlights rooms, creates links and distinguishes one area from another. Light can alter the appearance of a room or area without physically changing it. Light directs our view, influences perception and draws our attention to specific details. Light can be used to divide rooms in order to emphasize areas or establish continuity between the interior and exterior. Light distribution and illuminance have a decisive influence on how architecture is perceived.

Architectural space is born from the relationship between objects or boundaries and from planes which do not themselves have the character of object, but which define limits (Von Meiss 1990). Space would be a limitless void without some sense of enclosure or visual reference that communicates a sense of place (Michel, 1996). A composite set of boundaries at any place comprises the spatial envelope, a working mechanism for the design, analysis, and lighting of architectural space and this spatial envelope carries the dominant areas of stimuli for visual perception, and thereby establishes the major surface planes forming the physical limits of space as seen by human vision (Michel 1996).

Architectural space exists by the illumination of objects and enclosing surfaces. Von Meiss (1990) comments that architectural design could be considered the art of placing and controlling light sources in space. Light has a reciprocal relation with form, structure, and other basic components of space. Light illustrates form and structure, and

Table 2.2. Differences Between Quantitative and Qualitative Research
(Source: WEB_2 2005)

Characteristic	**Quantitative Research**	**Qualitative Research**
Approach	deductive	inductive
Purpose	theory testing, prediction, establishing facts, hypothesis testing	describing multiple realities, developing deep understanding, capturing everyday life
Research Focus	isolates variables, uses large samples, is often anonymous to participants, uses tests and formal instruments	examines full context, interacts with participants, collects data face-to-face from participants
Research Plan	developed before study is initiated, structured, formal proposal	Begins with an initial idea that evolves as researcher learns more about participants and setting, flexible, tentative proposal
Data Analysis	mainly statistical, quantitative	mainly interpretive, descriptive

these spatial components define its physical limits and quality in space. Architecture depends on light. As light reveals the forms of architecture and the places made by it, it simultaneously reveals the meaning and the intentions that are released through the process of conceiving, designing, and building (Millet 1996).

Light and architecture have a mutual relationship which is hard to define and which is only possible to understand by experiencing the effects of light on spatial creations. Some headings below may help to form an insight into the peculiarities of light in architecture:

- The interaction of light and structure
- Light as a stressing element on structure
- Light as a concealing element on structure
- Relating spaces through light
- Connecting spaces through light
- Separating spaces through light
- Differentiating spaces through light
- Light as a means of direction
- Light that creates a focus in space
- Light that encourages movement
- Light and its effects on form
- Light and its effects on texture
- Light and its effects on spatial mood
- Light and its effects on perception

These peculiarities of light which are essential in creating the sense of place in architecture may be increased in number. As Cullen (1986) says, light determines how we perceive our environment. And if carefully studied and successfully applied, lighting can play an integral role in creating architecture (Theodore and Bradshaw 1994).

There is a remarkable difference between architecture and other disciplines such as lighting engineering in defining the term “quality” . As Kay (1996) discusses, engineers say that one of the factors that affects quality in lighting is the uniform distribution of it. However, it is not, from the architectural point of view. Von Meiss (1990) mentions “light-space” , which is an imaginary space created when a portion of space is well lit while the rest is left in semi- or total darkness. The limits are imaginary but perfectly perceptible. He adds that the light-space is very useful in architectural design since it makes it possible to present scenes as in the theatre, circus or museum; also enables the person who is in the illuminated area to isolate himself and concentrate better. Its in the interior of Pantheon in Rome, where it is not possible to observe a uniform illumination. Sunlight penetrating from the oculus above and moving according to the movement of the sun, creates a spotlight effect and illuminates the sculptures placed in the circular wall of the Pantheon (Figure 2.5). According to Gordon (1987) non-uniform lighting helps to establish the relative strength of visual symbols, and therefore the organization of brightness patterns is a fundamental consideration in defining visual space (Figure 2.6 and Figure 2.7).

Figure 2.5. Pantheon, Rome
(Source: WEB_3 2006)

Figure 2.6. Unlike the walls, the object in the middle of space receives uniform illumination which makes it appear dull and uninteresting. (Source: Erco 1999)

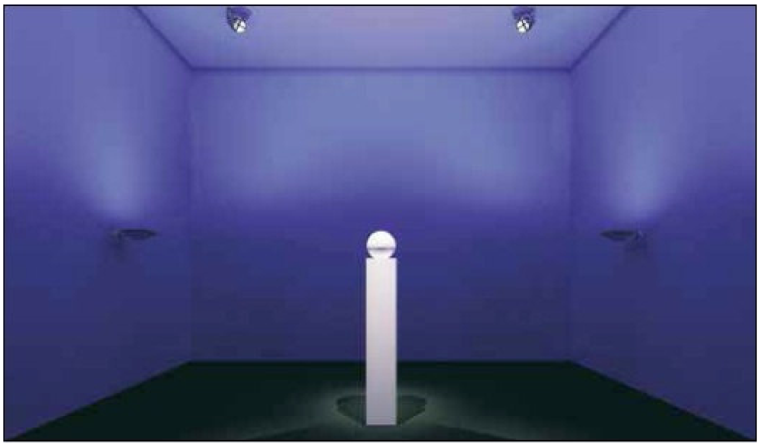

Figure 2.7. With the help of two spotlights the same object became a focal point in the space. (Source: Erco 1999)

In the illuminated world of architecture, shadows also seem to be forgotten. Arnheim (1977) says that shadow is light's counterpart and reflects on the three dimensional form of the body. If the lighting is uniform, coming from all sides, the object becomes flatter (Von Meiss 1990).

Lighting quality from the architectural point of view is defined not only by quantitative parameters such as the amount of light, or light's ability to set up required conditions for seeing; but also with its ability to add new dimensions to the life and experience in space. Next chapter will form a frame to assess quality of lighting considering several variables which are effective in spatial dynamics created through lighting as discussed in this chapter.

CHAPTER 3

THE STRUCTURE OF THE EVALUATION METHODOLOGY FOR ARTIFICIAL LIGHTING QUALITY

Based on a qualitative research tradition described before, and the existing literature on lighting quality, a conceptual framework was designed. It is proposed that lighting quality could be defined when the luminous environment supports the following requirements of the people who will use the space. One also could add further aspects to this list by considering different needs:

- Visual performance and safety;
- Task performance;
- Behavioral effects other than vision (attention, spatial hierarchy, phototropism)
- Mood state (pleasure, happiness, alertness, satisfaction, dominancy);
- Human physiology and health;
- Aesthetic judgments;
- Others.

Lighting quality, according to these parameters, is not directly measurable, but is a state created by the interplay of the lit environment and the person in that environment. Good lighting quality exists when a lighting system:

- Creates good conditions for seeing and safety;
- Supports task performance;
- Sets appropriate conditions for behavioral outcomes;
- Supports appropriate mood state in space;
- Provides good conditions for human physiology and health;
- Contributes to the aesthetical quality of the space;
- Others.

Deriving from these propositions three groups of aspects could be formed which together constitute a base for determining lighting quality (Figure 3.1). These are:

- Functional Aspects
- Physiological Aspects
- Psychological Aspects

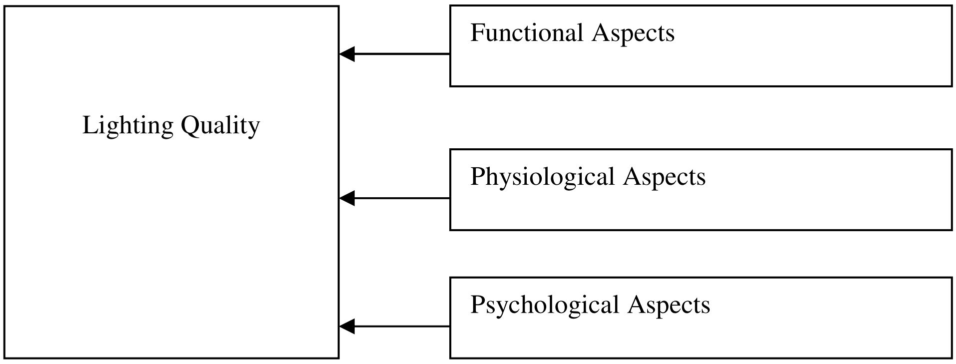

Figure 3.1. Three Aspects of Lighting Quality

3.1. Functional Aspects

As is widely known, in the lighting field each function such as office, classroom, living room, restaurant, museum, etc. requires different lighting solutions. Functional aspects are mostly concerned with visibility, thus safety; and with task performance in relation to the amount of light, lighting systems or lamp types chosen. Functional aspects check whether they are appropriate to the desired function or not. Functional aspects (Figure 3.2) include as well the color temperature of light in relation to varying lamb types chosen for varying spatial functions. The distribution of light throughout the space also effects visibility and task performance.

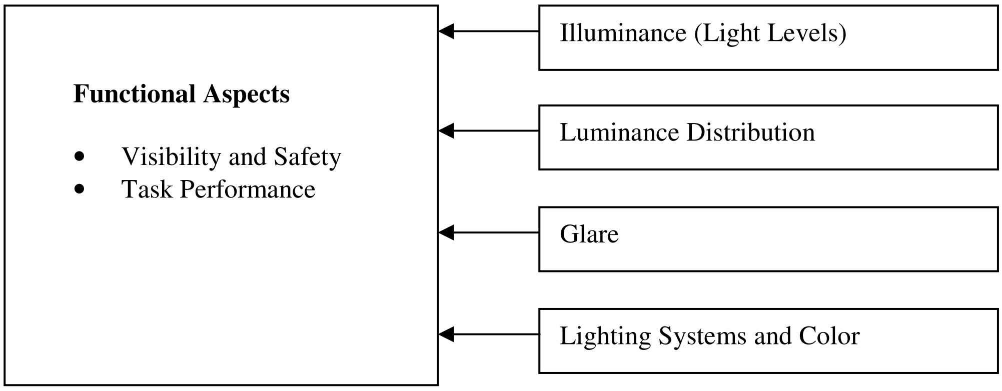

Figure 3.2. Determinants of Functional Aspects

3.1.1. Visibility, Safety and Task Performance

Illuminance: Illuminance is the technical term for the quantity of visible radiation incident on a surface, mostly known as “light levels” (Gligor 2003). Illuminance is measured in lux, or lumen per square meter (lm/m^2). The illuminance and its distribution on the task areas and the surrounding area bear a major impact on how quickly, safely and comfortably a person perceives and carries out the visual task.

There is a general consensus between lighting researchers and the American and European standards in illumination levels recommendations. Both of the standards recommend values of 300 lx to 500 lx for the desktop illuminance for a reading task. Also, the visual preferences of users will change in time depending on season or will be different for different genders. Laurentine et al. (2000) found that if 300 lx are usually a minimum value for an office task in the summer time (the lighting on the desk and lighting environment were rated as “unpleasant” but the tasks were performed correctly), the preferred artificial light level is much higher in winter time, the difference between warm and cool season rising to almost 300 lx. O’Donell et al. (1999) found that in subtropical regions the need for lighting is higher, by a rate of 500-700 lx.

According to the European standards minimum lighting values shall not be less than 200 lx in areas where continuous work is carried out. In normal conditions approximately 20 lx of horizontal illuminance is required just to detect features of the human face (WEB_4 2005).

Despite the results of Hawthorne Experiments, there is a general tendency in the lighting field for more light. This owes to a belief that more light leads to better work. However, the decision should be made according to the varying requirements of varying contexts. According to Gligor (2003) the illuminance should be increased when unusually low contrasts are present in the task, visual work is critical, errors are costly to rectify, accuracy or higher productivity is of great importance, the visual capacity of the worker is bellow normal. He adds that the required maintained illuminance may be decreased when the details are of an unusually large size or high contrast and the task is undertaken for an unusually short time.

There are numerous scientific works that seek the relation between illuminance and task performance, but they have reached inconsistent results. Hughes and McNelis (1978) reported that an increase in illuminance from 500 to 1500 lx caused an average 9 percent increase in the productivity of office workers during a difficult paper-based task. Baron et al. (1992) however, found that lower illuminance levels (150 lx) tended to improve performance on a complex word categorization task as compared to high levels (1500 lx). Nelson et al. (1983) found that performance on a difficult task was best under 80 lx, worst under 160 lx, and intermediate under 320 lx. There were no illuminance effects on reading or spatial relations tasks. Smith and Rea (1982) found no effect of illuminance levels on reading comprehension over a wide range (9.2 to 4540 lx). Nelson (et al. 1984) found no effect of illuminance levels of 100 and 300 lx on creative writing performance. Kaye (1988) compared task performance under 500 and 1200 lx and found no effects on visual search tasks. Looking at these results it is possible to say that there is no clear connection between illuminance and performance. This variable should be discussed for each context separately, with respect to user preferences.

Luminance Distribution: Luminance (also called *luminosity*) is a photometric measure of the density of luminous intensity in a given direction. It describes the amount of light that passes through or is emitted from a particular area. The unit for luminance is candela per square meter (cd/m^2). Luminance is often used to characterize emission or reflection from surfaces. The luminance indicates how much luminous power will be perceived by an eye looking at the surface from a particular viewpoint. Luminance is an indicator of how bright the surface will appear. To create variance in luminance distribution means to create a pattern of very light, light, semi-light, and dark areas within a space. The desired point should be that this pattern allows occupants to see what they want and creates the desired atmosphere.

The luminance distribution in the field of view controls the adaptation level of the eyes, which affects task visibility. According to Gligor (2003) a well-balanced adaptation is needed to increase visual acuity (sharpness of vision), contrast sensitivity (discrimination of relatively small luminance differences), efficiency of the ocular functions (such as accommodation, convergence, pupillary contraction, eye movements, etc.).

Diverse luminance distribution in the field of view (task surface, e.g. a work desk, a painting on the wall) also affects visual comfort and should be avoided. Too high luminances can give rise to glare; too high luminance contrasts will cause fatigue due to continuous re-adaptation of the eyes; too low luminances and too low luminance contrasts result in a dull and non-stimulating working environment (IESNA 2000).

The illuminance of immediate surrounding areas shall be related to the illuminance of the task area and should provide a well-balanced luminance distribution in the field of view. Rapid spatial changes in illuminances around the task area may lead to visual stress and discomfort (Gligor 2003). Sounders (1969) found that illuminance ratios lower than 0.7 caused a substantial increase in dissatisfaction. Luminance ratios of 1:1 are considered optimal in North America, with 3:1 (task brighter than surrounding area) being acceptable (Rea 1993). Both IESNA and CIE propose only that luminance ratios higher than 10:1 are needed to achieve dramatic effects, such as to highlight an architectural feature or to add interest to the space. However, Veitch and Newsham (2000) found that the degree of desirable luminance variation might be greater than current recommendations. In their study, participants were exposed to luminance ratios from 11:1 through 68:1. The study concluded in an upper limit of ratio of 20:1, which satisfies all the subjects' visual requirements for the relevant task.

Glare: Glare is the visual sensation produced by bright areas within the field of view and may be experienced either as disability glare or discomfort glare. When the background illuminance is low relatively to the source, objects near the source become invisible or it gets difficult to see them. This type of glare is known as disability glare. In some cases the illuminated field is brighter than one can adapt to, such as the sunlight reflected by snow. This type of glare is called discomfort glare. In simple terms discomfort glare is glare which causes discomfort, without leading to a decrease in vision. In contrast, disability glare may not cause any discomfort but leads to some or total loss in vision. Glare may also be caused by reflections on surfaces usually known as veiling luminance or reflected glare. Veiling reflection is usually caused by locating a luminaire directly above or slightly in front of a work station. Repositioning of the luminaire or task, or using special polarized lenses will solve that problem.

It is possible to eliminate glare by increasing the angle between the source and the line of sight. Figure 3.3 and Figure 3.4 show this angular separation between target and glare source. The perception of glare is different from person to person. In generally women and are more glare sensitive than men and older people are more glare sensitive than younger people (Figure 3.5) (Laurentine et al. 2000).

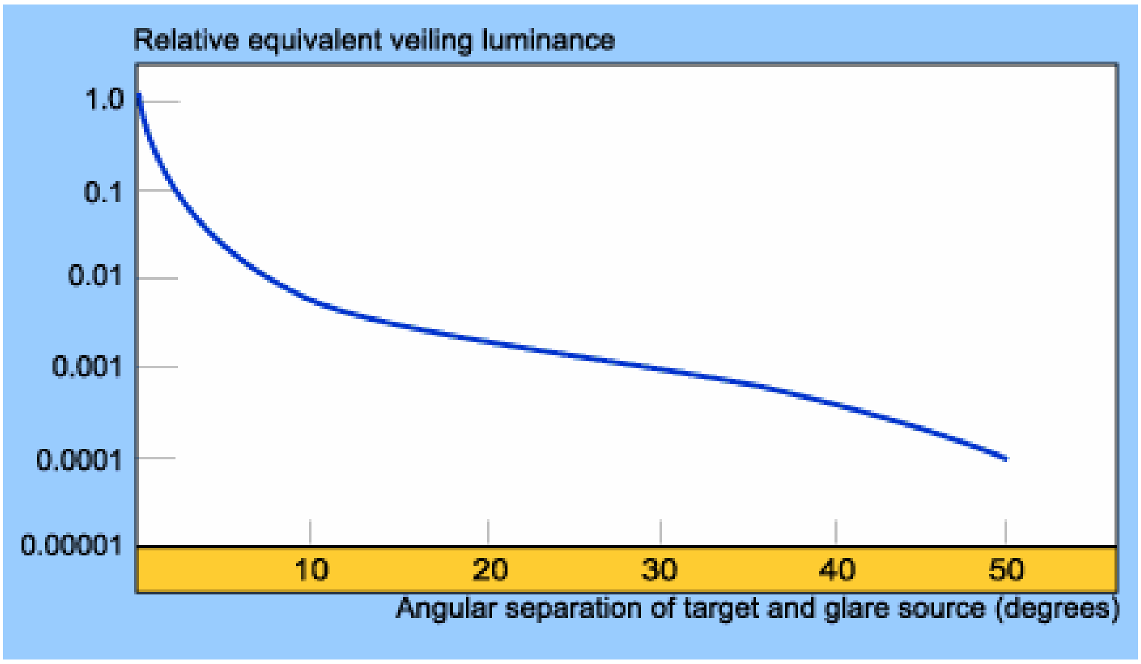

Figure 3.3. Relationship between equivalent veiling luminance and angular separation between line of sight and glare source. (Source: WEB_5 2005)

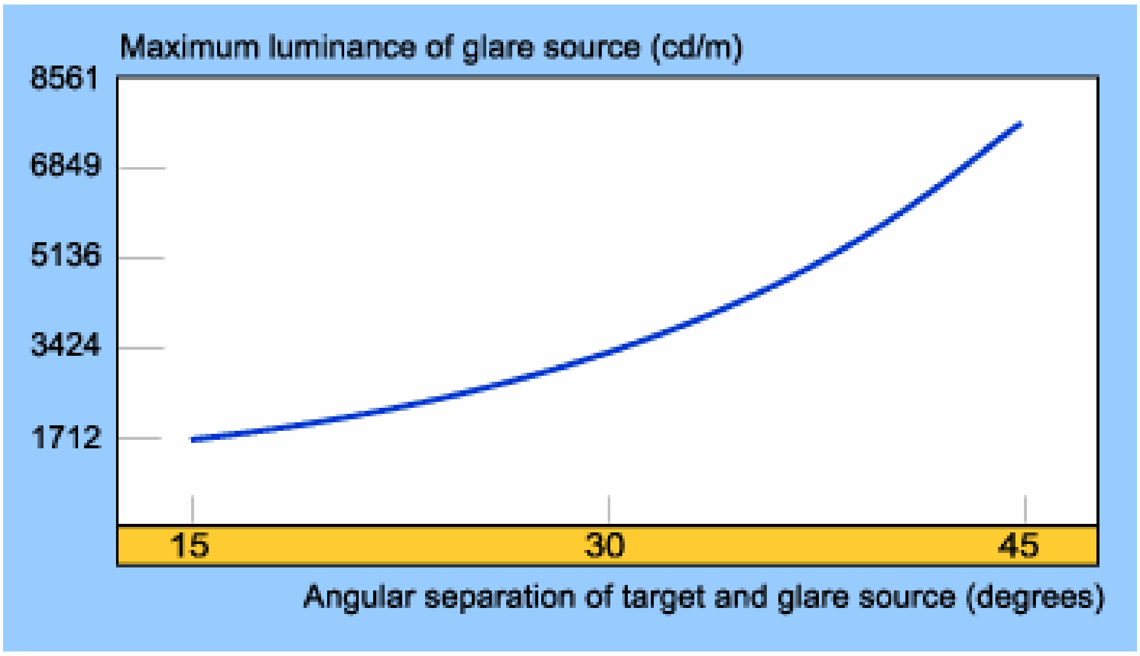

Figure 3.4. Relationship between maximum luminance of glare source and angular separation between line of sight and glare source (Source: WEB_5 2005)

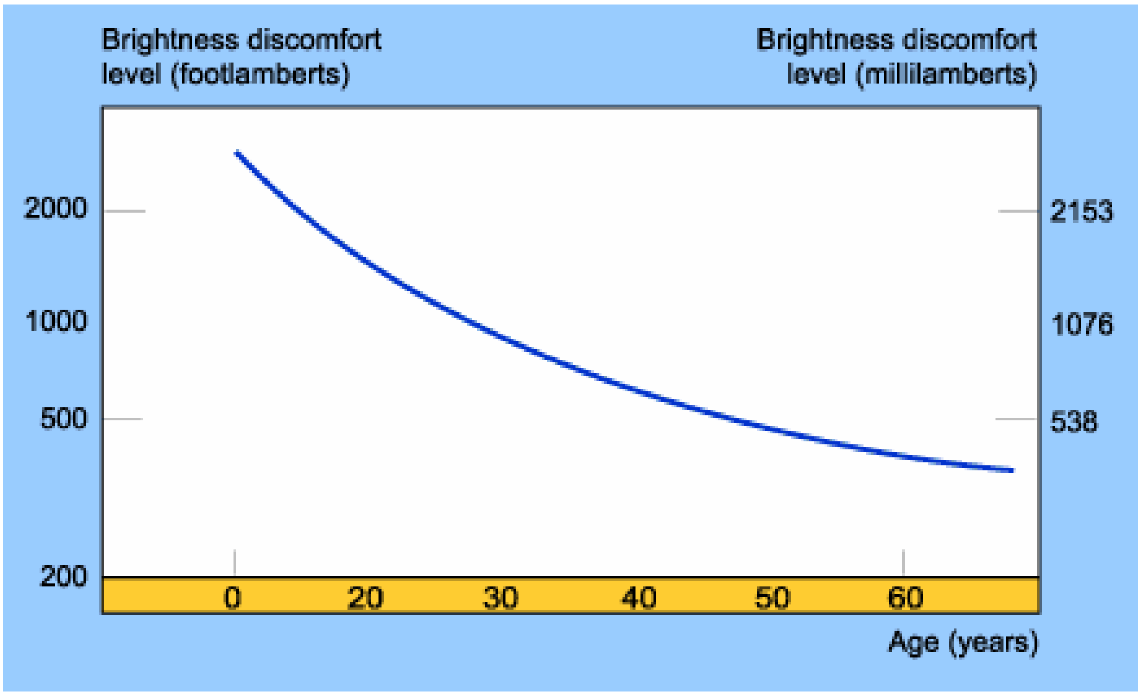

Figure 3.5. Age and sensitivity to brightness
(Source: WEB_5 2005)

Several attempts have been made to develop predictive models, such as Visibility Level Model (VL), and Visual Comfort Probability (VCP), which will help to form some regulations for eliminating glare problems.

Visual display terminals (VDT), such as computer monitors in an office or plasma screens in a contemporary art museum present special problems for lighting design in terms of glare. Unlike conventional tasks such as a horizontal desk in a library, VDT is a self-luminous, vertical task. Lighting, which is suitable for a conventional horizontal task, becomes a veiling luminance on a VDT. Careful selection and placement of luminaries is required to avoid the reflected luminaire images on the screen, which reduce visibility and cause discomfort.

Lighting Systems and Color: We experience our surroundings not just as brightness and darkness, light and shadow, but also in color. Color appearance is the color temperature[7] of a certain color of light (or wavelength) in Kelvin (K). Color Rendition Index (CRI) is a measure of how well a source renders colors compared to a natural light source. The higher the color temperature of a light source, the more blue it has in its spectral distribution. Discussions of lighting and color typically fall into two categories as the color appearance of the light source itself and the color appearance of various objects when they are illuminated by the light source

Lamps have good color rendition if, when illuminating a comprehensive range of colors they produce the least possible change in color effect in comparison to a standardized light source of similar color temperature (Ganslandt 1995). Thus every statement about the quality of color rendition refers to a particular color temperature and an equally valid color rendition value for all color temperatures does not exist. The color rendition of a light source depends on the construction of the specific lamp spectrum, whereas the quality of color rendition depends on the greatest possible continuity of the emitted spectrum. For color temperature the distribution of light output in the spectrum is decisive. If the light emitted is in the long wave, in red area of light, the result is a warm white light source, while the short wave end of the spectrum the color temperature is cooler. With incandescent lamps, this distribution is directly

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[7] The light color of a lamp is expressed in terms of color temperature Tc measured in degrees Kelvin (K). The Kelvin temperature scale begins at absolute zero (0 Kelvin ≈ -273°C). Color temperature is used to denote the color of a light source by comparison with the color of a standardized "black body radiator". A black body radiator is an "idealized" solid body, e.g. made of platinum, which absorbs all the light that hits it and thus has a reflective radiance of zero. When a black body is slowly heated, it passes through graduations of color from dark red, red, orange, yellow, white to light blue. The higher the temperature is, the whiter the color. The temperature in K at which a black body radiator is the same color as the light source being measured is known as the correlated color temperature of that light source. An incandescent lamp with its warm white light, for example, has a correlated color temperature of 2800 K, a neutral white fluorescent lamp 4000 K and a daylight fluorescent lamp 6000 K (Fraser and Banks 2004).

dependent on the filament temperature, which explains the term “color temperature” . With discharge and fluorescent lamps, on the other hand, light temperature depends on the filling and coatings used. Figure 3.6 and Figure 3.7 show the spectral power distribution for daylight and for a fluorescent light source respectively. Daylight provides the highest level of color rendering across the spectrum. In fluorescent light source all wavelengths (the full spectrum) are again present but only certain wavelengths (the spikes) are strongly present. The spikes indicate which parts of the color spectrum will be emphasized in the rendering of color for objects illuminated by this light source. It produces a light that is perceived as “warmer” than daylight. Its ability to render color across the spectrum is not bad, but certainly much worse than daylight.

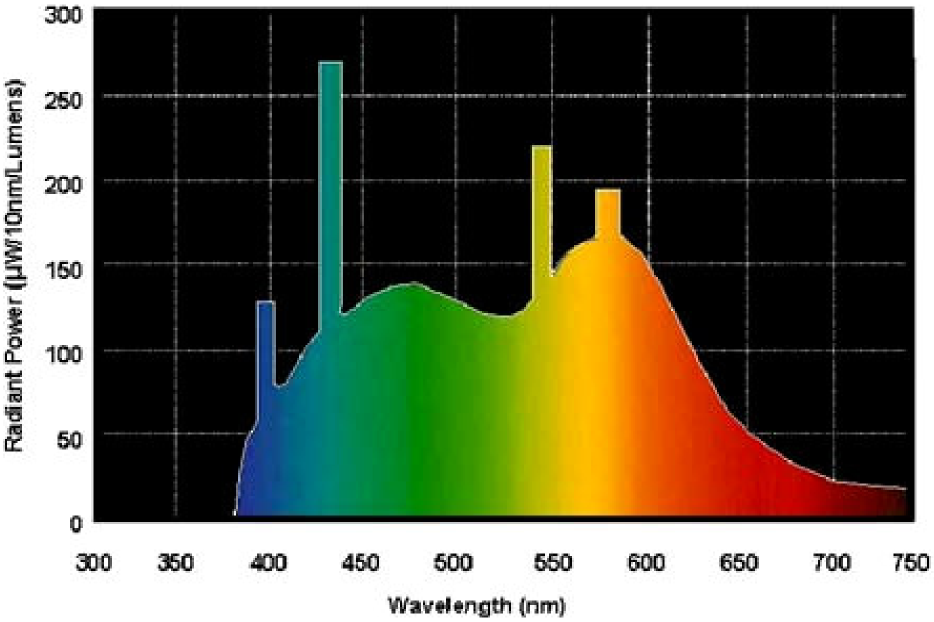

Figure 3.6. Spectral power distribution graph for daylight.
(Source: WEB_6 2006)

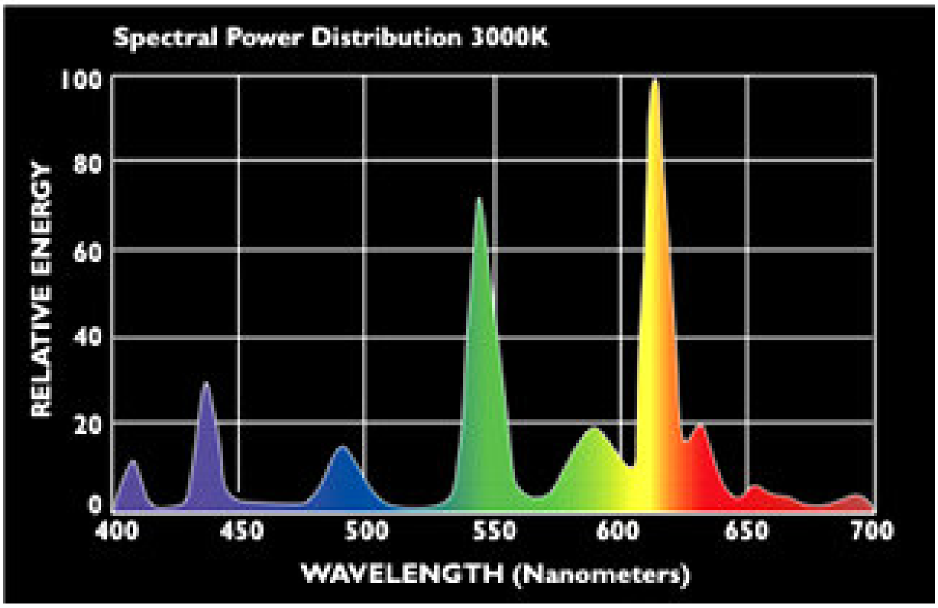

Figure 3.7. Spectral power distribution for a fluorescent lamp.
(Source: WEB_6 2006)

For reasons of standardization, the light colors of lamps are divided into three groups as daylight white (DW), neutral white (NW), and warm white (WW). Warm white lamps emphasize red and yellow hues, while blue and green are emphasized by daylight white light. The quality of the color rendition, on the other hand, determines whether for example the color of a fabric selected in daylight white fluorescent lighting will look the same in the open air. Color rendition is measured by the Color Rendition Index (CRI). A CRI value above 80 is considered of good quality. Figure 3.8 shows the color temperature of varying lamps. The CRI for each source is shown in the parentheses at the right.

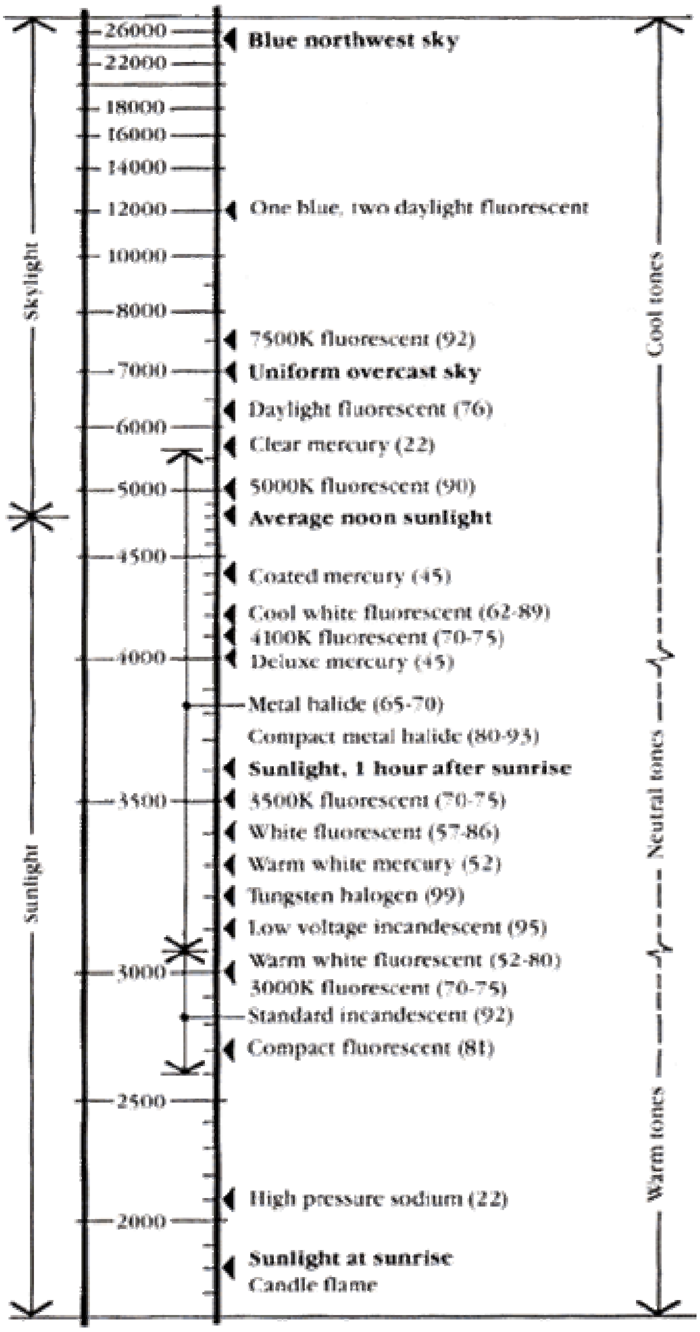

Figure 3.8. Color Temperature of Light Sources.
(Source: WEB_7 2004)

Shaw (1995) states that careful consideration should be made to select the most appropriate light sources available to the designer. He adds that requirements for highly accurate color rendition generally point to tungsten halogen and fluorescent light sources. Others such as high pressure sodium, metal halide, and high intensity discharge (HID), must be preferred where color rendition is not of primary importance.

3.2. Physiological Aspects

In this part the effects of lighting on human physiology are explored. These effects are analyzed in three main titles with varying determinants relevant to light and lighting conditions, as shown in Figure 3.9.

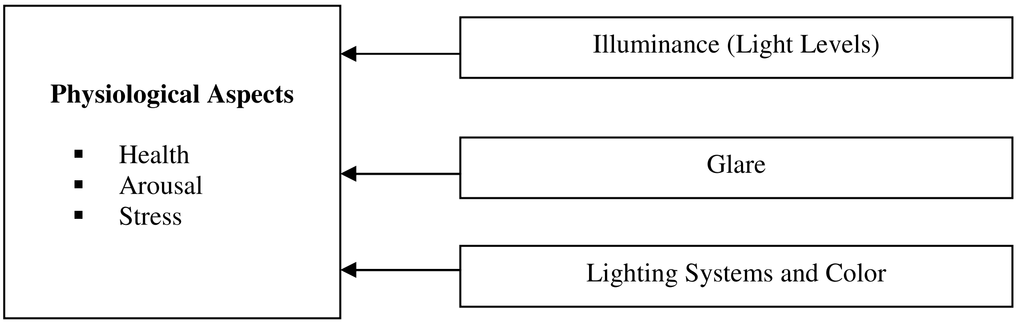

Figure 3.9. Determinants of Physiological Aspects

The physiological effects of light have been well known since ancient times, and have benefited as a tool for treatment of some diseases. Light therapy is still popular today with its important contributions to health after the discovery of the photoreceptor cells in the eye, which clarifies how light mediates and controls some biochemical processes in the human body. According to Bommel and Beld (2003), a new era has been launched by the scientific findings that are related to the control of the biological clock and to the regulation of some important hormones through regular light-dark rhythms.

3.2.1. Health, Arousal and Stress

Arousal is the state of physical and mental activation. Arousal theory, developed by Eysenck (1990) claims that there is an optimal level of arousal, and performance gets worse as one becomes aroused more or less than this optimal level. At very low and very high levels of arousal, performance is low, but at a more optimal mid-level of arousal, performance is maximized.

Stress is the name for a set of physiological and hormonal changes that arise as a response to unpleasant events. These unpleasant events could include environmental conditions such as direct glare, or noise.

Photobiology is a branch of biological science which studies the interactions of light with all living organisms. The reason making photobiology of interest in this research is the knowledge it offers related to the effects other than vision that occur when radiation is absorbed by the photoreceptors in the human eye.

Due to the relationship between what is perceived by the human eye and the nervous system, light is believed to have powerful influence on human biorhythms. Hill (1992) says that light has direct effect on the regulation of circadian rhythms. These rhythms depend on the night and day cycle, the lunar cycle, and the seasonal cycle are strong enough to affect human physiology and capabilities. The importance of lighting and the circadian rhythm can be best shown through the example of shift workers. Today it is a well-known fact that reversed sleep has some negative effects such as fatigue and bad arousal during work. It includes higher risks in a long period of time, such as cardiovascular disease, gastrointestinal ailments and social problems (WEB_8 2004). Shift workers have a mismatch between sleep and work, they work when their body needs sleep. In other words, they do something in night the cycle, which should be done in the day cycle. Researchers showed that bright light exposure could improve arousal and cognitive performance. Light exposure suppresses melatonin secretion (Figure 3.10) and melatonin induces sleep (Boyce et al. 1997). Bommel and Beld (2003: p. 9) discuss the effects of light on hormones as follows:

> The hormones cortisol ("stress hormone") and melatonin ("sleep hormone") play an important role in controlling alertness and sleep. Cortisol, amongst others, increases blood sugar to give the body energy and enhances the immune system. However, when cortisol levels are too high over a too-long period, the system becomes exhausted and inefficient. Cortisol levels increase in the morning and prepare the body for the coming day's activity. They remain at a sufficiently high level over the course of the bright day, falling finally to a minimum at midnight. The level of the sleep hormone melatonin drops in the morning, reducing sleepiness. It normally rises again when it becomes dark, permitting healthy sleep (also because cortisol is then at its minimum level). For good health, it is of importance that these rhythms are not disrupted too much. In case of a disruption of the rhythm, bright light in the morning helps restoring the normal rhythm. In a natural setting, light, especially morning light, synchronises the internal body clock to the earth's 24-hour light-dark rotational cycle. The deharmonisation in the absence of the "normal" light-dark rhythm would result in a wrong rhythm of alertness and sleepiness, ultimately leading to alertness during the dark hours and sleepiness during the bright hours.

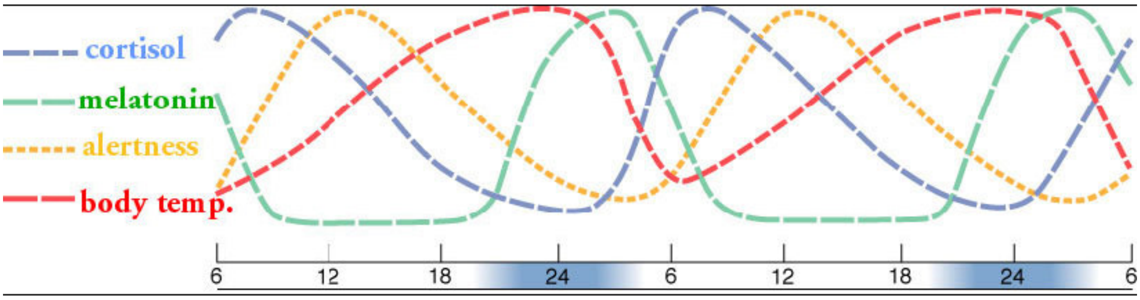

Figure 3.10. Typical daily rhythms of body temperature, melatonin, cortisol, and alertness in humans for a natural 24-hour light/dark cycle. (Source: Bommel and Beld 2003)

Illuminance: When arousal theory is applied to lighting, it may be readily claimed that higher illuminance levels stimulate greater arousal and if the arousal level is appropriate for the task, it results in improved performance. However, if the arousal level is too high, performance would be expected to decline.

Biner (1991) showed that an increase in illuminance from 32 lx to 1743 lx increases general arousal in a workstation. Hughes and McNelis (1978) reported that an increase in illuminance from 500 to 1500 lx caused an average 9 percent increase in the productivity of secretarial office workers doing a difficult paper-based task. Gifford, Hine and Veitch (1997) found that there is no significant difference in task performance between low (average 70 lx) and medium (average 486 lx) illumination levels; however task performance differs 25 percent between low and high (average 1962 lx) illumination levels. Costa (1993) found that night nurses who were exposed to short doses of high light exposure at work showed some signs of better adjustment to the schedule than those without low light exposure. Boyce (1997) found an illumination of 2800 lx triggers more arousal than 250 lx (Figure 3.11). A decline in arousal over the night occurs for both levels, but the high level always results in a significantly increased arousal level and thus better alertness and mood Another experiment in an office building in Florida showed that circadian lighting helps to keep employees awake and alert (Kelly 2003).

Delay and Richardson (1981) found that individual differences, such as sex, affect the arousal levels in accordance with illumination levels. Increasing illuminance (0,33 lx to 170 lx) has a greater effect on performance in men than women.

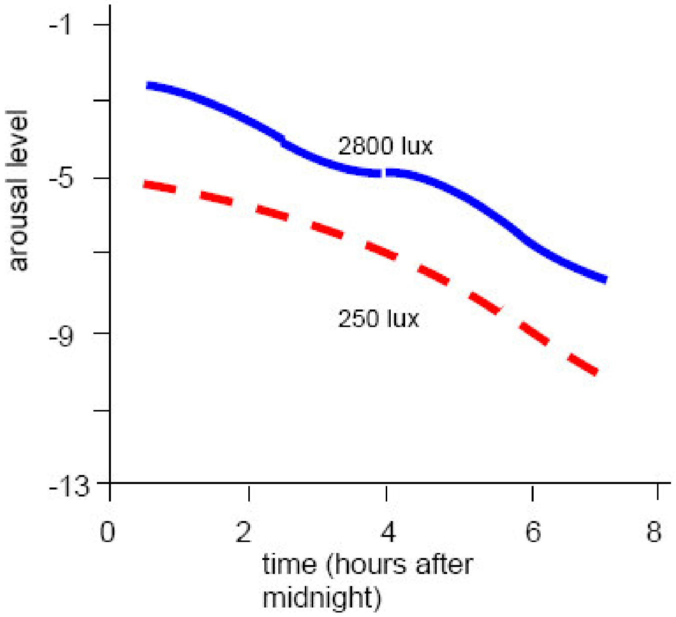

Figure 3.11. Alertness levels according to time passed after midnight.
(Source: Boyce 1997)

Glare: Very high luminances in the field of view or very high non-uniform luminance distributions can cause discomfort. Although the exact mechanism is unknown, today it is widely accepted that glare sources could constitute stressors (Berman et al. 1994). Glare sources can cause headaches (Veitch and Gifford 1996) by forcing the muscles in the eye, making them work harder than usual. Bright lights are more likely to trigger migraine headaches when they are of a "flickering" quality, and a slow flicker is usually more irritating than a more rapid one (WEB_9 2006). On certain places where VDTs are used, special attention must be paid to avoid glare and veiling reflections for physiological comfort.

Lighting Systems and Color: Deriving from their physical characteristics, some lamp types have negative effect on arousal and stress levels, , such as fluorescent light sources. Fluorescent lamps have long been associated with complaints of visual discomfort and headache (Stone, 1992). Known causes of this stress-related effect include flicker rate and spectral power distribution (Wilkins 1993). Wilkins (1990: p. 105) describes flicker as follows:

> Some of the commonly-used phosphors that emit long-wavelength light continue to do so for some time after the gas discharge, whereas phosphors with greater emission at shorter wavelengths persist for a shorter time. The longer persisting phosphors introduce a phase lag with the result that the light alternates in color as well as intensity. The degree of flicker depends on the lamp type as well as the ballast type; electronic ballasts reduce chromatic as well as luminous modulation.

Kuller and Laike (1998) found that in fluorescent lighting, using electronic ballasts, which have a frequency of 30 Hz, instead magnetic ballasts of 50 Hz, solves the flicker problem, and thus improves productivity.

It is a well-known fact that color of light itself has an emotional meaning, and is therefore important for the general atmosphere of a space. Today research shows that the spectrum has an important biological meaning, too. Brainard (2002) claims that the sensitivity of the novel photoreceptor cell in the eye varies in terms of melatonin suppression for different wavelengths of light, thus for different colors of light.

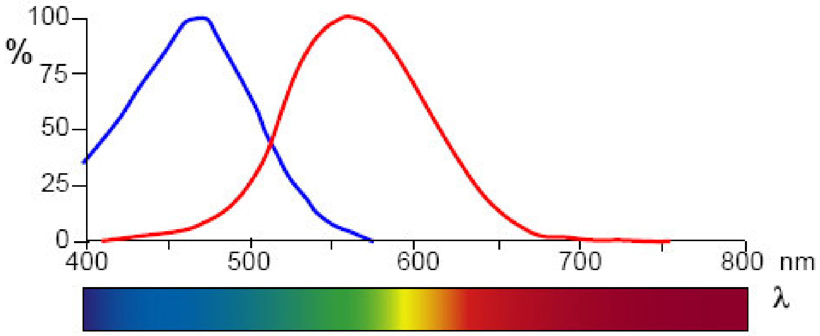

Figure 3.12. Spectral biological action curve (based on melatonin suppression), in blue, and the visual eye sensitivity curve, in red. (Source: Brainard 2002)

As shown in Figure 3.12 the bluish, cool light has biologically larger effect than red colored warmer light. The bluish morning light for example has biologically an activating (alerting) effect, while the red sky in the early evening has a relaxing effect. In an architectural environment, both activating and relaxing impressions are required. The color and level of the artificial lighting together may help to create these impressions.

3.3. Psychological Aspects

This part focuses on the psychological effects of lighting. These effects are analyzed in three main titles with varying determinants relevant to light and lighting conditions as shown in Figure 3.13.

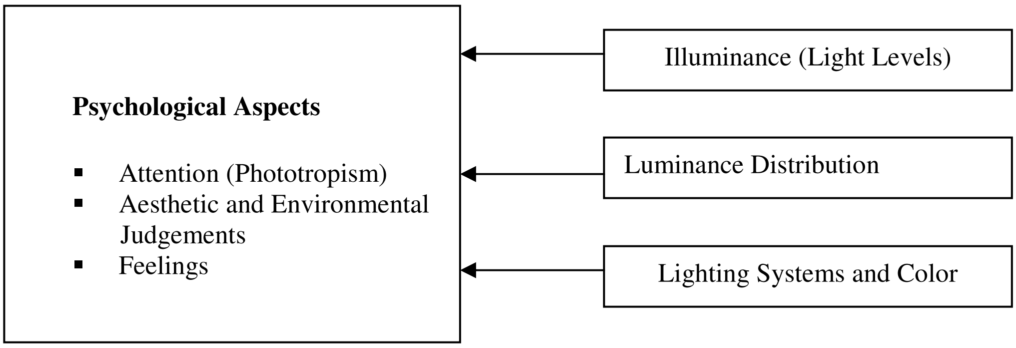

Figure 3.13. Determinants of Psychological Aspects

According to Wagner (1985), the quality of luminous environment can influence both comfort and well-being, which are psychological in nature and also behavioral. Boyce (1981) proposed that lighting quality exists when the luminous conditions support the behavioral needs of an individual in space. This definition could easily be expanded to include architectural considerations and individual well-being. The quality of the lighting in any installation is determined in the balance of these dimensions.

The aim of this part is to bring the scientific evidence to light concerning the psychological mechanisms that produce behavioral effects in response to luminous conditions. The goal is to describe the knowledge about these effects which are considered as an important dimension in explaining lighting quality. This part is organized under three main parts which are believed to underline the relationship between lighting and behaviors: Attention, Environmental Judgments, and Feeling and Preferences. This set may be expanded, but they together constitute a principal in approach to lighting. They are chosen because of the frequency of their use in explanations of lighting design choices. When one understands why certain luminous conditions produce certain behavioral outcomes, then one will be able to re-create those conditions and those outcomes.

3.3.1. Attention

According to Lam (1992), attention and the feeling of orientation is a need for human beings. Continuous visual information is required for all physical activities, such as walking, running, and working. In a space one searches for clues that give orientation for experiencing the inner atmosphere. When these clues are absent or distorted, the effect can be very disturbing.

Illuminance, Luminance Distribution: The main theory -which is widely accepted and rather beneficial- is that the light output could be increased to direct the viewer's attention to particular elements in the environment. For example, theatrical lighting design uses spotlights to direct the audience's attention to the important characters on stage. The aim is to make a target obvious by contrast against the background. Luminance distributions are used to generate attention response. In general high-brightness lighting that produces sharp contrasts and sharply defined outlines is more powerful than softly graded lighting.

Hopkinson and Longmore (1959) reported that attention on a vertical visual task was best when the task was locally lit, than when it was lit from general illumination alone. A small light source in high-brightness below the task attracted more glances, whereas a larger, low-brightness source appeared to be less attractive. Another research showed the increase in performance related to attention. Taylor et al. (1975) reported that adults were more successful in arithmetic calculations under non-uniform lighting with incandescent desk lamps (the task became the point of attention), than when the office was lit with uniform fluorescent lighting.

The effect which is called "human phototropism" also encourages movement. It is a widely accepted fact and one of the important effects of light benefited from in the creation of spatial organizations, although there is only one study to support this assertion, which is completed by Taylor and Sucov (1974). In their study they reached two conclusions: (1) For equivalent hallways 67% of the people will go to the right. (2) People tend to choose the brighter path.

3.3.2. Aesthetic and Environmental Judgments

Aesthetic judgments concern the interpretation and categorization of what we see; they are not only emotional reactions. The first task is to determine the dimensions through which we make aesthetic judgments, and the second is to determine how our aesthetic judgments relate to other responses such as feelings and preferences. Behavioral sciences developed some tools and methodologies to measure aesthetic judgments, such as Semantic Differential Rating Scales, Factor Analysis, Multidimensional Scaling, and various observation and mapping methods. Nowadays it is also possible to apply these methodologies on computer simulations.

Flynn (et al. 1992) argues that visual consciousness did not seem to be completely explainable with simple notion of an optical image imposed on the retina of the eye and photographically interpreted by the brain. Instead, he says, one finds indications that there is considerable selectivity in the process of visual experience- a search for meaningful information. He suggests that light could be discussed as a vehicle that facilitates the selective process and alters the information in the visual field. He further suggests that lighting design should be evaluated in part for its role in adequately establishing clues that facilitate or alter the user's understanding of his environment and activities around him.

In lighting design the work should convey a meaning. As in every kind of design, the end-product should neither lack something necessary nor include something unnecessary. As Waldram (1954) said, lighting designers must be warned against "doodling with light" . By saying this he was referring to the meaningless use of spotlighting outside of the architectural context.

Kaplan (1987) claimed that as humans need to make sense of what they see and to become involved in it. In his information-processing model he suggested four dimensions of appraisal, which are coherence, legibility, mystery, and complexity. The first two relate to the presence of information, and the latter two concern the need to be an active interpreter of the information.

Illuminance, Luminance Distribution and Lighting Systems: The first and most influential work in this subject is Flynn's work in 1973, where he applied sophisticated psychological techniques to lighting research. His aim was to find out how lighting affects user impressions. He obtained ratings on 34 semantic differential scales in response to six lighting configurations. A factor analysis grouped the scales into five categories, which are evaluative, perceptual clarity, spatial complexity, spaciousness, and formality. Conclusions were that an overhead diffusing light system may affect the impression of perceptual clarity but this has little effect on evaluative impressions such as pleasantness or friendliness. Overhead downlighting tends to give more positive evaluative impressions than overhead diffuse. Also the downlighting tends towards a more spacious impression.

His conclusions have been included in IESNA Lighting Handbook (1981) with little modification. For example, relaxation is said to be supported by non-uniformity, particularly non-uniform wall lighting. Perceptual clarity is said to be supported by higher horizontal illuminance in a central location. Spaciousness is said to be supported by uniform lighting and bright walls.

Judgments that a space appears interesting or pleasant are associated with non-uniform luminance distributions in the field of view. VDT operators preferred having a spot light to highlight a painting on the wall beyond the VDT screen, over the same wall with uniform illumination (Yearout and Konz 1989).

Inui and Miyata (1973) reported that the sense of spaciousness increases with an increase in horizontal illumination (from 50 lx to 750 lx). He used a scale model, where the walls could be moved and the size of the windows could be adjusted. An artificial sky was used with a set of variable luminaries.

Stone et al. (1980) tried to decipher variability according to illuminance differences. Subjects were asked to evaluate seven lecture theaters. Each person used a 15 point scale to judge the space as “totally similar” or “totally dissimilar” , comparing the quality of light in the current lecture theater to the once previously viewed. Three principles of dimensions of variability are as follows: 90% of the variance is accounted for the illuminance at the position of the lecturers head. 49% is accounted for the horizontal illuminance at the eye level of the sitting subjects.

Manav and Yener (1998) found that wall washing enhanced the impression of clarity and order, cove lighting enhanced spaciousness, and uplighting made the same space relaxing, private and pleasant. In Fleischer et al. s (2001) work, subjects rated their work environment as more pleasing and cheerful at higher levels of illuminance. In the research indirect lighting was preferred more than direct lighting, even with daylight colored lamps.

Color: Psychological research on color has been primarily directed at color in pigment, with limited attention to the effect of colored light. According to Fleischer et al. s (2001) work, warm white colored lighting installations are more pleasing than daylight colored lighting installations. Benya (1988) mentioned that blue-poor light sources impair focusing (because the eye mostly relies upon signals from the retina's cone cells in response to blue wavelengths) and make objects seem blurry. Low color temperature environments therefore appear soft-edged and unclear, while high color temperature environments appear cold and sharp. He also recommends a list for lighting designers, who wants to affect the mood in space through the use of colored light:

- Higher color temperatures are more tense and active; lower color temperatures are more relaxed and slow.
- To stimulate a feeling of warmth and coziness use lower color temperature sources.
- For a feeling of coolness or sharpness, use higher color temperature sources.
- To stimulate a feeling of uneasiness, use a poor CRI source. Sodium sources, for example, will appear stark and alarming.

3.3.3. Feelings and Preferences

People experience particular feelings or moods in all environments. Architects, designers and critics have always used the language of feeling to describe spaces. Rooms have been called “dreamlike” , “cold” , “tense” , “warm” , “cozy” , and been described in other subjective ways. These moods are the general result of humans' psychological response to architecture and undoubtedly light plays a great role in shaping them when it interacts with space.

Aesthetic judgments concern the appearance of space. Preferences include an emotional character and give answers to how the space makes the viewer feel. Today it is a well-known fact that environmental conditions that create a state of positive emotional response lead to better performance, greater effort and greater willingness to help others (Baron 1994).

This shortly framed theme has an intuitive character. In order to handle this knowledge, empirical demonstrations are needed. The first task is to find out which luminous conditions are preferred, and the second task is to check whether these preferred conditions lead to desired behavioral outcomes.

Illuminance: Preferences for illuminance levels are generally higher than the recommended levels, although preferences vary widely between individuals, settings, and tasks. Nelson et al. (1983) found that an increasing illuminance level from 100 to 320 lx, which was still lower than the male participants' preferred level for office work, decreased men's ratings on mood measures (concentration, activation), but increased women's scores on these measures.

Tregenza et al. (1974) stated that visual difficulty of the task, age of the subject and characteristics of the surfaces illuminated were the factors that effect illuminance selection. Begemann et al. (1995) reported that two male participants whose illuminance preferences were observed over a year showed difference in the preferred level, one with a very low level and one with a high level. Leslie and Hartleb (1990) found that female subjects prefer lower illumination levels than male subjects.

Boyce et al. (2001) concluded that the illuminance provided by a lighting installation is the major factor in determining whether that lighting installation will be liked or not. Kimmel and Blasdel (1973) found that student ratings of library lighting installations showed a preference of 425 lx, which was lower than they expected. Horst et al. (1988) found that ratings of the ease of working, desire to work under the lighting condition, and comfort, increased from 10 to 200 lx illuminance, and then remained stable. Increasing illuminance for these control room tasks from 200 up to 800 lx did not alter these subjective ratings.

Looking at the scientific results above, it is clear that there is an enormous individual variety in illuminance preferences.

Luminance Distribution: It is clear from many studies that vertical surfaces are key to satisfaction. People prefer brighter walls to dark ones. Rowlands et al. (1985) indicated that there was strong correlation between subjective ratings of satisfaction and the lighting on the work plane, the lighting on the walls, and the average luminance of the whole view. Non-uniform distributions from task/ambient combinations can contribute to the creation of environments that one would describe as comfortable, particularly for VDT work (Inui et al. 1989).

Collins (1990) found that work station brightness was a stronger determinant in comparison to task illuminance when determining satisfaction. Evaluation of subjective response to the brightness of the work station was obtained through the use of a seven point semantic scale of bright to dim. Results showed that occupants made their judgments on room luminance rather than illuminance. Subjects preferred direct furniture-mounted fluorescent luminaries, which causes high brightness and low task illuminance, rather than indirect furniture-mounted fluorescent luminaries, which causes a more uniform atmosphere with low brightness and high task illuminance.

Collins et al. (1990) concluded that the low ratings given by office occupants to the combination of indirect furniture-mounted fluorescent luminaries with undershelf task lamps was related to the high task illuminance and low peripheral brightness of the workstation. When the same systems furniture was lit with a direct system, vertical luminances were higher and so was satisfaction.

Kinkeldey et al. (1990) stated that brightness differences were the most important aspect for the user in assessing the lighting quality. His study concluded in a recommendation of more brightness than 1:10 between the working place and the room itself. Loe et al. (1991) found that people prefered to have some non-uniformity of brightness patterns, with a ratio of not less than 15. The general value for the preferred subjective brightness is 100 cd/m2.

Ooyen et al. (1986) studied preferences for various luminance distributions at a fixed task illuminance of 750 lx by varying the reflectance of room surfaces. They concluded that wall luminance is the principal contributor to the experience of the room. An increase in wall luminance will make the room feel more stimulating and make concentrating on the task easier. Another conclusion was that as the wall luminance increases, a lower desktop illuminance is preferred.

Mc Kennan and Parry (1984) found that non-uniform distributions were more acceptable. All the installations both localized (directed from the ceiling to the desk) and local (task lamps) lighting were rated satisfactory, even when they were lower than the recommended levels.

Hawkes et al. (1979) found that 8 configurations with diffuse light sources were all rated as uninteresting; 10 configurations with one or more focused source were rated as interesting. Loe (et al. 1982) determined that non-uniform wall lighting was preferred for viewing paintings in a gallery.

Lighting Systems and Color: Hawkes et al. (1979) found that the least preferred lighting scheme in offices is one with regular receding luminaries. Kaneko and Tagahashi (1973) stated that recessed fluorescent luminaries with clear prismatic panels or with plastic louver were not preferable because of their tendency to make the interior gloomy.

Flynn (1977) found that wall lighting added to overhead downlighting were preferable over peripheral overhead lighting in all his three categories of impression, which are evaluative, visual clarity, and spaciousness. Overhead downlighting alone produce a better impression of visual clarity than peripheral systems.

Hedge et al. (1995) managed a study of suspended lensed-indirect and parabolic louvered lighting systems. The results showed that office workers preferred the lensed-indirect systems.

Evans (2000) stated that the functional use of color is designed around the use of a variety of colors in order to keep human responses continually active and to avoid severe visual adaptation or emotional monotony.

Knez (1997) reported that there is a slight difference in color preferences between men and women. In his study he used two lighting system with varying CRI and illuminance. According to the positive mood results, for females the most optimal lighting combination in preserving that mood over a period of 80 minutes of intellectual work was the 300 lx at CRI 95 lighting. For males, on the other hand, the 300 lx by CRI 55 and 1500 lx by CRI 95 lightings accounted for a similar effect.

Tulmann (2000) searched the effects of colored light on consumers' preferences. In his experiment he used two storefront displays in a shopping mall, one with general ambient lighting closer to the daylight spectrum, one with dynamic full-spectrum digital lighting. The colored storefront display has received attention 40 percent more than the one with white light and the traffic in the store increased 20.7 percent relatively to the same time period a year earlier.

Knez (1995) found that warm (more reddish) lighting has a positive effect on mood, while cool lighting (more bluish) has a negative effect on mood in younger participants. In older participants the reverse effect was observed. This implies that coloring quality of indoor lighting has different emotional meanings for younger and older people.

In the light of this detailed knowledge, an evaluation methodology is designed to assess lighting quality. As seen in Figure 3.14 each of three aspects work as a plug, which make the evaluation methodology flexible for varying architectural functions. It is possible to remove or add new aspects or criteria according to the relevant function. It is important to make a pre-evaluation study where the lighting needs were discussed concerning architectural function.

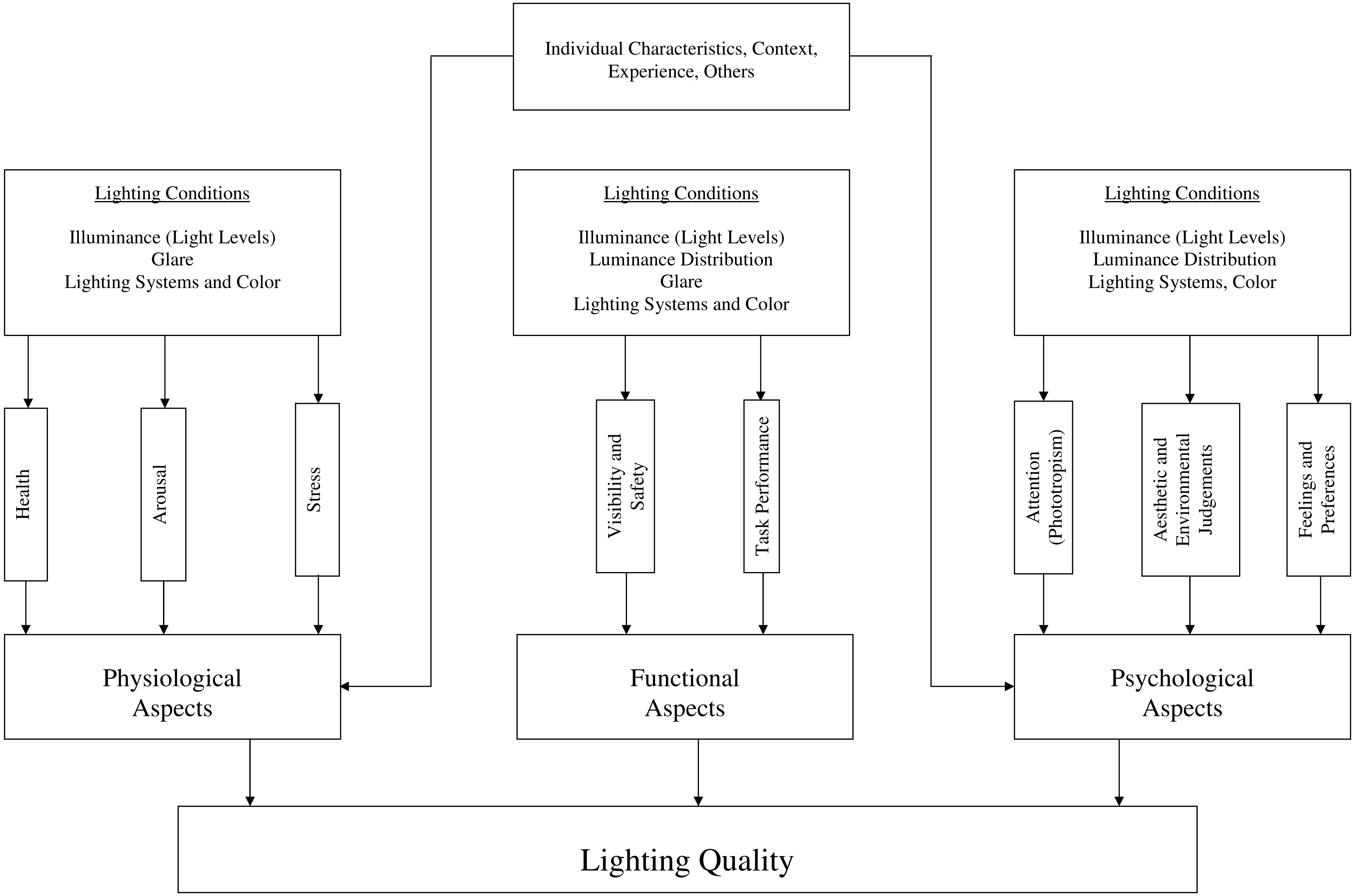

Figure 3. 14. Diagram of the Evaluation Methodology for Artificial Lighting Quality

CHAPTER 4

CASE STUDY

It is necessary to make a research concerning the architectural function of the case prior to evaluation because each function has its own unique lighting requirements as mentioned before. Due to the special requirements of the function, the proposed evaluation methodology may change through addition or removal of certain criteria. Following part will focus on detailed lighting requirements of museums and art galleries in terms of artificial lighting, since the case of this dissertation is a permanent gallery for educational purposes.

4.1. The Requirements of Museums and Art Galleries in Terms of Artificial Lighting

In the history of lighting, museums and art galleries have been the forerunners of advanced solutions. Museum architecture developed during the nineteenth century. Since then architecture and art have changed a lot, but the basic lighting problem has remained the same, perhaps having become even more severe than before because of the wide use of glass surfaces. Since this dissertation focuses only on electric lighting natural lighting and its effects on various objects will not be discussed.

Museum and art galleries are areas in which objects of art (with historical value, or for educational purposes) are displayed to the public. They vary in size, shape, and texture, also in the manner or position in which they can be shown best. In the nineteenth century gas lighting was used (Figure 4.1) to illuminate those pieces of art, which had severe disadvantages both in quality and quantity. Today the vast industry of illumination provides lots of possibilities in lighting if it is used carefully. Lighting requirements of museums and art galleries could simply be divided into two subgroups, such as:

- Quantitative requirements
- Qualitative requirements

4.1.1. Quantitative Requirements

Lighting in museums and galleries has a double-sided character, which requires solutions for opposing requirements. Art Objects in museums and galleries must be preserved and, at the same time, be available for display. Pigments tend to deteriorate with illumination, but illumination is necessary to see the art works (Scuello et al. 2003). Although we could not do without light in museums and art galleries, it is important to remember that light is an environmental factor that contributes to the deterioration of our valued collections (Figure 4.2). All common light sources, such as the sun, light bulbs and fluorescent tubes, also give out other forms of radiation to varying degrees. The most significant of these are ultraviolet[8] and infrared[9] radiation. Ultraviolet radiation is potentially the most damaging form of energy present in museums, and art galleries. So when lighting an area where important or valuable works are housed, it is essential to take precautions to minimize the potential damage.

Although light is not fully responsible for most of the damage, there is a clear relationship between exposure to light and the amount of deterioration in museum collections. Deterioration caused by light can be divided into two main types: thermal and photochemical.[10] While thermal effects are attributed to the infrared content of the

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[8] Ultraviolet (UV) light is electromagnetic radiation with a wavelength shorter than that of visible light, but longer than soft X-rays. The name means "beyond violet" (from Latin ultra, "beyond"), violet being the color of the shortest wavelengths of visible light. Some of the UV wavelengths are colloquially called black light, as it is invisible to the human eye (WEB_10 2006).

[9] Infrared (IR) radiation is electromagnetic radiation of a wavelength longer than that of visible light, but shorter than that of radio waves. The name means "below red" (from the Latin infra, "below"), red being the color of visible light of longest wavelength. Infrared radiation spans three orders of magnitude and has wavelengths between approximately 750 nm and 1 mm (Wikipedia 2005). Infrared radiation is less energetic than ultraviolet radiation and visible light. It heats materials and can cause them to expand, leading to mechanical stresses; and can also cause chemical changes to progress more rapidly. As a result, infrared radiation can increase the destructive effects of visible light and ultraviolet radiation. Once started, photochemical reactions can continue even after the exposure to light or ultraviolet radiation has stopped. This means the deterioration of objects does not stop when the objects are placed in the dark (Heritage Collection Council 1998).

[10] When light and ultraviolet radiation fall on an object, they deliver bundles of energy to that object. As a result, various chemical reactions can take place, depending on the amount of energy delivered. These reactions are called photochemical reactions. In some cases it is very easy to see the effects of these reactions: try leaving a piece of newsprint in the sun for a few hours and examine the results. The paper becomes discolored—yellowed. However, most changes caused by photochemical reactions are not as quick as this nor as obvious; so it is difficult to know they are occurring. Nevertheless their effects can be devastating and ongoing by causing extreme and irreversible damage to many materials, most notably organic materials that derive from plants and animals. In a museum, gallery or library, these will include furniture, textiles, prints, books, drawings, manuscripts, wallpaper, dyes and inks, feathers and fur. (Gabosh 1994)

light source, photochemical effects are attributed to the ultraviolet content of the light. Local heating caused by this infrared radiation results in a change in relative humidity in the immediate region of the illuminated object, which can cause movement, warping and splitting in moisture-absorbing materials such as wood and some types of glass (CIBSE 1994). More important is the photochemical damage, which causes color change and physical deterioration.[11]

Figure 4.1. Detail of a gas pipe, showing the burners on both sides.
(Source: Swinney 1999)

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[11] Pavlogeorgatos G. (2003) points out the deterioration process related to lighting as follows:
It is well known that the deterioration process of materials requires energy. Light is the most powerful source of energy in museums. Thus, (natural and artificial) illumination in museums can:

- accelerate the deterioration and corruption of several materials, because it acts as a catalyst to their oxidization;
- subsidize and raise the fragility level of cellulose fibres (wood, paper);
- discolor, fade or blacken the paper;
- fading and/or alter the dye/painting colors and materials of works of art;
- corrode significantly every natural fabric;
- deteriorate exhibits in Natural History Museums; and
- increase the surface temperature of exhibits.

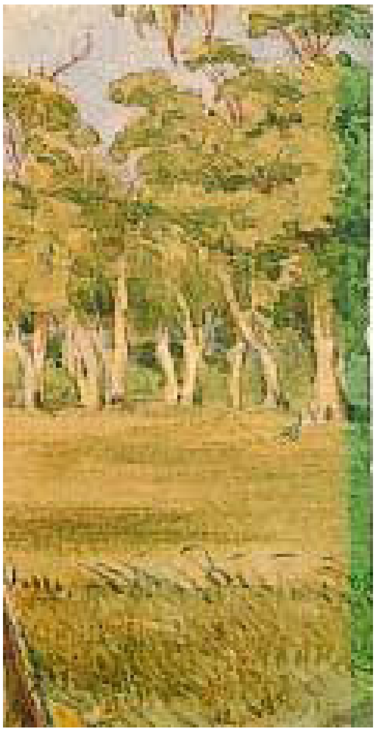

Figure 4.2. The pigments on the edge of this watercolor have not faded because they have been protected by the mount. (Source: Heritage Collection Council 1998)

Some objects are insensitive to light while others are so easily damaged that a very short exposure will produce a change in appearance. This sensitivity depends on the chemical composition. As a general rule, inorganic materials such as glass, ceramic, stone, and metals are less sensitive to photochemical deterioration than organic materials such as dyes, pigments, textile, wood, and paper. Photochemical change is irreversible. Thus lighting must be considered a high priority issue in museums and art galleries.

In selecting light sources it is vital to know that visible light is often accompanied by these ultraviolet and infrared radiations. There are many types of artificial light sources. Each has advantages and disadvantages. Incandescent lamps, in spot or floodlights, have a low ultraviolet output, but emit infrared radiation in the form of heat. Therefore, if they are close to items or placed in a closed case, they can cause damage by raising the temperature of the objects because of the high intensity. If we want to lower the intensity of light falling on an object we can simply move it further away from the light source. For example, if the brightness or intensity of light falling on an object is measured at 100 lx when the object is one meter away from the light source, we can decrease that intensity to 25 lx by moving the object to a distance of two meters from the light source.

Fluorescent light tubes are cold, but many emit higher than acceptable levels of ultraviolet radiation (Heritage Collection Council 1998). However, fluorescent tubes are generally preferred, because they are more effective in cost and are longer-lasting than incandescent bulbs. If fluorescent or halogen lights are used, low ultraviolet-emitting fluorescent tubes should be preferred, and/or some sort of ultraviolet-absorbing filter should be used to remove the ultraviolet radiation. This filter can be used on the lamps or on display cases and frames. They are available in forms of films, acrylic sheets, and lacquers

Tungsten metal halide bulbs, which are more efficient than ordinary incandescent bulbs, also give out higher than acceptable levels of ultraviolet. So they need to be filtered in order to avoid any potential damage.

Illumination standards in museums and galleries have been established to control the amount of damage caused by light. While all wavelengths of light can cause some damage, the shorter wavelengths are more damaging (Scuello et al. 2003).

Illuminance ratios in museums are becoming lower as a tendency in the world, since high illumination means more problems in the way of preservation. There are varying standards of illuminance for museums and art galleries, formed by varying authorities in the world, such as the IES (Illuminating Engineering Society), JIS (Japan Illumination Standards), and ICOM (International Council of Museums). These standards considering varying materials are indicated in Table 4.1, Table 4.2, Table 4.3, Table 4.4.

As seen in the tables, for sensitive materials such as textiles and watercolors the brightness of the light should not be greater than 50 lx and the exposure in one year should not be greater than 150 kilolux-hours. In addition to this the ultraviolet content of the light should not be greater than 75 µW/lm[12], and preferably 30 µW/lm (CIBSE 1994). For moderately sensitive materials such as oil paintings and furniture the brightness of light should be between 75-200 lx and the exposure in one year should be between 180-600 kilolux hours.

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[12] µW/lm (Microwatts per lumen) is the unit which indicates the amount of UV energy in the light coming from a light source. Microwatts are a measure of energy; lumens measure the quantity of light from a particular light source. This measurement is constant for a light source and does not alter if the readings are taken at a greater distance from the source. If one needs to lower the UV content of the light, one can use absorbing filters on light sources, or can install lights that give out only small amounts of UV radiation. (Light and Ultraviolet Radiation 2005)

Table 4.1. Maximum Illuminance Recommended (lx)
(Source: International Lighting Review 1977)

Object	**ICOM**	**IES**
Metal Stone Glass and ceramics Stained glass Jewellery Enamel	**not restricted** but rarely necessary to exceed 300 (colour temperature 4000-6500K)	**unlimited** but subject to display and radiant heat considerations in practice
Oil and tempera painting Natural leather Horn Bone Ivory Wood and lacquer	**150-180 in service** (Color-temperature ca. 4000K)	**150**
Textiles, Costumes Water colors Tapestries Prints and Drawings Stamps Manuscripts Miniatures Gouaches Dyed leather	**50** (less if possible) (Color temperature ca. 2900K)	**50**

Table 4.2. Recommended Illuminance and Illuminance-Hours per Year
(Source: IESNA 1987)

Item			**Illuminance (lx)**	**Total exposure limits per year (lx-hour)** [13] **(lx x hr x day)**
Displays of non-sensitive materials			200-300-500	No limit
Displays of sensitive materials	High susceptible displayer materials	Silk Art on paper, Antique documents, Lace Fugitive dyes	50	120,000 (50 x 8 x 300)
	Moderately susceptible displayer materials	Oil Paintings Cotton Wool Other textiles where the dye is stable Certain wood finishes Leather	75	180,000 (75 x 8 x 300)
Lobby, general gallery areas, corridors			100-150-200	No limit
Restoration or conservation shop and laboratories			500-750-1000	No limit

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[13] Lux-hour is the unit which indicates the exposure to light over a period of time. Take the example of an historical costume on permanent display in a museum. The museum is open 5 days a week for 5 hours a day all year round and while the museum is open, the costume receives light to an intensity of 200 lx. In a year -the costume is exposed to: 5 x 5 x 52 x 200 lux-hours = 260000 lux-hours or 260 kilolux-hours
This could be brought to within the levels recommended in the guidelines by adjusting the intensity of light falling on the costume and/or reducing the display time. For example, if the intensity of light was lowered to 50 lx and the costume was on display for only 6 months of the year, the total annual exposure would be significantly altered: 5 x 5 x 26 x 50 lux-hours = 32500 lux-hours or 32.5 kilolux-hours (Heritage Collection Council 1998)

Table 4.3. JIS Illuminance Standards
(Source: WEB_11 2003)

Illuminance (lx)	Museum
750-1000-1500	Sculpture (stone, metal) Molding object Model
300-500-750	Sculpture (plaster, tree, paper) Oil painting Laboratory Investigation room Stand Entrance hall
150-250-300	Pictures (with glass) Japanese painting Rest room Small meeting room Classroom
75-100-150	Gallery Dining room Tea room Passage Stairs
30-50-75	Receipt warehouse

Table 4.4. CIE Illuminance Standards
(Source: WEB_5, 2003)

Material Classification	Examples of materials	Limiting illuminance	Limiting annual exposure
Insensitive	metal, stone, glass, ceramic	no limit	no limit
Low sensitivity	canvases, frescoes, wood, leather	200 lx	600 000 lxh/a
Medium sensitivity	watercolor, pastel, various papers	50 lx	150 000 lxh/a
High sensitivity	silk, newspaper, sensitive pigments	50 lx	15 000 lxh/a

In museums and art galleries there are three ways for materials to be put on view depending on their type, nature and size:

- Hanging on a wall or a surface within the exhibition (Oil paintings, watercolors, print-outs, etc.)
- Putting in a display case (jewelry, ceramics, pottery, glass, textiles, etc.)
- Leaving as free-standing objects (Sculptures, furniture, skeletons, etc.)

All these materials give different responses to light. Thus each of them needs to be illuminated according to different techniques concerning conservation and also visibility. Major considerations will be the maximum amount of light permitted, the ultraviolet content of light, and the placement of light sources.

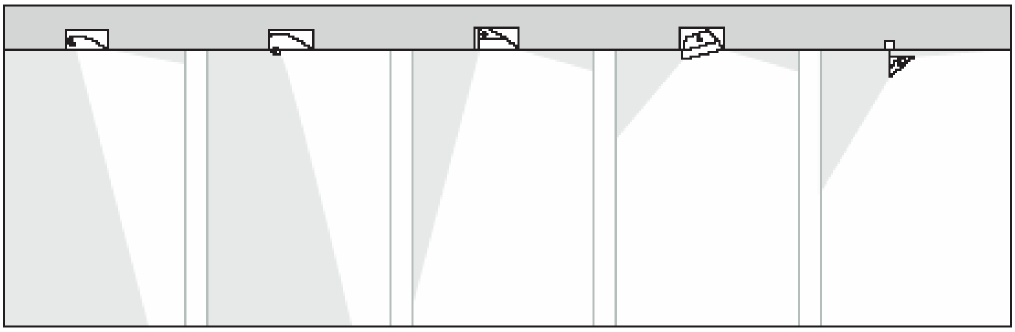


Figure 4.3. Wall lighting using linear luminaries
(Source: Ganslandt and Hoffmann 1992)

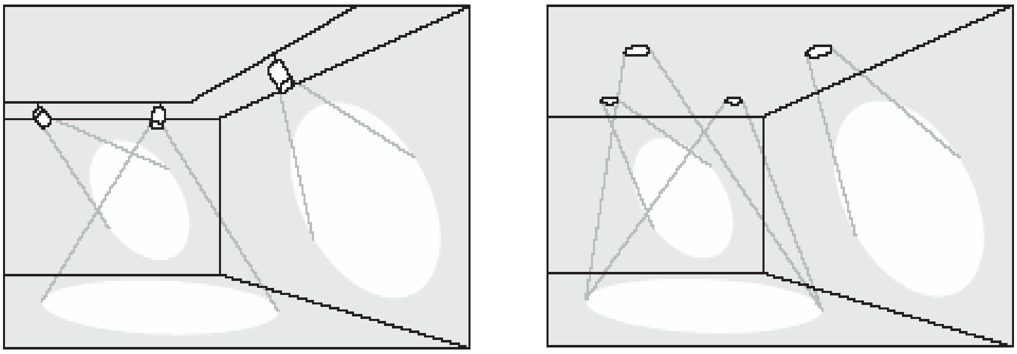


Figure 4.4. Individual Lighting
(Source: Ganslandt and Hoffmann 1992)

There are two possible approaches to lighting for materials hung on surfaces. One is to light the display wall with a relatively even distribution of light, which will be usually provided by a linear system of lighting (Figure 4.3). The second approach is to highlight each painting or a group of paintings (Figure 4.4). First approach is particularly used for large paintings and wall paintings. If the second approach is preferred, it is necessary to aim the spotlighting from such a position that reflected images of the lamp do not occur in directions of view and cause glare. When illuminating paintings using spotlights, the luminaries should be arranged so that the angle of incidence of the light is approximately 30° (Figure 4.5), the so-called "museum angle." This produces maximum vertical lighting and avoids reflected glare that may disturb the observer (Ganslandt and Hoffmann1992). This angle handles reflected glare, illuminance and frame shadows optimally. Figure 4.6 shows the different lighting solutions considering glare.

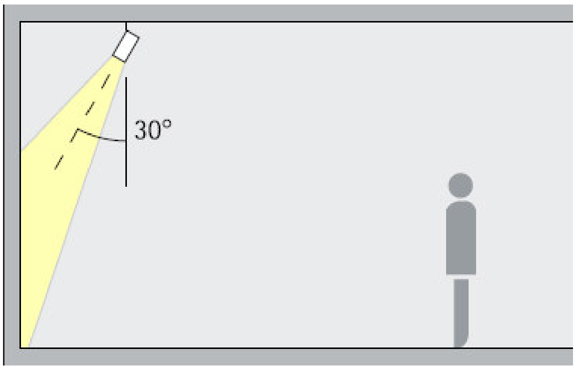


Figure 4.5. The optimum angle of incidence for the illumination of paintings is 30°. (Source: Ganslandt and Hoffmann 1992)

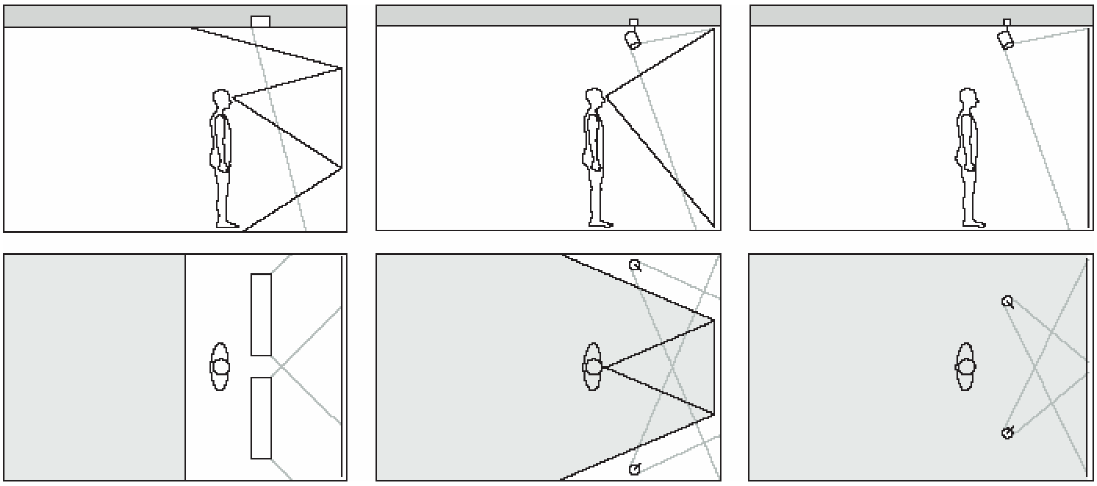


Figure 4.6. Lighting solutions for vertical visual tasks free of reflected glare (from left to right): if the reflective surface is arranged transversely, the luminaires can be mounted in front of the excluded ceiling zone. If the reflective surface is arranged vertically, then next to the excluded ceiling zone (centre). If the entire wall surface is reflective, the luminaires must be mounted within the excluded zone; the cut-off angles must be planned such that the observer is not disturbed by reflected light. (Source: Ganslandt and Hoffmann 1992)

In many museums, especially those where archaeological, ethnological or scientific information is presented, the exhibits are primarily displayed in showcases. This is for protecting exhibits from possible damage by visitors and bad environmental conditions while providing increased security. When developing the lighting design concept, priority must be given to the showcases. The first task of the lighting is to illuminate the exhibits in accordance with their particular qualities. It is possible to illuminate the showcases both internally (Figure 4.7) and externally (Figure 4.8).

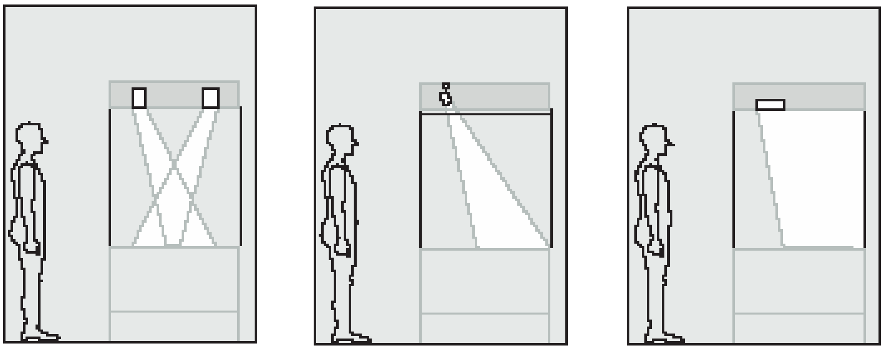


Figure 4.7. Internal illumination for showcases. Left: Accent lighting inside the showcase is provided by recessed low-voltage directional spotlights. The luminaries are equipped with covered reflector lamps to avoid danger to the exhibits. Middle: Showcase lighting using spotlights. The showcase is shielded by a filter attachment and an anti-dazzle screen. The upper section of the showcase can be ventilated separately. Right: Wide-beam lighting of the showcase using a washlight for compact fluorescent lamps or halogen lamps. (Source: Ganslandt and Hoffmann 1992)

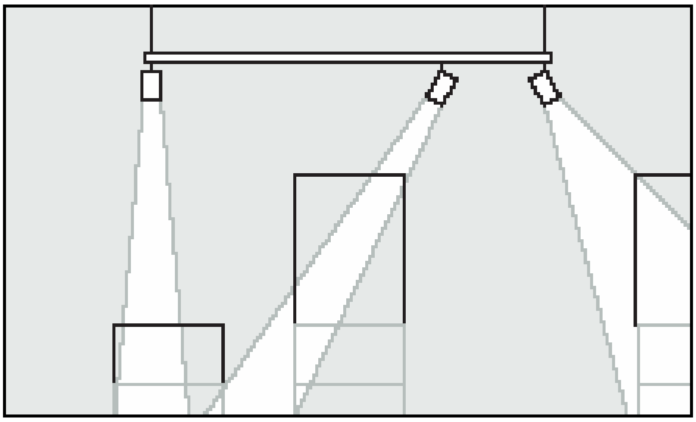


Figure 4.8. External illumination of showcases. Spotlights are mounted on a suspended light structure. (Source: Ganslandt and Hoffmann 1992)

Depending on the type of materials that are to be illuminated, choice of lamp, filtering and illuminance control must be investigated carefully for not to damage the exhibit. The damage caused by visible light, ultraviolet and infrared radiation, overheating in showcases due to convection is also an aspect to be considered. In the case of sensitive exhibits it may be necessary to install integral luminaries in a separate compartment of the showcase. The lighting equipment should ideally be isolated from the display area of the case in a compartment with separate access so that the lighting can be maintained and lamps replaced without disturbing the exhibits (CIBSE 1994).

When lighting showcases it is especially important to avoid reflected glare on horizontal and vertical glass surfaces. Careful attention must be paid to the positioning and direction of luminaries when illuminating the showcase from the outside. One of the most difficult problems to overcome is the unwanted light reflections on the external surface of the showcases. These can cause irritation, distraction, and in some cases obliterate the view of the exhibit. The main reason is the electric lighting equipment mounted in the "forbidden zones" (Figure 4.9).

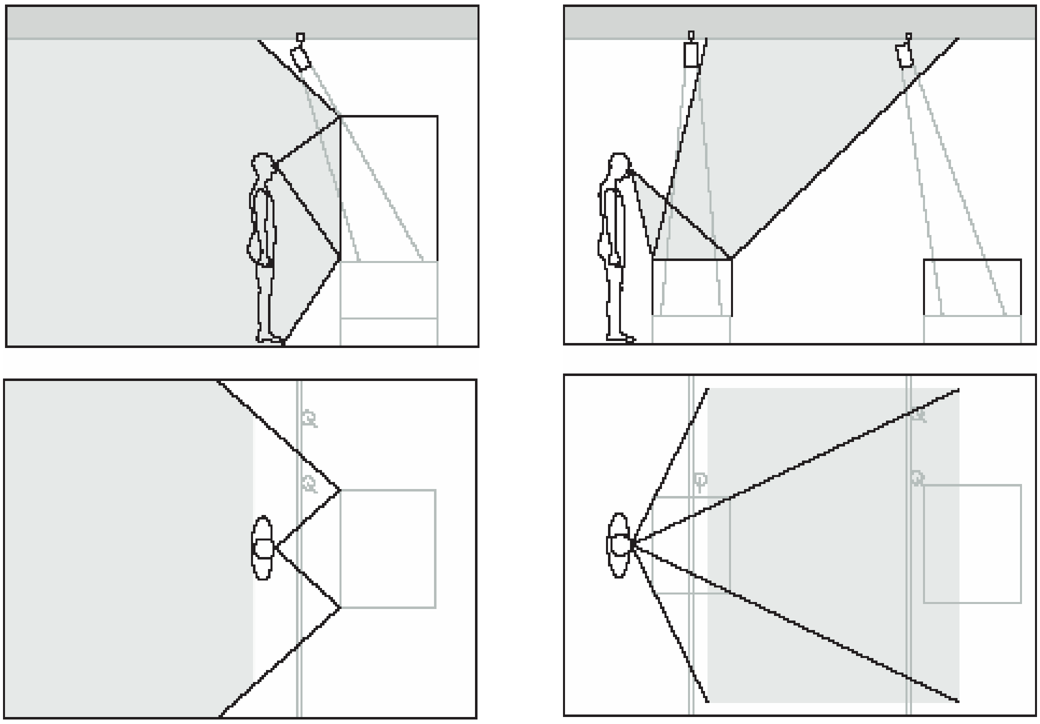


Figure 4.9. Identifying the "forbidden zones" for horizontal reflecting surfaces. No lamp luminances should be reproduced on the reflecting surfaces from these areas of the ceiling. It is acceptable to position luminaries in these areas, provided they are directed or shielded so as not to produce glare effects. (Source: Ganslandt and Hoffmann 1992)

Transparent materials, such as glassware, can be illuminated by a system integrated into the base of the showcase. Generally halogen and fluorescent lamps are used. Fiber optic systems can also be considered if thermal load due to lamps inside the cases are high, or if the showcase dimensions do not allow the installation of conventional luminaries. In addition to integral showcase lighting separate ambient lighting is invariably required. Depending on the required atmosphere and the illuminance laid down in curatorial stipulations, ambient lighting may range from a lighting level just above the level of the showcase lighting down to orientation light produced by spill light from the showcases (Ganslandt, 1995). Lighting strategies vary according to the size, position, and the material of the showcase. Shaw (1994) discusses showcase lighting as follows:

> With a display case all the preceding points are condensed into a very small space and it is therefore important to discuss case lighting with the exhibition designers early on in a project to ensure that there will be enough space for the lighting. There can be no general rule as to what is the correct solution as this will depend on the nature of the objects to be displayed and their positions within the case. What can be said is that the box full of fluorescent tubes at the top of the case is rarely satisfactory. Low voltage dichroic lamps can be used to great effect from within a top box providing they are freely positionable, however undimmed direct light from even a 20W dichroic lamp will exceed most conservation levels. The trick is to use careful focusing to spill light onto delicate objects rather than light them directly as this allows you to minimize dimming and so retain a good color temperature. When it comes to larger or undercut three dimensional objects top box lighting on its own is very limited and in these situations it is often necessary to introduce light within the case from other angles. Putting any light source in the same airtight space as the exhibit is unacceptable due to the inevitable heat rise within the case. This is where Fiber Optics are at their most useful as it is possible to position the fiber ends inside the case without risking heat build up or unacceptable Ultraviolet and lighting levels (Figure 4.10). Fiber Optics can also be effectively used within the top box of a display case, alongside low voltage lamps, where there are particularly light sensitive objects such as paper or textiles.

Free-standing objects such as sculptures and furniture have a wide variance in material thus careful decisions should be made concerning conservation categories. While inorganic material like stone and metal are insensitive, organic materials are highly sensitive to light. The important thing is that the lighting should render the form and texture of the object (Figure 4.11). Sculptures generally require directed light to reveal the three-dimensional quality and surface structure. They are usually illuminated by spotlights or recessed directional spotlights.

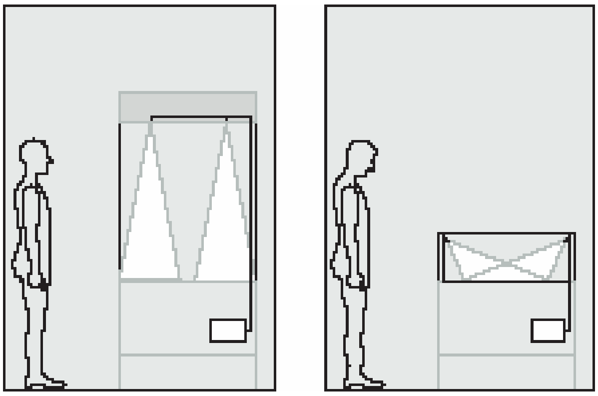


Figure 4.10. Showcase lighting using a fibre optic system. One central light source supplies a number of light heads. Integral lighting of this kind can be installed in the smallest of spaces. (Source: Ganslandt and Hoffmann 1992)

Figure 4.11. The lighting should render the form and the texture of the sculpture. (Source: Fördergemeinschaft Gutes Licht 2002)

If the exhibition is housed by a historical building then a set of constraints will be available in terms of lighting to preserve the architectural and historical value of the building. The major constraint will be the limited options available for providing an electrical supply to lighting equipment such as wiring. The wiring should be as invisible as possible. One of the other constraints is that it may not be permitted to mount the lighting equipment on any surface of the building. On these occasions floor-standing luminaries (Figure 4.12Figure 4.12) should be preferred or a solution with minimum touch should be developed (Figure 4.13). The process of designing lighting for a museum or gallery in a historical building may sometimes require taking advice from authorities on historical buildings.

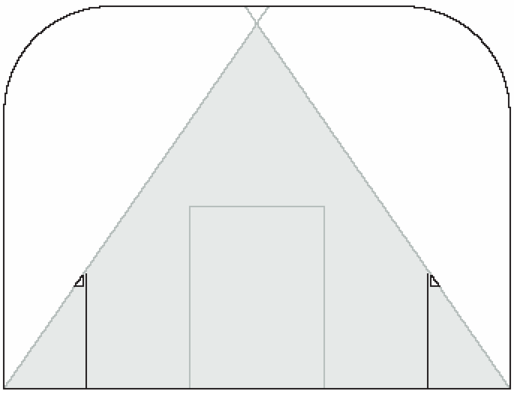


Figure 4.12. Floor-standing luminaries.
(Source: Ganslandt and Hoffmann 1992)

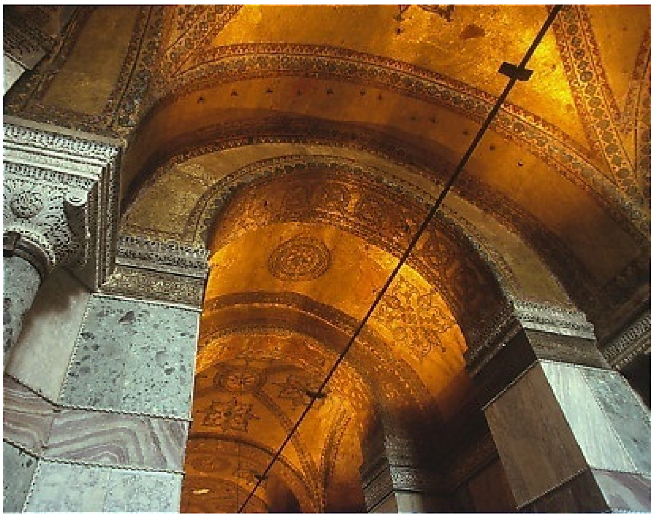


Figure 4.13. Hagia Sophia, Istanbul. The halogen uplights are mounted onto a rail with as minimum connection detail on walls as possible.

4.1.2. Qualitative Requirements

As mentioned before, "lighting quality" in this dissertation is described as a phenomenon which accompanies spatial quality with its peculiarities far more than vision. In order to develop successfully lit environments, one need to consider the third factor alongside architecture and light, which is perceptual psychology. Light is not/should not be just a physical quantity that provided sufficient illumination. It is a decisive factor in human perception. The ability of lighting is not only to make things and spaces around us visible, but also to determine the priority and the way individual objects in our visual environment are seen.

With Kelly in the fifties the issue of quantity is replaced by different qualities of light, a series of functions that lighting had to serve the needs of the perceiver. Kelly developed a basic description of the various functions of light as a medium for conveying information. He described the first and basic form of light as ambient light. This is the light that provides for the general illumination of our environment. It guarantees that the surrounding space, objects and persons in it, are visible. This form of overall, uniform lighting ensures that we can orient ourselves and carry out general tasks.

To achieve differentiation, a second form of lighting is required which Kelly described as focal glow. This is the first instance where light becomes an active participant in conveying information. One important aspect that is taken into account here is the fact that our attention is automatically drawn towards brightly lit areas. It is therefore possible to arrange the mass of information contained in an environment via the appropriate distribution of brightness. This also applies to orientation within space – e.g. the ability to distinguish quickly between a main entrance and a side entrance – and for the accentuation of objects, as we find in product displays or the emphasizing of the most valuable sculpture in a collection (Marsteller 1987).

Light is necessary in museums and art galleries not only for viewing exhibitions, and safety but also to provide a comfortable, pleasing, and informative viewing environment for people. Lighting must be designed to help create an attractive general appearance in space and also the feeling of well-being of the visitor.

Research in varying disciplines has showed that, well-being in terms of lighting is mostly related to the distribution of light in the space, color rendition, color temperature, visual access, and ability to control light. If the case is a museum or an exhibition hall, letting visitors control lighting may not be possible because of the requirements of conservation. Moreover museum is a public space, and one’s subjective decisions may interfere with the subjective decisions of others. However, it is possible to determine general lighting preferences of people by means of questionnaires and other data collection methods which are available.

Correct distribution of light and shadow makes for clearer perception of three-dimensional objects and thus helps us get our bearings in a room (Fördergemeinschaft 2002). Without shadow we see objects only as two-dimensional images. Direction of light is important to permit 3D projection and to give objects depth. A bright room with nothing but diffuse lighting and no shadows makes for a monotonous impression and causes lack of orientation, poor definition of objects and difficulty in estimating distances which makes people feel uncomfortable. However, harsh shadows should be used carefully because on the contrary, they could render objects unrecognizable and sometimes even could be unsafe in certain locations such as stairs. Figure 4.14 shows the effect of shadows in perceiving three dimensional objects.

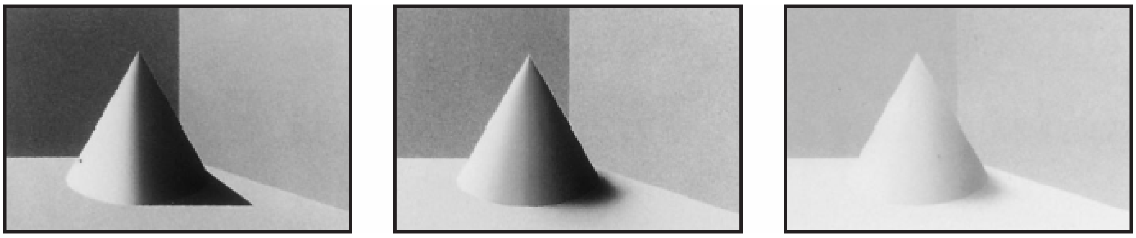


Figure 4.14. Perception of three-dimensional forms and surface structures under different light-shadow conditions. Left: Directed light produces pronounced shadows and strong shaping effects. Forms and surface structures are accentuated, while details can be concealed by the shadows. Middle: Lighting that consists of both diffuse and directed lighting produces soft shadows. Forms and surface structures can be recognized clearly. There are no disturbing shadows. Right: Diffuse lighting produces negligible shadowing. Shapes and surface structures are poorly recognizable. (Source: Ganslandt and Hoffmann 1992)

Museums and art galleries could often include requirements for more dramatic style lighting which sometimes require theatrical lighting techniques and equipment to provide particular points of emphasis, or dynamic moving effects to enhance the spatial experience (Shaw 1994). In the theatre, the question of illuminance levels and uniform lighting is of minor importance. The aim of stage lighting is not to render the stage or any of the technical equipment it contains visible. Besides, it aims at altering the perception of the audience with changing scenes and moods. Stage lighting goes much further in its intentions than architectural lighting does by creating illusions, whereas architectural lighting is concerned with rendering real structures visible. Nevertheless stage lighting serves as an example for architectural lighting. It identifies methods of producing differentiated lighting effects and the instruments required to create these particular effects.

Another important difference between diffuse and concentrated light is the characteristic related to the accurate and pleasant viewing of color. Diffuse light tends to “desaturate” colors and imparts dullness to them (Kaufmann 1966) (Figure 4.15). Directional light strongly renders saturation in colors. Paintings, such as Osman Hamdi’s, which have rich surface textures and colors, would be perceived inaccurately under such diffuse or uniform way of lighting. According to Taylor (1993) the difference between diffuse and concentrated light shows up markedly on paintings having more than one coat or varnish. He continues that both concentrated and diffuse light together are desirable for full appreciation of the surface characteristics of art works.

Figure 4.15. The diffuse lighting system in Istanbul Modern desaturates colors of art objects.

In some cases the differentiation between building and display lighting is not always clearly designed as where the reflected light from the display lighting provides the building lighting. It is important for the designer to consider both elements of the lighting to ensure that the electrically-lit gallery space appears pleasant and attractive in addition to providing appropriate lighting for the exhibits (CIBSE 1994). Depending on the architectural character of the gallery and on how exhibits are to be displayed and lit, the building lighting may constitute some form of concealed or indirect lighting which balances the light pattern to ensure an appropriate light contrast between the exhibits and the gallery space (CIBSE 1994). The aim of the lighting in such spaces should be to provide a pattern of light where the exhibits are the brightest part of the field of view. Without a visual contrast between the exhibit and background lighting, a gallery could appear dull.

Typically, the contrast between the illuminance on the exhibits and general lighting of the gallery is 3:1. If the illuminance on the exhibits is significantly greater than the levels on the background, viewing exhibits becomes difficult. This is because of the level of illuminance on the exhibit will be much brighter than the level of visual adaptation of the viewer. However where more visually dramatic effect is required, and a high level of visibility is not important, the brightness ratio can be greater than 3:1, such as 10:1 or 15:1.

The purpose of gallery lighting is to present the exhibits in such a way that they may be studied and enjoyed. In most cases this means providing a lighting system that enables fine detail to be examined and reveals the form, color, and texture of the object. In some cases, the overall appearance of the display may be more important than the visibility of the individual exhibits, where "effects" lighting may be required. So, before installation, the general lighting requirements of the display must be discussed carefully. Each exhibition requires unique solutions, thus lighting in a gallery cannot be fixed and stable, unless it is a permanent-exhibit gallery.

Color rendition is another important criterion for museums. It affects the percentage of appearance of the object with its real color. Lamp types with high color renditions, such as tungsten halogen, fluorescent, and metal halide, must be preferred when illuminating museums. Light sources with a CRI above 90 are considered to be very good, while those with below 80 are not appropriate for museum and gallery lighting installations. As color temperature, except the JIS Standards the typical lighting is 3000-4000 K at 200-300 lx. A recent experiment by Scuello (2003) found that the general preference of the observers in lighting of the museums is 3600 K at 200 lx.

However there could be some cases that color rendition should bear less importance than the general visual characteristics of the exhibition. Furthermore colored light could be used dramatically as an effective and enriching tool for service spaces in museum and art galleries. Designers must be aware of the properties of color in terms of psychophysical methodologies. Mattiello (2004: p. 190) discusses color and its contributions to lighting as follows:

> In the field of lighting research it has mostly aimed to solve aspects of visibility and comfort, while in the field of color attempts have been made to solve the needs of design, style and fashion, but have not always been based on verifiable data and/or criteria. This has led some to believe that "everything is possible", while others take the view that it is a "topic for specialists". However, both views are misguided. Thanks to the labor of qualified architects and designers, and with the evidence of their work all around us, no doubt remains today as to the importance of their research. In particular, psychophysical methodology applied to the analysis of individual or multiple variables, has allowed certain criteria to be established and basic aspects to be resolved both in the field of color and in lighting, and although few persons are interested in color and light *per se*, the importance of these investigations in solving basic aspects which contribute to human comfort is today widely recognized. Therefore, it appears that these investigations have a prosperous future ahead of them in helping us to understand and improve fundamental aspects of life such as health, the economy, security and even emotion and feeling.

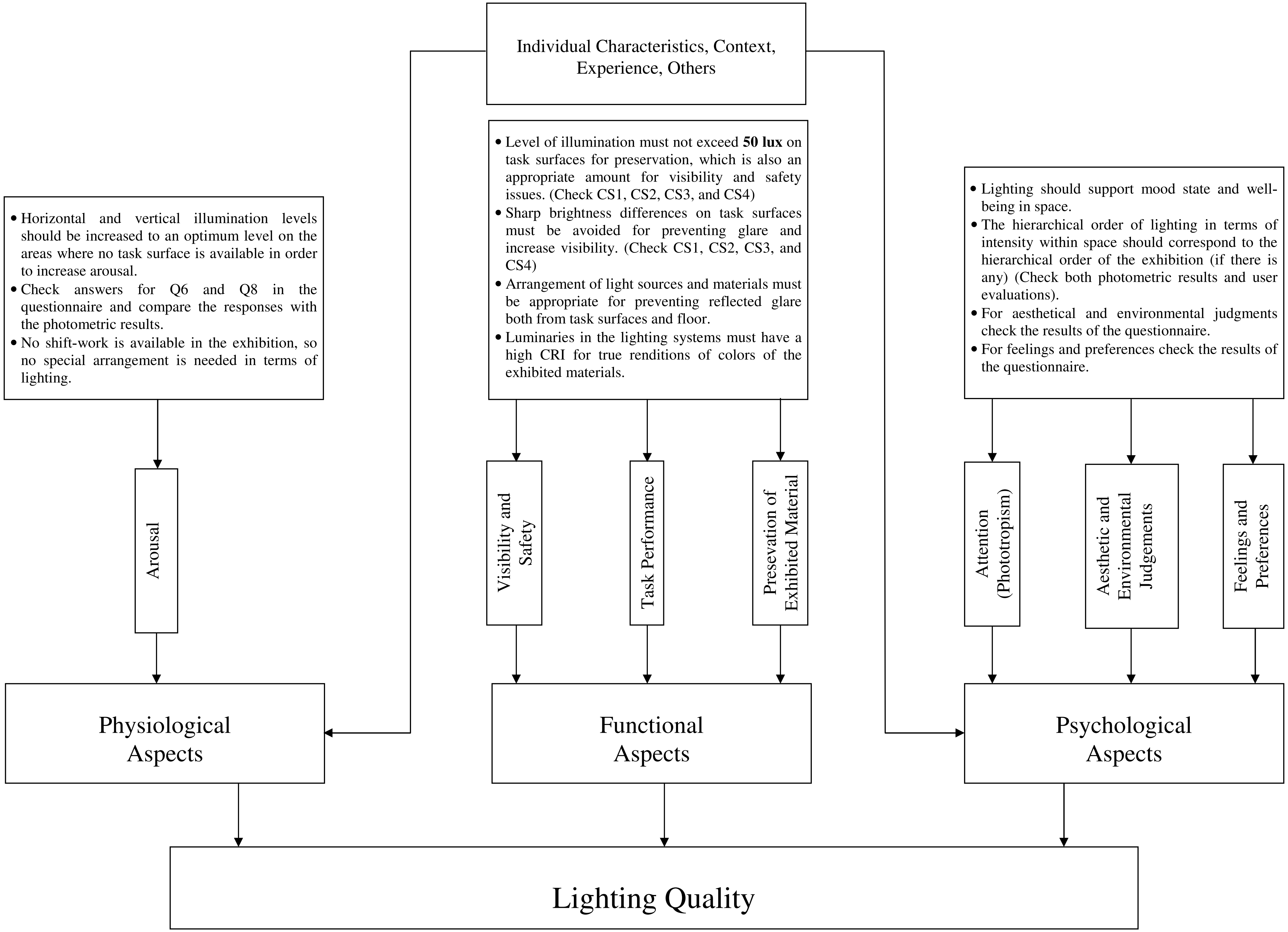
Another important requirement of museums and art galleries in terms of lighting is to design a flexible system. Even permanent exhibitions go through changes in amount of material and the way they are displayed. For art galleries a new exhibition means a requirement for a new lighting system. Conventionally this can be provided by track systems. It is not the only solution, however. For example, in the Collective Gallery in Edinburgh, lighting designer Kevan Shaw designed a steel ceiling where spotlights with magnetic bases provide the lighting with ultimate positioning flexibility.

4.2. Evaluation of the Data

This part undertakes an analysis of the two lighting systems and their effects on spatial dynamics under the guidance of the pre-given evaluation methodology which includes the three basic sections of the functional, physiological, and psychological aspects. In the light of the pre-research concerning the requirements of lighting in museums and art galleries several changes were made in the evaluation methodology as seen in Figure 4.16.

4.2.1. Functional Aspects

The objects that are subject to the exhibit are poster printouts with informative texts. All posters have thin transparent plastic coating which helps reduce thermal effects. However, it does not supply any protection from photochemical damage which means change in color. According to the standards formed by varying authorities, the level of illuminance for organic materials such as papers, and prints should not exceed 50 lx. It is necessary to mention that lamps used in the halogen spotlighting system have a cold-light reflector, which reduces the heat approximately %66, and a UV filter, which stops the UV emission produced by the lamp. Fluorescent bulbs on the other hand do not produce any heat, and they are of low ultraviolet-emitting type. In order to calculate the task surface illuminations in the exhibition hall in APIKAM four calculation surfaces (CS) were utilized in Dialux. The amount of the calculation surfaces derives from the variety of the horizontal illuminance levels supplied by the lighting systems, which means all photometric results for bright, semi-bright, and dark



- Horizontal and vertical illumination levels should be increased to an optimum level on the areas where no task surface is available in order to increase arousal.
- Check answers for Q6 and Q8 in the questionnaire and compare the responses with the photometric results.
- No shift-work is available in the exhibition, so no special arrangement is needed in terms of lighting.

- Level of illumination must not exceed **50 lux** on task surfaces for preservation, which is also an appropriate amount for visibility and safety issues. (Check CS1, CS2, CS3, and CS4)
- Sharp brightness differences on task surfaces must be avoided for preventing glare and increase visibility. (Check CS1, CS2, CS3, and CS4)
- Arrangement of light sources and materials must be appropriate for preventing reflected glare both from task surfaces and floor.
- Luminaries in the lighting systems must have a high CRI for true renditions of colors of the exhibited materials.

- Lighting should support mood state and well-being in space.
- The hierarchical order of lighting in terms of intensity within space should correspond to the hierarchical order of the exhibition (if there is any) (Check both photometric results and user evaluations).
- For aesthetical and environmental judgments check the results of the questionnaire.
- For feelings and preferences check the results of the questionnaire.

Figure 4.16. Diagram of the Evaluation Methodology for Artificial Lighting Quality of APIKAM

surfaces are included in the evaluation process. Figure 4.17 shows the placement of calculation surfaces for recessed fluorescent lighting system and Table 4.5 lists their general photometric properties.

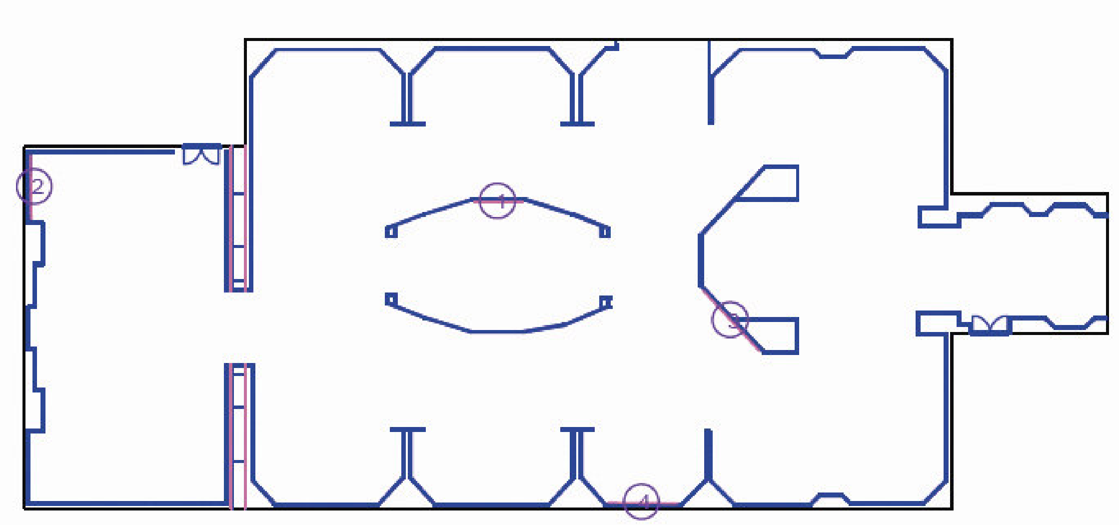
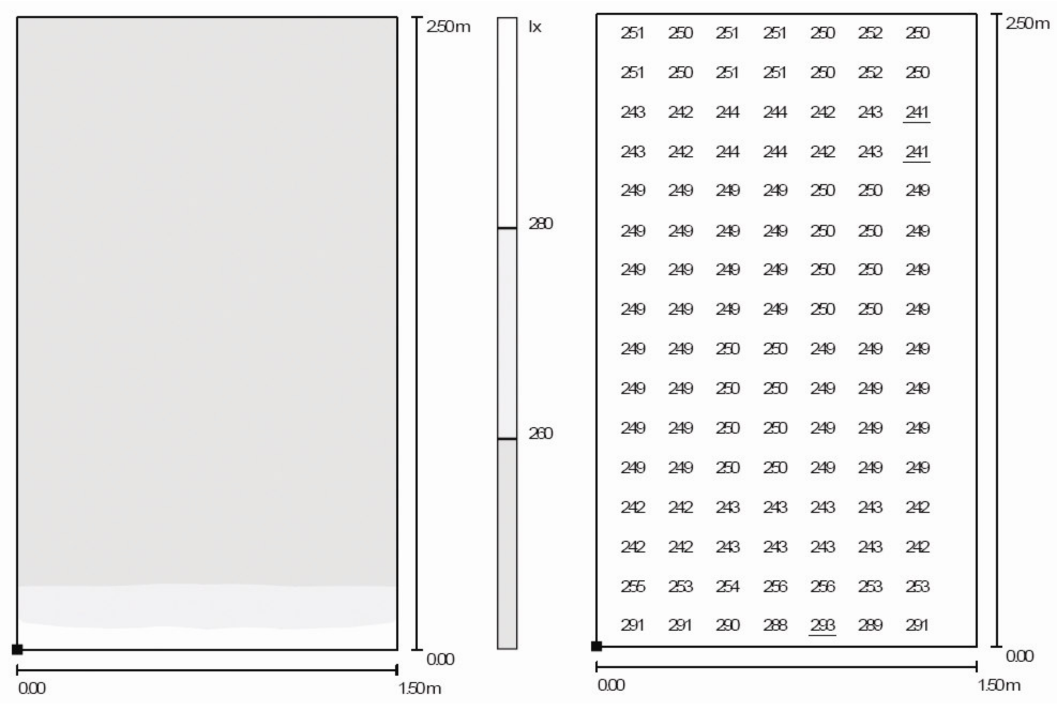


Figure 4.17. Placement of calculation surfaces both lighting systems in the exhibition

Table 4.5. Calculation surface list for recessed fluorescent lighting system

No	**Designation**	**Grid**	**E_{av} [lx]**	**E_{min} [lx]**	**E_{max} [lx]**	**u0**	E_{min}/E_{max}
1	**Calculation Surface 1**	16x16	251	241	293	0.96	0.82
2	**Calculation Surface 2**	8x8	100	88	113	0.88	0.78
3	**Calculation Surface 3**	32x32	180	153	234	0.85	0.65
4	**Calculation Surface 4**	16x16	153	141	169	0.92	0.83

CS1 is placed to the brightest location, CS2 is placed to the darkest location, CS3 and CS4 are placed to semi-bright locations in the exhibition.



251	250	251	251	250	252	250
251	250	251	251	250	252	250
243	242	244	244	242	243	241
243	242	244	244	242	243	241
249	249	249	249	250	250	249
249	249	249	249	250	250	249
249	249	249	249	250	250	249
249	249	249	249	250	250	249
249	249	250	250	249	249	249
249	249	250	250	249	249	249
249	249	250	250	249	249	249
249	249	250	250	249	249	249
242	242	243	243	243	243	242
242	242	243	243	243	243	242
255	253	254	256	256	253	253
291	291	290	288	293	289	291

Figure 4.18. Photometric results for CS1 (lx) (Recessed Fluorescent)

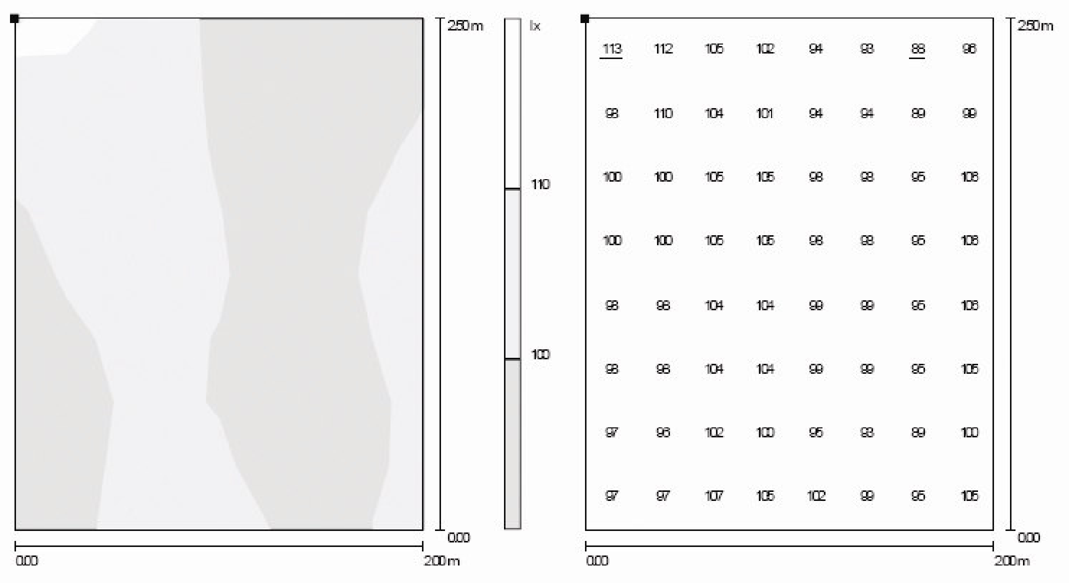
As seen in

Figure 4.18 shown in Figure 4.18, the level of illumination on the surface is between 241 and 251 lx, which is higher than the recommended level. There is no variety in brightness on task surface as shown in grayscale image.

Figure 4.19 shows the results for CS2. The level of illumination is 88 lx at minimum and 113 lx at maximum, which are again higher than acceptable levels in terms of conservation. The variations in brightness are disturbing because they vertically create zones without providing a constant level at the level of eyesight. However, there is no risk for glare since the difference is only 37 lx at maximum.

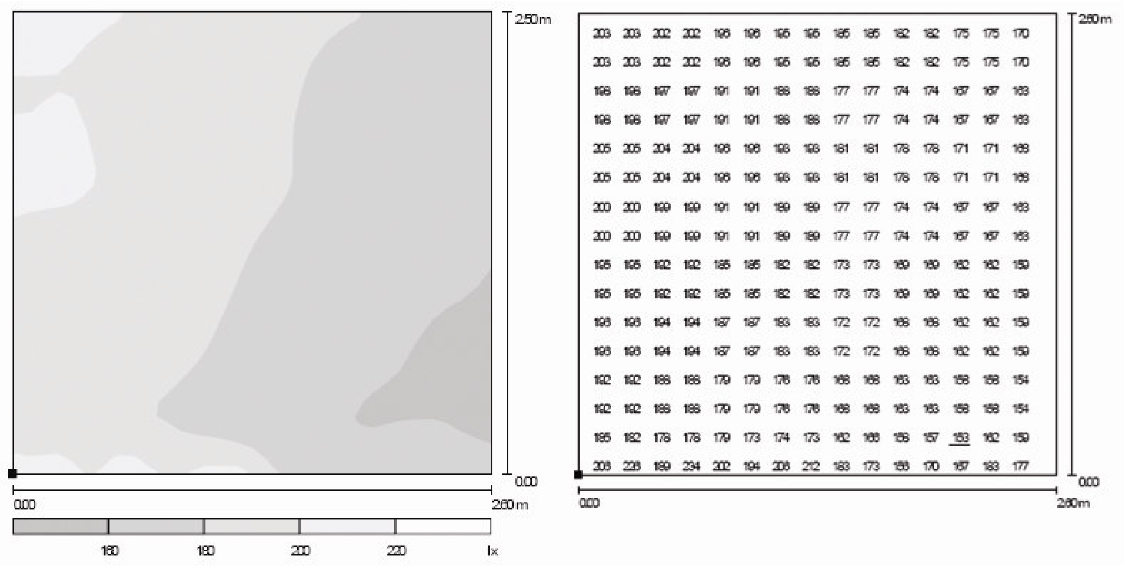
Figure 4.2020 shows the results for CS3. The amount of illumination on the surface is between 153 and 234 lx. This surface too is subject to vertical brightness differences of negligible amount on the level of eyesight.

Figure 4.21 shows the results for CS4. The level of illumination is 141 lx at minimum and 169 lx at maximum. The average illumination is 153 lx. All four calculation surfaces are brighter than the acceptable level which is 50 lx.



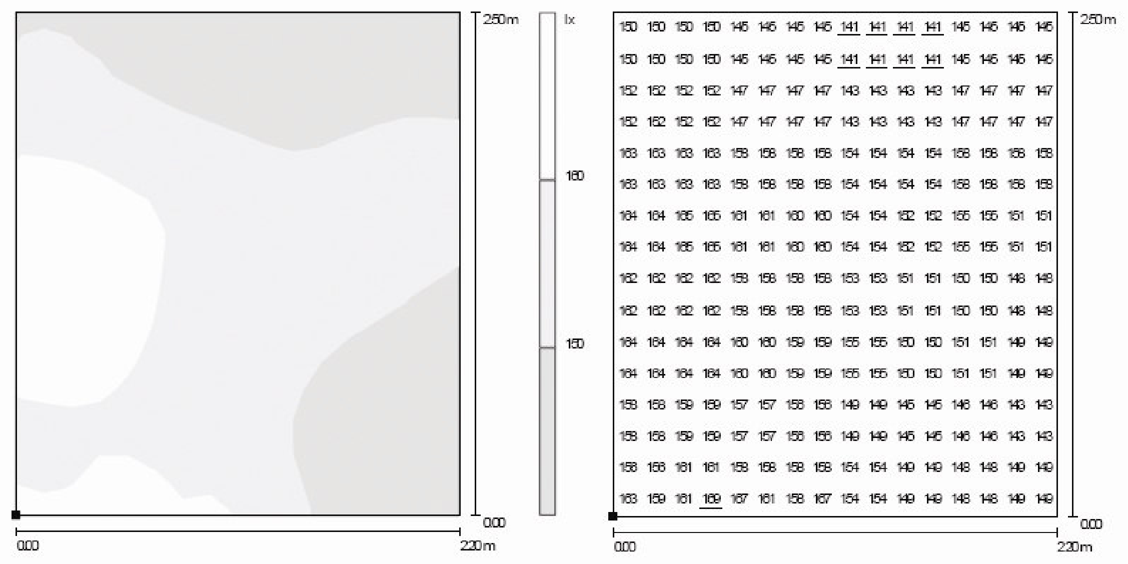
113	112	105	102	94	93	88	96
98	110	104	101	94	94	89	99
100	100	105	105	98	98	95	106
100	100	105	105	98	98	95	106
98	96	104	104	99	99	95	106
98	96	104	104	99	99	95	105
97	96	102	100	95	93	89	100
97	97	107	105	102	99	95	105

Figure 4.19. Photometric results for CS2 (lx) (Recessed Fluorescent)



203	203	202	202	196	196	195	195	185	185	182	182	175	175	170
203	203	202	202	196	196	195	195	185	185	182	182	175	175	170
198	198	197	197	191	191	188	188	177	177	174	174	167	167	163
198	198	197	197	191	191	188	188	177	177	174	174	167	167	163
205	205	204	204	198	198	193	193	181	181	178	178	171	171	169
205	205	204	204	198	198	193	193	181	181	178	178	171	171	169
200	200	199	199	191	191	189	189	177	177	174	174	167	167	163
200	200	199	199	191	191	189	189	177	177	174	174	167	167	163
195	195	192	192	185	185	182	182	173	173	169	169	162	162	159
195	195	192	192	185	185	182	182	173	173	169	169	162	162	159
198	198	194	194	187	187	183	183	172	172	166	166	162	162	159
198	198	194	194	187	187	183	183	172	172	166	166	162	162	159
192	192	186	186	179	179	178	178	168	168	163	163	158	158	154
192	192	186	186	179	179	178	178	168	168	163	163	158	158	154
185	182	178	178	179	173	174	173	162	166	156	157	153	162	159
208	228	189	234	202	194	206	212	183	173	158	170	167	183	177

Figure 4.20. Photometric results for CS3 (lx) (Recessed Fluorescent)



150	150	150	150	146	146	146	146	141	141	141	141	146	146	146	146
150	150	150	150	146	146	146	146	141	141	141	141	146	146	146	146
152	152	152	152	147	147	147	147	143	143	143	143	147	147	147	147
152	152	152	152	147	147	147	147	143	143	143	143	147	147	147	147
163	163	163	163	158	158	158	158	154	154	154	154	158	158	158	158
163	163	163	163	158	158	158	158	154	154	154	154	158	158	158	158
164	164	165	165	161	161	160	160	154	154	152	152	155	155	151	151
164	164	165	165	161	161	160	160	154	154	152	152	155	155	151	151
162	162	162	162	158	158	158	158	153	153	151	151	150	150	148	148
162	162	162	162	158	158	158	158	153	153	151	151	150	150	148	148
164	164	164	164	160	160	159	159	155	155	150	150	151	151	149	149
164	164	164	164	160	160	159	159	155	155	150	150	151	151	149	149
158	158	159	159	157	157	158	158	149	149	145	145	146	146	143	143
158	158	159	159	157	157	158	158	149	149	145	145	146	146	143	143
156	156	161	161	158	158	158	158	154	154	149	149	148	148	149	149
163	159	161	169	167	161	158	167	154	154	149	149	148	148	149	149

Figure 4.21. Photometric results for CS4 (lx) (Recessed Fluorescent)

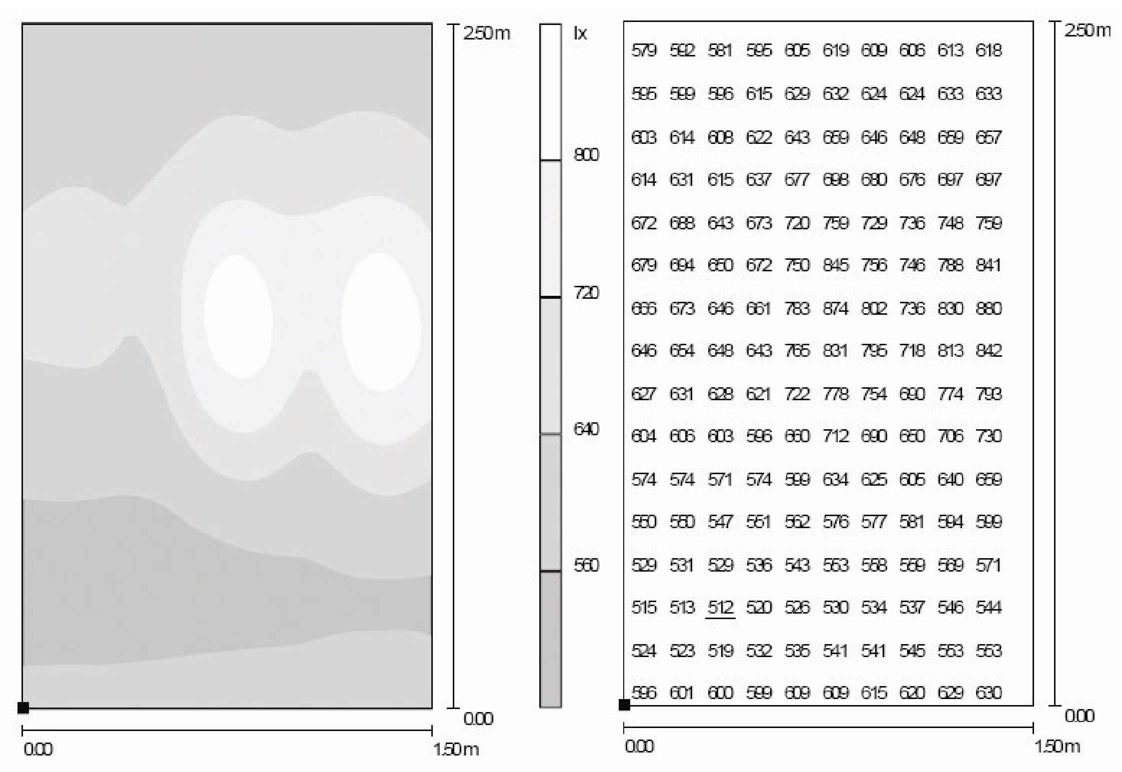
Table 4.6. Calculation surface list for recessed halogen spotlighting system

No	**Designation**	**Grid**	**E_{av} [lx]**	**E_{min} [lx]**	**E_{max} [lx]**	**u0**	E_{min}/E_{max}
1	**Calculation Surface 1**	32x32	640	512	882	0.80	0.58
2	**Calculation Surface 2**	32x32	315	243	413	0.77	0.59
3	**Calculation Surface 3**	32x32	436	345	543	0.79	0.64
4	**Calculation Surface 4**	32x32	527	449	638	0.85	0.70

Table 4.6 lists the general photometric properties of the calculation surfaces for halogen spotlighting system. CS1 and CS4 are placed to the brightest locations in the exhibition. CS2 is placed to the darkest location and CS3 is placed to a semi-bright location in the exhibition. Figure 4.22 shows the photometric results for CS1. The level of illumination is 512 lx at minimum and 882 lx at maximum. The variations in brightness at the level of eyesight would definitely create glare because of the sharp transitions from 621 lx to 882 lx. The same disturbing effect occurs in the CS3 and CS4 too, as shown in Figure 4.24 and Figure 4.25.

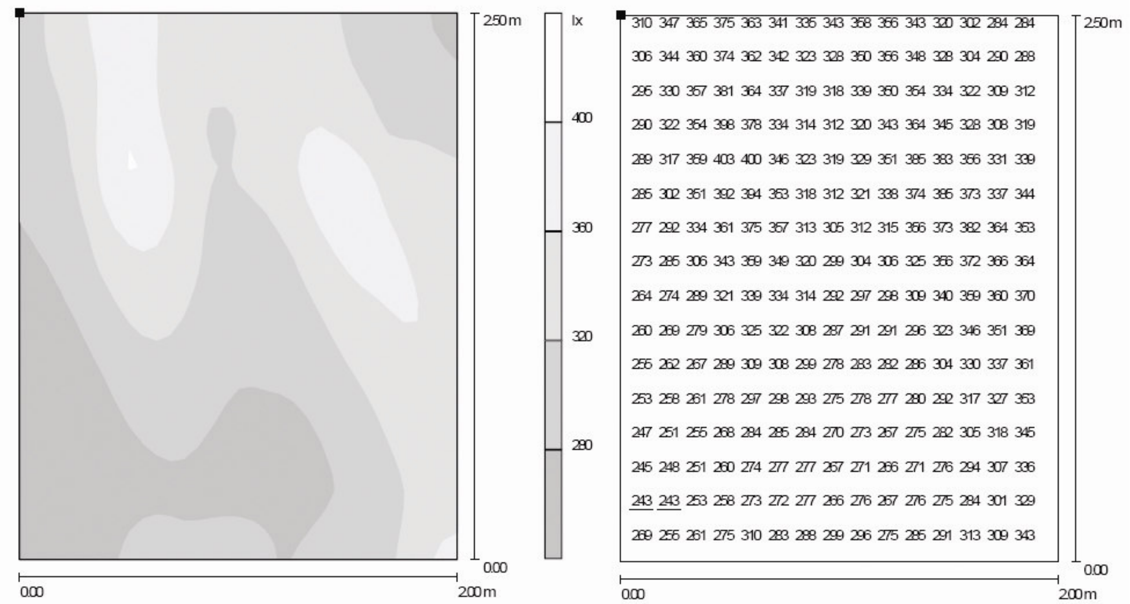
Figure 4.23 show the photometric results for CS2. Illumination range is between 243 and 413 lx with an average illumination of 315 lx which is the lowest illumination supplied by the halogen spotlighting system. Surface in the level of eyesight is again subject to glare, with sharp brightness differences as shown in the grayscale visualization.

The amount of light on all four calculations surfaces are higher than the recommended level.



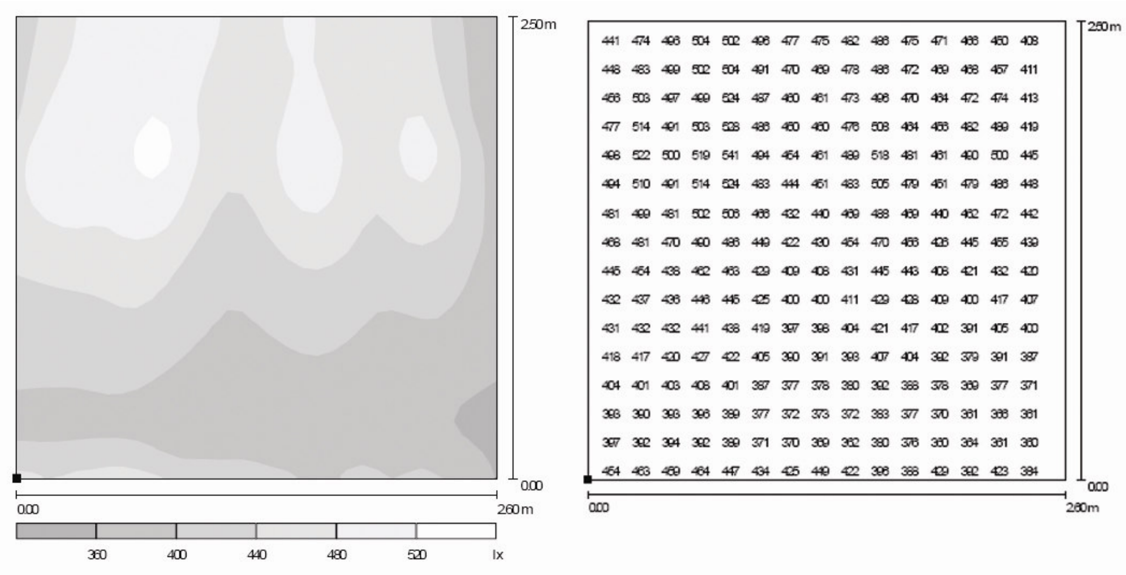
579	592	581	595	605	619	609	606	613	618
595	599	596	615	629	632	624	624	633	633
603	614	608	622	643	669	646	648	669	657
614	631	615	637	677	698	680	676	697	697
672	688	643	673	720	759	729	736	748	759
679	694	650	672	750	845	756	746	788	841
666	673	646	661	783	874	802	736	830	880
646	654	648	643	765	831	795	718	813	842
627	631	628	621	722	778	754	690	774	793
604	606	603	596	660	712	690	650	706	730
574	574	571	574	599	634	625	605	640	659
550	550	547	551	562	576	577	581	594	599
529	531	529	536	543	563	568	569	569	571
515	513	512	520	526	530	534	537	546	544
524	523	519	532	535	541	541	545	553	553
596	601	600	599	609	609	615	620	629	630

Figure 4.22. Photometric results for CS1 (lx) (Halogen Spotlighting)



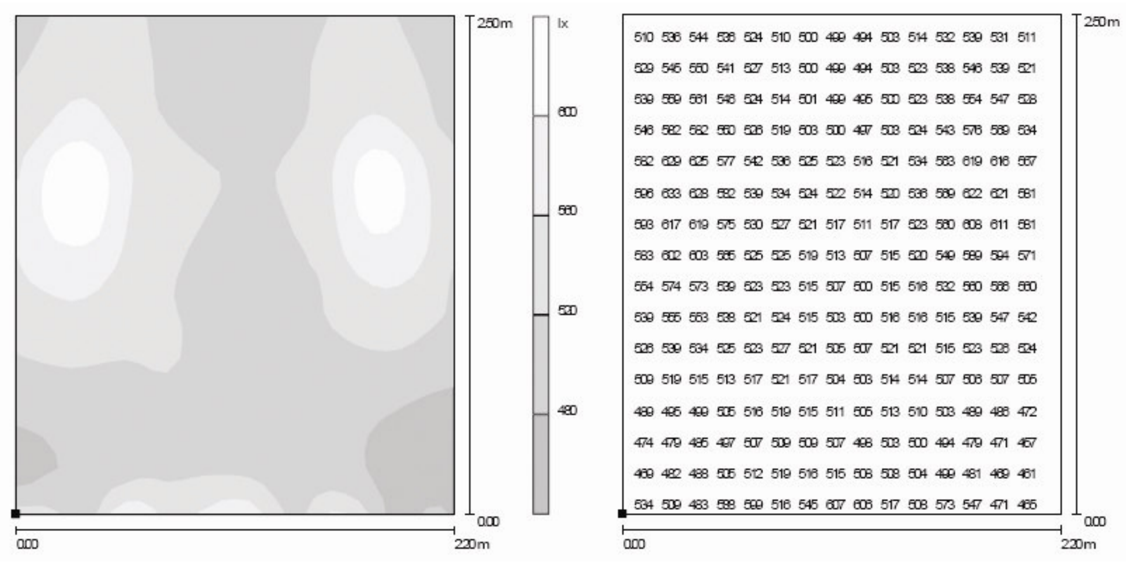
310	347	365	375	363	341	335	343	358	356	343	320	302	284	284
306	344	360	374	362	342	323	328	350	356	348	328	304	290	288
295	330	357	381	364	337	319	318	339	350	354	334	322	309	312
290	322	354	398	378	334	314	312	320	343	364	345	328	308	319
289	317	359	403	400	346	323	319	329	351	385	383	356	331	339
285	302	351	392	394	353	318	312	321	338	374	385	373	337	344
277	292	334	361	375	357	313	305	312	315	356	373	382	364	353
273	285	306	343	359	349	320	299	304	306	325	356	372	366	364
264	274	289	321	339	334	314	292	297	298	309	340	359	360	370
260	269	279	306	325	322	308	287	291	291	296	323	346	351	369
256	262	267	289	309	308	299	278	283	282	286	304	330	337	361
253	258	261	278	297	298	293	275	278	277	280	292	317	327	353
247	251	255	268	284	285	284	270	273	267	275	282	305	318	345
245	248	251	260	274	277	277	267	271	266	271	276	294	307	336
243	243	253	258	273	272	277	266	276	267	276	275	284	301	329
269	255	261	275	310	283	288	299	296	275	285	291	313	309	343

Figure 4.23. Photometric results for CS2 (lx) (Halogen Spotlighting)



441	474	496	504	502	496	477	475	462	486	475	471	466	450	408
448	463	499	502	504	491	470	469	478	486	472	469	468	457	411
466	503	497	499	524	487	460	461	473	496	470	464	472	474	413
477	514	491	503	528	486	460	460	476	508	464	456	462	489	419
498	522	500	519	541	494	464	461	489	518	461	461	460	500	445
494	510	491	514	524	483	444	461	483	505	479	451	479	486	448
481	499	481	502	506	466	432	440	469	488	469	440	462	472	442
466	481	470	490	486	449	422	430	454	470	456	426	445	455	439
445	454	438	462	463	429	409	408	431	445	443	408	421	432	420
432	437	436	446	445	425	400	400	411	429	428	409	400	417	407
431	432	432	441	438	419	397	398	404	421	417	402	391	405	400
418	417	420	427	422	405	390	391	398	407	404	392	379	391	387
404	401	403	408	401	387	377	378	380	392	388	378	369	377	371
393	390	393	396	389	377	372	373	372	383	377	370	361	368	361
397	392	394	392	389	371	370	369	362	380	376	360	364	361	360
454	463	459	464	447	434	425	449	422	396	388	429	392	423	384

Figure 4.24. Photometric results for CS3 (lx) (Halogen Spotlighting)



510	536	544	536	524	510	500	499	494	503	514	532	539	531	511
529	545	550	541	527	513	500	499	494	503	523	538	546	539	521
539	559	561	548	524	514	501	499	495	500	523	538	554	547	528
546	582	582	560	526	519	503	500	497	503	524	543	576	589	534
562	629	625	577	542	536	525	523	516	521	534	563	619	616	567
596	633	628	582	539	534	524	522	514	520	536	569	622	621	581
593	617	619	575	530	527	521	517	511	517	523	580	608	611	581
583	602	603	585	525	525	519	513	507	515	520	549	589	594	571
554	574	573	539	523	523	515	507	500	515	516	532	560	586	560
539	555	553	538	521	524	515	503	500	516	516	515	539	547	542
526	539	534	525	523	527	521	505	507	521	521	515	523	526	524
509	519	515	513	517	521	517	504	503	514	514	507	506	507	505
489	495	499	505	516	519	515	511	505	513	510	503	489	486	472
474	479	485	497	507	509	509	507	498	503	500	494	479	471	467
469	482	488	505	512	519	516	515	508	508	504	499	481	469	461
534	509	483	588	599	516	545	607	606	517	508	573	547	471	465

Figure 4.25. Photometric results for CS4 (lx) (Halogen Spotlighting)

Another problem in the exhibition is the reflected glare from the floor, which occurs under both lighting systems. The floor is covered by granite tiles with a very high level of reflectance which is almost 70 %. This causes for almost all locations in the exhibition a reflected image of the light source on the floor (Figure 4.26 and Figure 4.27), which distracts the attention from the task surfaces and exposes the users to bright lights of sources.

Figure 4.26. Reflected glare from floor under recessed fluorescent lighting

Figure 4.27. Reflected glare from floor under halogen spotlighting

Vertical task surfaces are subject to reflected glare, too. Glare occurs mostly on posters which are dark in color. On certain angles these posters act like mirrors where viewers can easily see the image of light sources and themselves (Figure 4.28 and Figure 4.29).

Figure 4.28. Reflected glare on vertical panels under recessed fluorescent lighting

Figure 4.29. Reflected glare on vertical panels under halogen spotlighting. Both the light sources and the standing person are reflected on the surface.

Recessed fluorescent lighting system is fixed and does not offer the ability for repositioning. Even when a permanent exhibition is at stake, the exhibition can go through some changes in time and there would be a need for change in the arrangement of lighting. The halogen spotlighting system provides flexibility with tracks, thus could be adapted to any possible spatial variation.

4.2.2. Physiological Aspects

The lighting systems in the exhibition differ in their effects on the level of arousal. As discussed before, high level of illumination triggers arousal. The illumination supplied by the recessed fluorescent lighting system varies between 88 lx and 420 lx and the average illumination is 211 lx within the space, whereas the illumination supplied by halogen spotlighting system is between 243 lx and 1185 lx. Although the neutral white fluorescent light source with 4000 K triggers more arousal than the reddish warm halogen light source with 2900 K, the amount of light here plays the main role. Below are the results of the two questions from the survey in the feelings section which deals with arousal levels.

Q6. I feel **aroused-unaroused** under this lighting arrangement.

Table 4.7. Mean and SD for aroused-unaroused

Lighting	n	Mean	SD
Recessed Fluorescent Lighting	67	4.0	0.79
Halogen Spotlighting	67	1.6	0.66

Table 4.7 shows that the mean for recessed fluorescent system is 4.0 which means slightly unaroused, and 1.6 for halogen spotlighting which means aroused. The standard deviations are 0.79 and 0.66. Table 4.8 shows the t-test results with the hypothesis of “recessed fluorescent lighting ≠ halogen spotlighting” .

Table 4.8. T-Test for aroused-unaroused

Lighting	**n**	**Mean**	**SD**	**SE**
Recessed Fluorescent Lighting	67	4.0	0.8	0.10
Halogen Spotlighting	67	1.5	0.6	0.08
Difference	67	2.5	1.1	0.14
Difference between means	2.5			
95% CI	2.2	to 2.8		
t statistic	17.81			
2-tailed p	<0.0001			

The hypothesis is true, because the p value is smaller than 0.01. The halogen spotlighting system creates more arousal than recessed fluorescent lighting system. Table 4.9 shows the variance for fluorescent system according to age. As age increases level of unarousal increases, too.

Table 4.9. Variance for Age (aroused-unaroused)

Lighting	**n**	**Mean**	**SD**
Fluorescent by Age - B 20-30	39	3.9	0.84
Fluorescent by Age - B 30-35	17	4.0	0.71
Fluorescent by Age - B 35-40	8	4.3	0.71
Fluorescent by Age - B 40-50	3	5.0	-
Halogen by Age - B 20-30	39	1.6	0.64
Halogen by Age - B 30-35	17	1.5	0.72
Halogen by Age - B 35-40	8	1.4	0.74
Halogen by Age - B 40-50	3	2.0	-

Q8. I feel sleepy-wideawake under this lighting arrangement.

Table 4.10. Mean and SD for sleepy-wideawake

Lighting	n	Mean	SD
Recessed Fluorescent Lighting	67	1.8	0.97
Halogen Spotlighting	67	4.0	0.87

Table 4.10 shows that the mean for recessed fluorescent system is 1.8 which means slightly sleepy, and 4.0 for halogen spotlighting which means slightly wideawake. The standard deviations are 0.97 and 0.87. Table 4.11 shows the t-test results with the hypothesis of "recessed fluorescent lighting ≠ halogen spotlighting" .

Table 4.11. T-test for sleepy-wideawake

Lighting	n	Mean	SD	SE
Recessed Fluorescent Lighting	67	1.8	1.0	0.12
Halogen Spotlighting	67	4.0	0.9	0.11
Difference	67	-2.2	1.4	0.17
Difference between means	-2.2			
95% CI	-2.5	to -1.8		
t statistic	-12.97			
2-tailed p	<0.0001			

The hypothesis is true, because the p value is smaller than 0.01. The halogen spotlighting system creates more arousal than recessed fluorescent lighting system.

As mentioned in the functional evaluation, certain locations in the exhibition are subject to glare especially under halogen spotlighting. It is widely known that glare acts as a stressor and causes severe health problems such as headache and fatigue. However, visitors are not exposed to glare as much as they get physiologically affected, because it is an exhibition, a temporary space for a quick visit.

Fluorescent light sources are generally also known as flicker sources. The ballasts of fluorescent light sources need to be checked regularly every six months by a specialist and replaced if they cause flicker.

4.2.3. Psychological Aspects

4.2.3.1. Attention

The posters in the exhibition in APIKAM have a hierarchical order. In other words, there is a sequential categorization for the posters, so each poster has a distinct place in the order for viewing. For group visitors an official guide who works for APIKAM supervises through the whole exhibition. However, others who visit the exhibition by themselves must find their own way. This part investigates whether the lighting conditions within the space help or guide them correctly or not and whether the lighting conditions give them a feeling of orientation or not.

The visiting order for the poster is shown in Figure 4.30. As mentioned before in Chapter 3, as brightness increases in a specific direction, people tend to walk to that direction. With this assumption one expects a gradual increase in brightness down from point 1 to 3, then to the right from point 3 to 7, then again to the right point 8 which in the cubical in the middle of the exhibition. Another gradual increase must be provided from point 9 to 10 and finally the brightest area must be the point 11 in the adjacent rectangle.

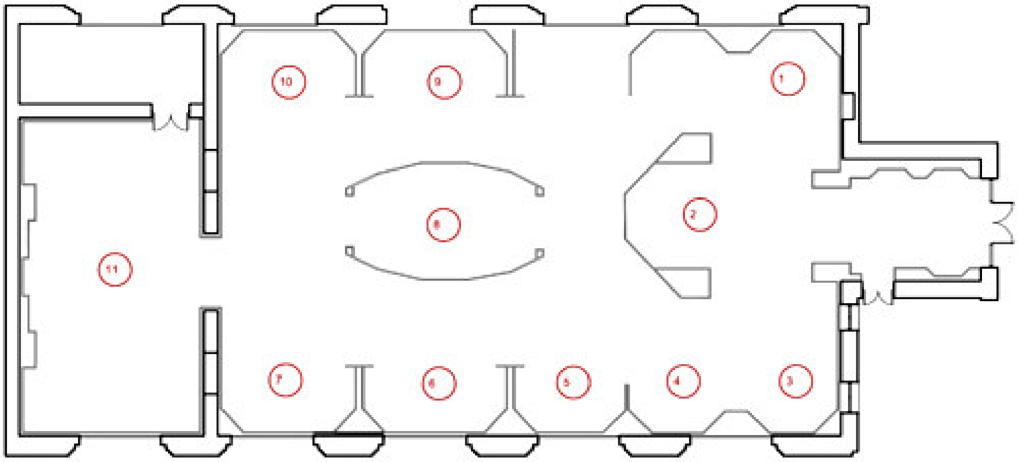


Figure 4.30. Visiting order for the exhibition hall in APIKAM

If we take a look at the photometric results for ceiling recessed fluorescent box system (Figure 4.31 and Figure 4.32), we see that there is an increase in the average horizontal illuminance from 180 lx to 360 lx between points 1 and 2.

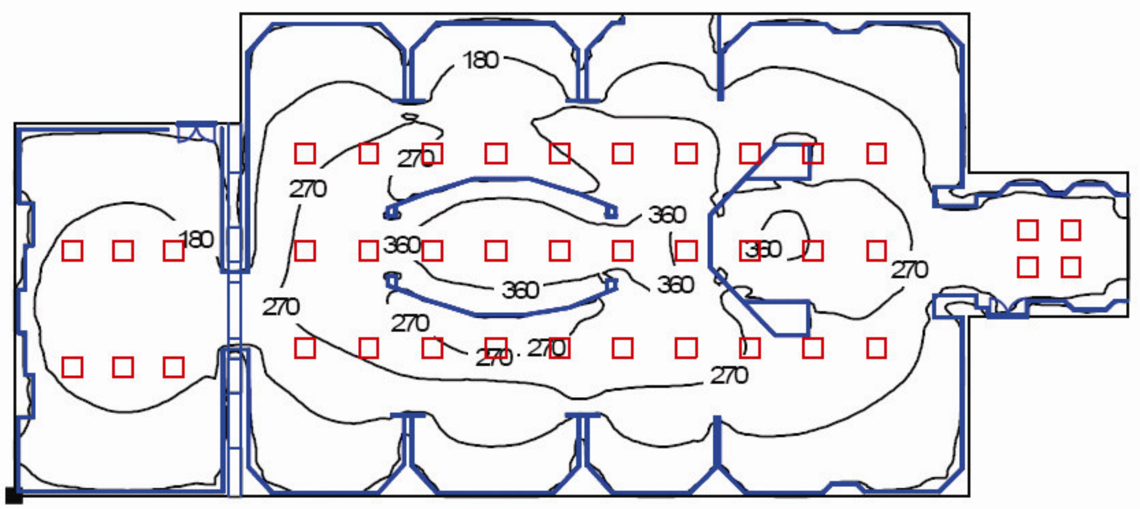


Figure 4.31. Horizontal illumination levels for recessed fluorescent in isolines (lx)

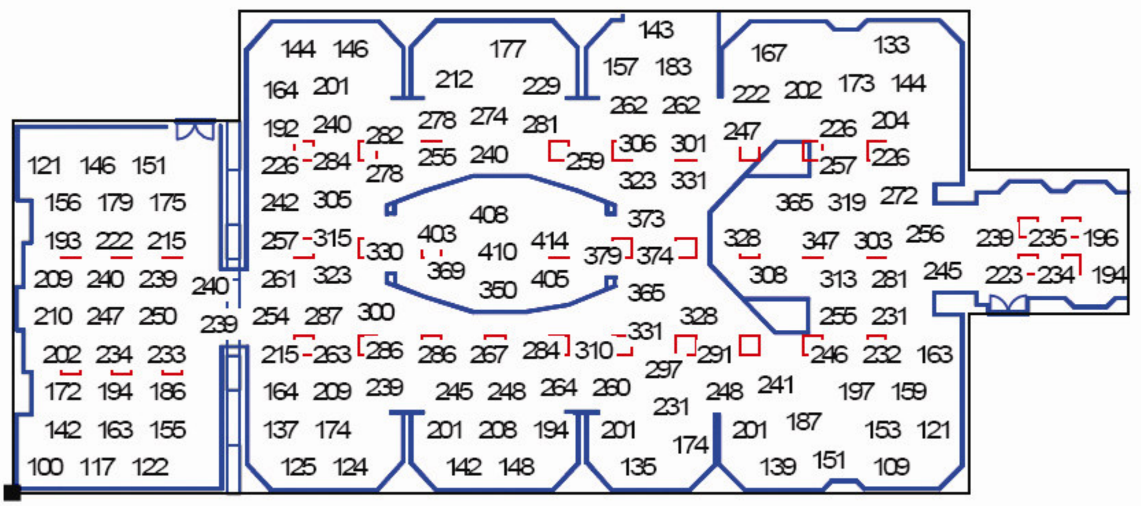


Figure 4.32. Horizontal illumination levels for recessed fluorescent in value chart (lx)

The average horizontal illuminance drops again to 180 lx at point 3 and stays stable at 180 lx till point 7. Again it increases to 360 lx at point 8 and drops to 180 at point 9 and 10. The adjacent rectangle has an average illuminance level of 180 lx and 240 lx at the point of entrance. The continuity is interrupted between points 2 and 3 then between 8 and 9.

The photometric results for halogen spotlighting systems are quite different (Figure 4.33 and Figure 4.34). The level of horizontal illuminance at point 1 is 480 lx in average and it increases to 662 lx at point 2. It drops to an average of 480 lx at points 3 and 4. We notice an increase to 720 lx at point 5 and then a decrease to 480 lx at points 6 and 7. Point 8 has an average illuminance of 600 lx and it drops to 480 lx at point 9 and 10. At Point 11 the horizontal illuminance is at 240 lx. Again in halogen spotlighting system the continuity interrupted between points 2 and 3, 6 and 7, then 10 and 11.

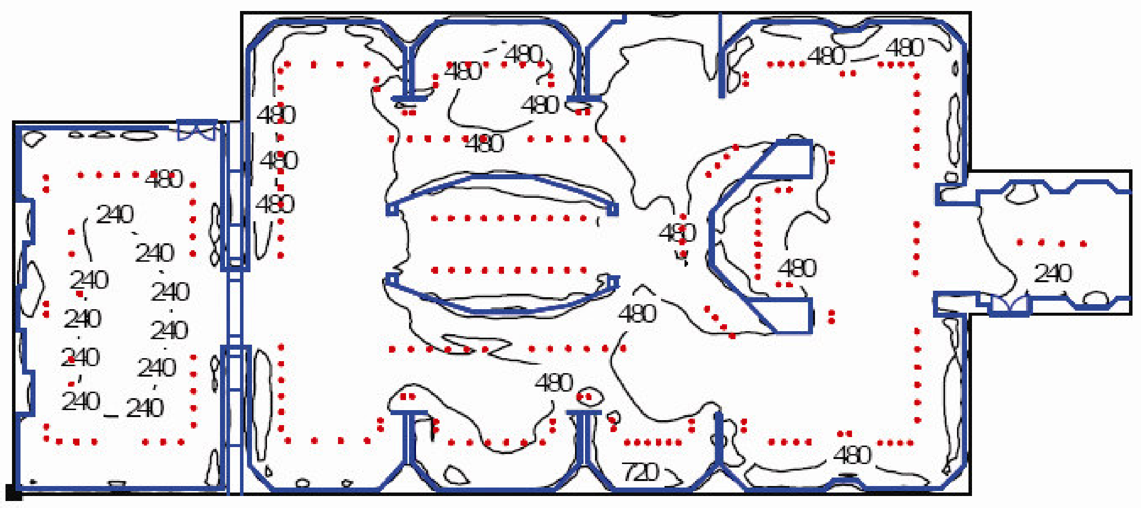


Figure 4.33. Horizontal illumination levels for halogen spotlighting in isolines (lx)

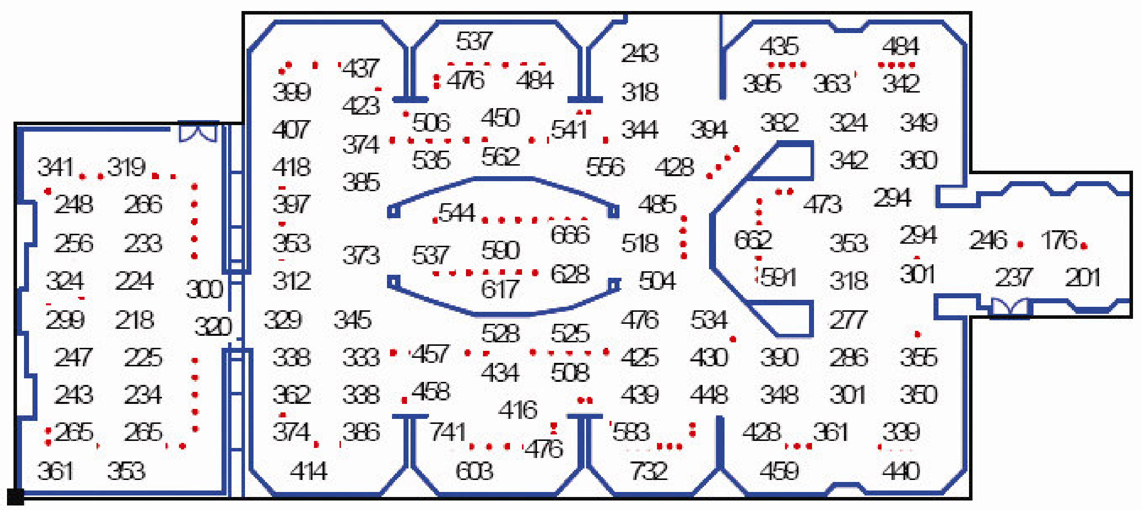


Figure 4.34. Horizontal illumination levels for halogen spotlighting in value chart (lx)

One of the two questions of the fifth section in the survey was asking the subjects to stand on two pre-given points as shown "sp1" and "sp2" on Figure 4.35 and to decide to take one of the many directions listed on the map. For sp1 under fluorescent lighting system, 29 of the subjects decided to take d1; 25 of them decided to take d2 and the rest checked the "it doesn't matter" option. For sp2 under fluorescent lighting system no one decided to take d1, 35 of them decided to take d2, 21 of them decided to take d3, and for the rest it did not matter. These results are consistent with the photometric results and show people's tendency in following light. Both lighting systems need to be improved at certain locations in terms of the brightness pattern which directly affects the attention cycle within the exhibition.

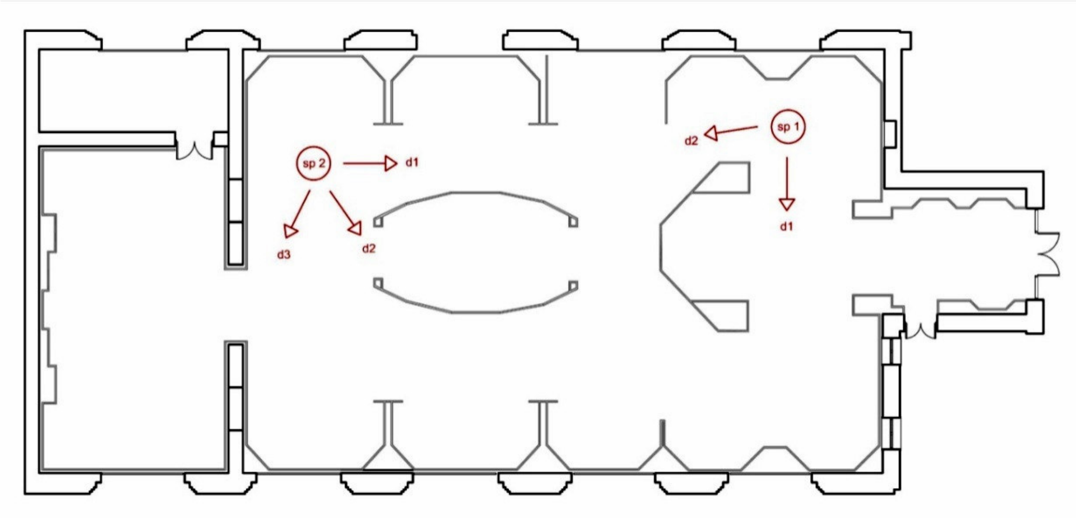


Figure 4.35. Perceptual preferences and attention study in survey

4.2.3.2. Aesthetic and Environmental Judgments

The third section of the survey was related to aesthetical and environmental judgments. Subjects' evaluations concerning the effects of two lighting systems on the general appearance of the space were revealed. The results for the selected four questions are as follows:

Q1. Perception of the form of the gallery under this lighting arrangement is strong-weak

Table 4.12. Mean and SD for perception of form (strong-weak)

Lighting	n	Mean	SD
Resecced Fluorescent Lighting	67	3.2	1.01
Halogen Spotlighting	67	1.7	0.73

Table 4.12 shows that the mean for recessed fluorescent system is 3.2 which means neutral and 1.7 for halogen spotlighting which means slightly strong. Table 4.13

shows the results of the t-test which was run to ascertain whether there is a significant difference for these parameters between the two lighting systems. The hypothesis is “recessed fluorescent lighting ≠ halogen spotlighting” .

Table 4.13. T-test for perception of form (strong-weak)

Lighting	n	Mean	SD	SE
Recessed Fluorescent Lighting	67	3.2	1.0	0.12
Halogen Spotlighting	67	1.7	0.7	0.09
Difference	67	1.5	1.2	0.14
Difference between means	1.5			
95% CI	1.2	to 1.8		
t statistic	10.63			
2-tailed p	**<0.0001**			

The p value at the end of table verifies that the hypothesis is true as being smaller than 0.01.

Q2. Perception of the structural elements under this lighting arrangement is strong-weak

Table 4.14. Mean and SD for perception of structural elements (strong-weak)

Lighting	n	Mean	SD
Resecced Fluorescent Lighting	67	2.8	1.11
Halogen Spotlighting	67	2.3	1.16

Table 4.14 shows that the mean for recessed fluorescent system is 2.8 which means neutral and 2.3 for halogen spotlighting which means slightly strong. Table 4.15 shows the results of the t-test with the hypothesis of “recessed fluorescent lighting ≠ halogen spotlighting” .

Table 4.15. T-test for perception of structural elements (strong-weak)

Lighting	n	Mean	SD	SE
Recessed Fluorescent Lighting	67	2.8	1.1	0.14
Halogen Spotlighting	67	2.3	1.2	0.14
Difference	67	0.5	1.4	0.17
Difference between means	0.5			
95% CI	0.2	to 0.9		
t statistic	2.91			
2-tailed p	**0.0050**			

The p value shows that the hypothesis is not true.

Q3. Perception of details [materials of architectural components and furnishing and their characteristics such as texture and color] of the gallery under this lighting arrangement is strong-weak

Table 4.16. Mean and SD for the Perception of details

Lighting	n	Mean	SD
Resecced Fluorescent Lighting	67	2.6	1.19
Halogen Spotlighting	67	2.3	1.15

Table 4.16 shows that the mean for recessed fluorescent system is 2.6 which means neutral and 2.3 for halogen spotlighting which means slightly strong. Table 4.17 shows the results of the t-test with the hypothesis of “recessed fluorescent lighting ≠ halogen spotlighting” .

Table 4.17. T-test for perception of details

Lighting	n	Mean	SD	SE
Recessed Fluorescent Lighting	67	2.6	1.2	0.15
Halogen Spotlighting	67	2.3	1.2	0.14
Difference	67	0.3	1.2	0.15
Difference between means	0.3			
95% CI	0.1	to 0.6		
t statistic	2.34			
2-tailed p	**0.0223**			

The p value shows that the hypothesis is not true.

Q4. The gallery under this lighting arrangement appears as cozy-cold

Table 4.18. Mean and SD for cozy-cold

Lighting	n	Mean	SD
Resecced Fluorescent Lighting	67	3.8	0.83
Halogen Spotlighting	67	1.4	0.60

Table 4.18 shows that the mean for recessed fluorescent system is 3.8 which means slightly cold and 1.4 for halogen spotlighting which means slightly cozy. Table 4.19 shows the results of the t-test which was run to ascertain whether there is a significant difference for these parameters between the two lighting systems. The hypothesis is “recessed fluorescent lighting ≠ halogen spotlighting” .

Table 4.19. T-test for cozy-cold

Lighting	n	Mean	SD	SE
Recessed Fluorescent Lighting	67	3.8	0.8	0.10
Halogen Spotlighting	67	1.4	0.6	0.07
Difference	67	2.5	1.1	0.14
Difference between means	2.5			
95% CI	2.2	to 2.7		
t statistic	17.59			
2-tailed p	**<0.0001**			

The p value at the end of table verifies that the hypothesis is true as being smaller than 0.01. These results are consistent with the color temperatures of the bulbs used for the two lighting systems. The color temperatures are 4000 K and 2900 K for fluorescent and halogen bulbs respectively. As mentioned before in Chapter 3, light sources with a lower color temperature stimulate a feeling of warmth and coziness.

Q5. The gallery under this lighting arrangement appears as **interesting-dull**

Table 4.20. Mean and SD for interesting-dull

Lighting	n	Mean	SD
Recessed Fluorescent Lighting	67	3.8	0.81
Halogen Spotlighting	67	1.4	0.54

Table 4.20 shows that the mean for recessed fluorescent system is 3.8 which means slightly dull and 1.4 for halogen spotlighting which means slightly interesting. The standard deviations are 0.81 and 0.54. Table 4.21 shows the t-test results with the hypothesis of "recessed fluorescent lighting ≠ halogen spotlighting" .

Table 4.21. T-test for interesting-dull

Lighting	n	Mean	SD	SE
Recessed Fluorescent Lighting	67	3.8	0.8	0.10
Halogen Spotlighting	67	1.4	0.5	0.07
Difference	67	2.4	1.0	0.13
Difference between means	2.4			
95% CI	2.2	to 2.7		
t statistic	18.91			
2-tailed p	<0.0001			

The p value at the end of table verifies that the hypothesis is true as being smaller than 0.01.

Q6. The gallery under this lighting arrangement appears as **inviting-repulsive**

Table 4.22. Mean and SD for inviting-repulsive

Lighting	n	Mean	SD
Recessed Fluorescent Lighting	67	3.8	0.87
Halogen Spotlighting	67	1.4	0.61

Table 4.22 shows that the mean for recessed fluorescent system is 3.8 which means slightly repulsive and 1.4 for halogen spotlighting which means slightly inviting. The standard deviations are 0.87 and 0.61. Table 4.23 shows the t-test results with the hypothesis of “recessed fluorescent lighting ≠ halogen spotlighting” .

Table 4.23. T-test for inviting-repulsive

Lighting	n	Mean	SD	SE
Recessed Fluorescent Lighting	67	3.8	0.9	0.11
Halogen Spotlighting	67	1.4	0.6	0.07
Difference	67	2.3	1.1	0.14
Difference between means	2.3			
95% CI	2.1	to 2.6		
t statistic	16.70			
2-tailed p	<0.0001			

The p value at the end of table verifies that the hypothesis is true as being smaller than 0.01.

Q7. I like the gallery under this lighting arrangement

Table 4.24. Mean and SD for "I like the gallery"

Lighting	n	Mean	SD
Recessed Fluorescent Lighting	67	3.8	0.80
Halogen Spotlighting	67	1.3	0.44

Table 4.24 shows that the mean for recessed fluorescent system is 3.8 which means slightly no and 1.3 for halogen spotlighting which means yes. The standard deviations are 0.80 and 0.44. Table 4.25 shows the t-test results with the hypothesis of "recessed fluorescent lighting $\neq$ halogen spotlighting" .

Table 4.25. T-test for “I like the gallery”

Lighting	n	Mean	SD	SE
Recessed Fluorescent Lighting	67	3.8	0.8	0.10
Halogen Spotlighting	67	1.3	0.4	0.05
Difference	67	2.5	0.9	0.11
Difference between means	2.5			
95% CI	2.3	to 2.7		
t statistic	22.13			
2-tailed p	<0.0001			

The p value at the end of the table verifies that the hypothesis is true as being smaller than 0.01.

User evaluations show that halogen spotlighting is the preferred one in terms of aesthetic and environmental judgments. For all the four questions in survey halogen spotlighting system received more positive response than the recessed fluorescent lighting system.

4.1.3.3. Feelings and Preferences

A P.A.D. scale with fourteen pairs of adjectives is used to measure emotional outcomes. Four pairs of them are used to control subjects in terms of whether they are consistent in their answers or not. The results are as follows:

Q1. I feel **happy-unhappy** under this lighting arrangement.

Table 4.26. Mean and SD for happy-unhappy

Lighting	n	Mean	SD
Recessed Fluorescent Lighting	67	3.3	0.86
Halogen Spotlighting	67	1.7	0.70

Table 4.26 shows that the mean for recessed fluorescent system is 3.3 which means neutral; in other words, it bears no effect on happiness; and 1.7 for halogen spotlighting which means slightly happy. The standard deviations are 0.86 and 0.70. Table 4.27 shows the t-test results with the hypothesis of “recessed fluorescent lighting ≠ halogen spotlighting” .

Table 4.27. T-test for happy-unhappy

Lighting	**n**	**Mean**	**SD**	**SE**
Recessed Fluorescent Lighting	67	3.3	0.9	0.10
Halogen Spotlighting	67	1.7	0.7	0.09
Difference	67	1.6	1.1	0.13
Difference between means	1.6			
95% CI	1.4	to 1.9		
t statistic	12.47			
2-tailed p	<0.0001			

The p value at the end of table verifies that the hypothesis is true as being smaller than 0.01.

Q2. I feel **annoyed-pleased** under this lighting arrangement.

Table 4.28. Mean and SD for annoyed-pleased

Lighting	**n**	**Mean**	**SD**
Recessed Fluorescent Lighting	67	2.9	0.61
Halogen Spotlighting	67	4.5	0.61

Table 4.28 shows that the mean for recessed fluorescent system is 2.9 which means neutral; in other words, lighting has no effect on these feelings; and 4.5 for halogen spotlighting which means extremely pleased. The standard deviations are 0.61 for both lighting system. Table 4.29 shows the t-test results with the hypothesis of “recessed fluorescent lighting ≠ halogen spotlighting” .

Table 4.29. T-test for annoyed-pleased

Lighting	n	Mean	SD	SE
Recessed Fluorescent Lighting	67	2.9	0.6	0.07
Halogen Spotlighting	67	4.5	0.6	0.07
Difference	67	-1.6	0.9	0.11
Difference between means	-1.6			
95% CI	-1.9	to -1.4		
t statistic	-15.53			
2-tailed p	<0.0001			

The p value at the end of table verifies that the hypothesis is true as being smaller than 0.01.

Q3. I feel **relaxed-tense** under this lighting arrangement.

Table 4.30. Mean and SD for relaxed-tense

Lighting	n	Mean	SD
Recessed Fluorescent Lighting	67	3.2	0.97
Halogen Spotlighting	67	1.6	0.76

Table 4.30 shows that the mean for recessed fluorescent system is 3.2 which means neutral; in other words, lighting has no effect on these feelings; and 1.6 for halogen spotlighting which means slightly relaxed. The standard deviations are 0.97 and 0.76. Table 4.31 shows the t-test results with the hypothesis of "recessed fluorescent lighting ≠ halogen spotlighting" .

Table 4.31. T-test for relaxed-tense

Lighting	n	Mean	SD	SE
Recessed Fluorescent Lighting	67	3.2	1.0	0.12
Halogen Spotlighting	67	1.6	0.7	0.09
Difference	67	1.7	1.2	0.14
Difference between means	1.6			
95% CI	1.3	to 1.9		
t statistic	11.06			
2-tailed p	<0.0001			

The hypothesis is true. Table 4.32 shows the variance in feelings according to age. Subjects between ages 40-50 rated their feelings as slightly tense under fluorescent lighting while others rated as neutral.

Table 4.32. Variance related to age (relaxed-tense)

Lighting	n	Mean	SD
Fluorescent by Age - B 20-30	39	3.1	0.86
Fluorescent by Age - B 30-35	17	3.4	1.06
Fluorescent by Age - B 35-40	8	3.4	1.19
Fluorescent by Age - B 40-50	3	4.0	1.00
Halogen by Age - B 20-30	39	1.5	0.64
Halogen by Age - B 30-35	17	1.5	0.51
Halogen by Age - B 35-40	8	1.9	1.13
Halogen by Age - B 40-50	3	2.7	1.53

Q4. I feel **autonomous-guided** under this lighting arrangement.

(Compare with the results of Q7 and Q11)

Table 4.33. Mean and SD for autonomous-guided

Lighting	n	Mean	SD
Recessed Fluorescent Lighting	67	2.0	0.91
Halogen Spotlighting	67	1.8	0.74

Table 4.33 shows that the mean for recessed fluorescent system is 2.0 which means slightly autonomous, and 1.8 for halogen spotlighting which again means slightly autonomous. The standard deviations are 0.91 and 0.74. Table 4.34 shows the t-test results with the hypothesis of "recessed fluorescent lighting ≠ halogen spotlighting" .

Table 4.34. T-test for autonomous-guided

Lighting	n	Mean	SD	SE
Recessed Fluorescent Lighting	67	2.0	0.9	0.11
Halogen Spotlighting	67	1.8	0.7	0.09
Difference	67	0.1	1.0	0.13
Difference between means	0.1			
95% CI	-0.1	to 0.4		
t statistic	1.07			
2-tailed p	0.2889			

The hypothesis is not true as the p value is bigger than 0.01. There is clear distinction between two lighting systems for this feeling.

Q5. I feel **hopeful-despairing** under this lighting arrangement.

Table 4.35. Mean and SD for hopeful-despairing

Lighting	**n**	**Mean**	**SD**
Recessed Fluorescent Lighting	67	3.0	0.75
Halogen Spotlighting	67	2.6	0.70

Table 4.35 shows that the mean for recessed fluorescent system is 3.0 which means neutral, and 2.6 for halogen spotlighting which means neutral again. The standard deviations are 0.75 and 0.70. Table 4.36 shows the t-test results with the hypothesis of "recessed fluorescent lighting ≠ halogen spotlighting" .

Table 4.36. T-test for hopeful-despairing

Lighting	**n**	**Mean**	**SD**	**SE**
Recessed Fluorescent Lighting	67	3.0	0.7	0.09
Halogen Spotlighting	67	2.6	0.7	0.09
Difference	67	0.4	0.9	0.11
Difference between means	0.4			
95% CI	0.2	to 0.7		
t statistic	3.97			
2-tailed p	0.0002			

The hypothesis is not true; both lighting systems do not have a particular effect for these feelings.

Q6. I feel **aroused-unaroused** under this lighting arrangement.(For results see page 88)

Q7. I feel **dominant-submissive** under this lighting arrangement.

(Compare with the results of Q4 and Q11)

Table 4.37. Mean and SD for dominant-submissive

Lighting	n	Mean	SD
Recessed Fluorescent Lighting	66	3.4	0.86
Halogen Spotlighting	67	2.5	1.06

Table 4.37 shows that the mean for recessed fluorescent system is 3.4 which is between neutral and slightly submissive, and 2.5 for halogen spotlighting which is between neutral and slightly dominant. The standard deviations are 0.86 and 1.06. Table 4.38 shows the t-test results with the hypothesis of "recessed fluorescent lighting ≠ halogen spotlighting" . The n value is 66 in the tables since one subject did not mark anything for fluorescent lighting.

Table 4.38. T-test for dominant-submissive

Lighting	n	Mean	SD	SE
Recessed Fluorescent Lighting	66	3.4	0.9	0.11
Halogen Spotlighting	66	2.5	1.1	0.13
Difference	66	0.8	1.5	0.19
Difference between means	0.8			
95% CI	0.5	to 1.2		
t statistic	4.53			
2-tailed p	<0.0001			

The hypothesis is true, because the p value is smaller than 0.01. This analysis shows that halogen spotlighting has a slightly more effect than recessed fluorescent lighting on the feeling of dominancy.

Table 4.39. Variance related to sex (dominant-submissive)

Lighting	n	Mean	SD
Fluorescent by Sex - F	29	3.1	0.82
Fluorescent by Sex - M	37	3.6	0.83
Halogen by Sex - F	29	2.6	1.15
Halogen by Sex - M	38	2.4	1.01

Table 4.39 shows the variance in feelings related to sexual differences. Male subjects feel more submissive than female subjects under recessed fluorescent lighting system.

Table 4.40. Variance related to age (dominant-submissive)

Lighting	n	Mean	SD
Fluorescent by Age - B 20-30	38	3.4	0.71
Fluorescent by Age - B 30-35	17	3.5	1.07
Fluorescent by Age - B 35-40	8	3.5	1.07
Fluorescent by Age - B 40-50	3	2.7	0.58
Halogen by Age - B 20-30	39	2.6	1.07
Halogen by Age - B 30-35	17	2.3	0.85
Halogen by Age - B 35-40	8	2.0	0.76
Halogen by Age - B 40-50	3	4.3	1.15

Table 4.40 shows the variance in feelings related to age. Subjects aged between 20 and 30 rated their feelings as neutral under the halogen spotlighting, while subjects between 30 and 40 feel more dominant. The significant variance comes from subjects aged between 40 and 50 with a rating of 4.3, which means slightly submissive.

Q8. I feel **sleepy-wideawake** under this lighting arrangement. (For results see page 90)

Q9. I feel **talkative-shy** under this lighting arrangement.

Table 4.41. Mean and SD for talkative-shy

Lighting	n	Mean	SD
Recessed Fluorescent Lighting	67	3.0	0.82
Halogen Spotlighting	67	1.8	0.84

Table 4.41 shows that the mean for recessed fluorescent system is 3.0 which means that lighting has no effect on these feelings, and 1.8 for halogen spotlighting which means slightly talkative. The standard deviations are 0.82 and 0.84. Table 4.42 shows the t-test results with the hypothesis of "recessed fluorescent lighting ≠ halogen spotlighting" .

Table 4.42. T-test for talkative-shy

Lighting	n	Mean	SD	SE
Recessed Fluorescent Lighting	67	3.0	0.8	0.10
Halogen Spotlighting	67	1.8	0.8	0.10
Difference	67	1.2	1.2	0.15
Difference between means	1.2			
95% CI	0.9	to 1.5		
t statistic	7.85			
2-tailed p	<0.0001			

The hypothesis is true, because the p value is smaller than 0.01.

Q10. I feel **excited-calm** under this lighting arrangement.

Table 4.43. Mean and SD for excited-calm

Lighting	n	Mean	SD
Recessed Fluorescent Lighting	67	3.9	0.95
Halogen Spotlighting	67	1.9	0.74

Table 4.43 shows that the mean for recessed fluorescent system is 3.9 which means slightly calm and 1.9 for halogen spotlighting which means slightly excited. The standard deviations are 0.95 and 0.74. Table 4.44 shows the t-test results with the hypothesis of "recessed fluorescent lighting ≠ halogen spotlighting" .

Table 4.44. T-test for excited-calm

Lighting	n	Mean	SD	SE
Recessed Fluorescent Lighting	67	3.9	1.0	0.12
Halogen Spotlighting	67	1.9	0.7	0.09
Difference	67	2.0	1.4	0.17
Difference between means	2.0			
95% CI	1.7	to 2.4		
t statistic	12.17			
2-tailed p	<0.0001			

The hypothesis is true, since the p value is smaller than 0.01.

Q11. I feel **controlling-controlled** under this lighting arrangement.
(Compare with the results of **Q4** and **Q7**)

Table 4.45. Mean and SD for controlling-controlled

Lighting	n	Mean	SD
Recessed Fluorescent Lighting	67	2.7	0.83
Halogen Spotlighting	67	2.6	0.76

Table 4.45 shows that the mean for recessed fluorescent system is 2.7 which stands between neutral and controlling, and 2.6 for halogen spotlighting which again stands between neutral and controlling. The standard deviations are 0.83 and 0.76. Table 4.46 shows the t-test results with the hypothesis of "recessed fluorescent lighting ≠ halogen spotlighting" .

Table 4.46. T-test for controlling-controlled

Lighting	**n**	**Mean**	**SD**	**SE**
Recessed Fluorescent Lighting	67	2.7	0.8	0.10
Halogen Spotlighting	67	2.6	0.8	0.09
Difference	67	0.2	1.2	0.15
Difference between means	0.2			
95% CI	-0.1	to 0.5		
t statistic	1.10			
2-tailed p	0.2770			

The hypothesis is not true as the p value is bigger than 0.01. There is clear distinction between two lighting systems for this feeling.

Q12. I feel **satisfied-unsatisfied** under this lighting arrangement.

Table 4.47. Mean and SD for satisfied-unsatisfied

Lighting	**n**	**Mean**	**SD**
Recessed Fluorescent Lighting	67	3.9	0.99
Halogen Spotlighting	67	1.7	0.74

Table 4.47 shows that the mean for recessed fluorescent system is 3.9 which means slightly unsatisfied, and 1.7 for halogen spotlighting which means slightly satisfied. The standard deviations are 0.99 and 0.74. Table 4.48 shows the t-test results with the hypothesis of "recessed fluorescent lighting ≠ halogen spotlighting" .

Table 4.48. T-test for satisfied-unsatisfied

Lighting	n	Mean	SD	SE
Recessed Fluorescent Lighting	67	3.9	1.0	0.12
Halogen Spotlighting	67	1.7	0.7	0.09
Difference	67	2.1	1.3	0.16
Difference between means	2.1			
95% CI	1.8	to 2.5		
t statistic	13.72			
2-tailed p	<0.0001			

The hypothesis is true, since the p value is smaller than 0.01. Table 4.49 shows the variance in feelings according to age. Subjects aged between 35 and 40 feel neutral under recessed fluorescent lighting system, while the rest feel slightly and extremely unsatisfied.

Table 4. 49. Variance related to age (satisfied-unsatisfied)

Lighting	n	Mean	SD
Fluorescent by Age - B 20-30	39	3.8	1.04
Fluorescent by Age - B 30-35	17	4.1	0.83
Fluorescent by Age - B 35-40	8	3.1	0.83
Fluorescent by Age - B 40-50	3	4.7	0.58
Halogen by Age - B 20-30	39	1.7	0.66
Halogen by Age - B 30-35	17	2.0	0.94
Halogen by Age - B 35-40	8	1.4	0.52
Halogen by Age - B 40-50	3	1.3	0.58

Q13. I feel **stable-depressed** under this lighting arrangement.

Table 4.50. Mean and SD for stable-depressed

Lighting	n	Mean	SD
Recessed Fluorescent Lighting	67	3.5	1.09
Halogen Spotlighting	67	1.9	0.74

Table 4.50 shows that the mean for recessed fluorescent system is 3.5 which stands between neutral and slightly depressed, and 1.9 for halogen spotlighting which means slightly stable. The standard deviations are 1.09 and 0.74. Table 4.51 shows the t-test results with the hypothesis of "recessed fluorescent lighting ≠ halogen spotlighting" .

Table 4.51. T-test for stable-depressed

Lighting	n	Mean	SD	SE
Recessed Fluorescent Lighting	67	3.5	1.1	0.13
Halogen Spotlighting	67	1.9	0.7	0.09
Difference	67	1.6	1.3	0.15
Difference between means	1.6			
95% CI	1.3	to 1.9		
t statistic	10.52			
2-tailed p	<0.0001			

The hypothesis is true, since the p value is smaller than 0.01.

Q14. I feel **important-unimportant** under this lighting arrangement.

Table 4.52. Mean and SD for important-unimportant

Lighting	n	Mean	SD
Recessed Fluorescent Lighting	67	2.0	0.98
Halogen Spotlighting	67	1.7	0.72

Table 4.52 shows that the mean for recessed fluorescent system is 2.0 which means slightly important, and 1.7 for halogen spotlighting which again means slightly important. The standard deviations are 0.98 and 0.72. Table 4.53 shows the t-test results with the hypothesis of "recessed fluorescent lighting ≠ halogen spotlighting" .

Table 4.53. T-test for important-unimportant

Lighting	n	Mean	SD	SE
Recessed Fluorescent Lighting	67	2.0	1.0	0.12
Halogen Spotlighting	67	1.7	0.7	0.09
Difference	67	0.3	1.3	0.16
Difference between means	0.3			
95% CI	-0.1	to 0.6		
t statistic	1.60			
2-tailed p	0.1135			

The hypothesis is not true as the p value is bigger than 0.01.

4.1.4. Imperfections

Although environmental psychology do possess several studies which reveals the effects of lighting on human psychology and certain behaviors, it does not offer a variety in terms of architectural function. Most of the studies deal with office environments and try to expose the psychological impacts of lighting in reference to performance. There are a few works which were realized in other environments, such as libraries, hospitals, and factories, again with a tendency to increase performance. It is not possible to meet any study of that kind which is realized where labor performance is of secondary importance, such as museums, art galleries, cafeterias, and others. This caused to prepare, perform, and evaluate all related measurement studies for the case, such as the survey, which prolonged the data collection process for this evaluation methodology. This creates a disadvantage in terms of time-management. The researchers of environmental psychology should expand their preferences in terms of spatial function and form a base of knowledge which would be beneficial for related studies.

The evaluation methodology reached at satisfying results for most of the criteria under functional, physiological, and psychological aspects and enabled a detailed judgment about quality of lighting in APIKAM. However it was insufficient to measure the effects of lighting on the perception of structural elements, materials, and their characteristics such as texture and color. The third part in the survey was dealing with the aesthetic and environmental judgments by means of eleven questions. Only and the last four questions that measure the direct influence of space on users were reached at satisfying results. Four other questions were related to the general appearance of lighting on spatial components, such as wall, ceiling, and floor, reached to consistent results too. However these four questions were asked only to test subject's reliability, because the answers for these four questions were already acquired by the photometric calculations. The first three questions were testing the effects of lighting on the perception of spatial components. Excluding the first question which was related to the perception of form, no satisfying results were acquired for the two questions in this section.

The survey was not successful in measuring the users' emotional responses in the case of the feeling of dominancy. Three questions concerning this feeling concluded at conflicting results.

Figure 4.36 and Figure 4.37 show the general problems of the lighting systems in APIKAM .

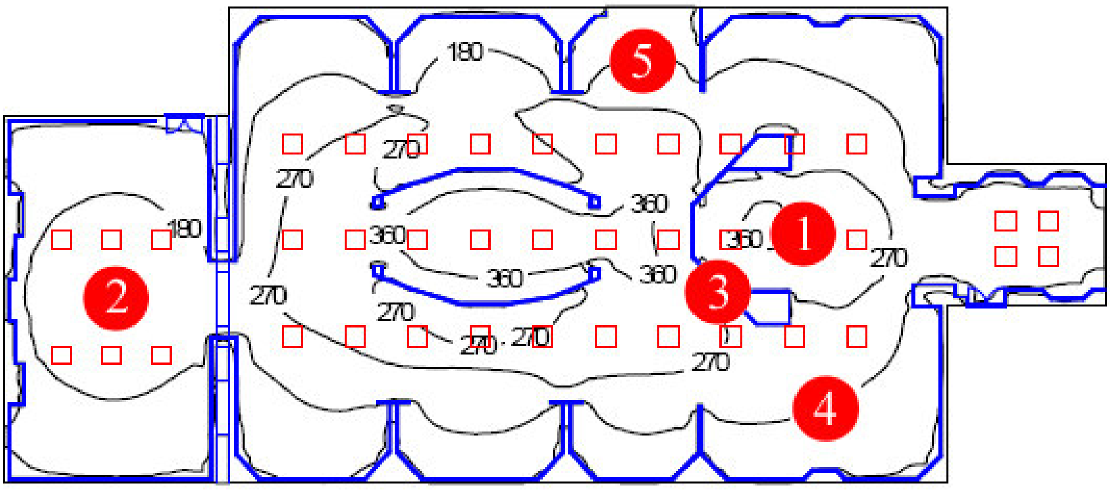


Figure 4.36. General problems under recessed fluorescent lighting system: **1.** The general level of illumination is high for the exhibition of organic-based materials. A dimmer system could be installed to reduce the amount of light. **2.** The lighting system is fixed and does not allow repositioning according to the changing lighting needs. **3.** Task surfaces are subject to glare related to the positions of light sources. No solution is possible, since the lighting system is fixed. **4.** The granite floor with a high reflectance factor creates glare. Another material with a low reflectance factor such as vinyl or wood should be selected. **5.** The distribution of light creates three separate uniformly lit areas which lead to an uninteresting and dull environment. Differentiation should be achieved through a dimmer system by changing the amount of light on certain places besides task surfaces.

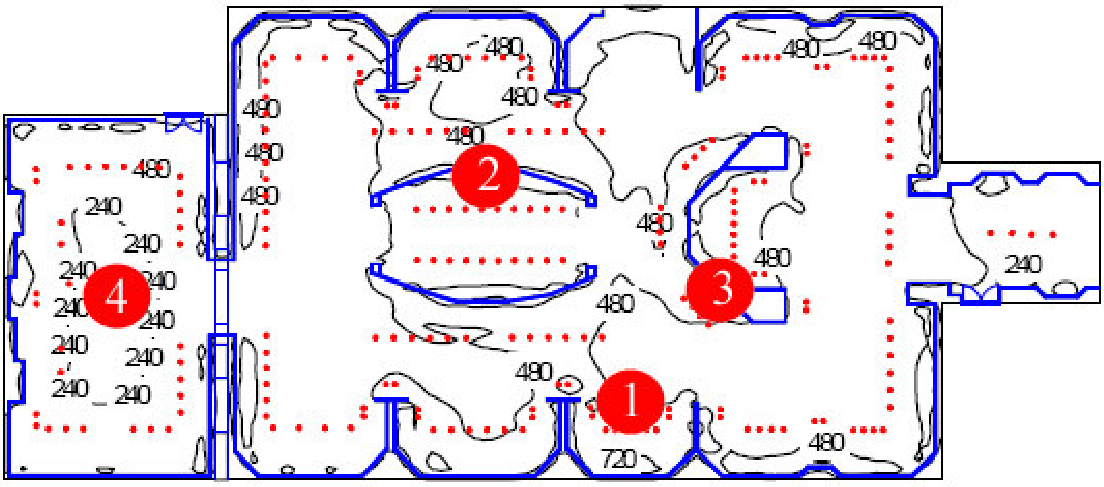


Figure 4.37. General problems under halogen spotlighting system: **1.** The general level of illumination is too high for the exhibition of organic-based materials. A dimmer system could be installed to reduce the amount of light. **2.** Task surfaces are subject to glare related to the harsh brightness differences on the surface. Brightness differences must ne minimized. Variety should be achieved on certain locations other than task surfaces. **3.** Task surfaces are subject to glare related to the positions of light sources. The tracks allow the lighting system to be repositioned. **4.** The granite floor with a high reflectance factor creates glare. Another material with a low reflectance factor such as vinyl or wood should be selected.

CHAPTER 5

CONCLUSIONS

The evaluation methodology for artificial lighting quality was successfully operated on APIKAM and several results were acquired, which will help in interpreting and judging the quality of lighting supplied by two different lighting systems. The success and failure of the lighting systems were revealed according to the three aspects in the evaluation process, as functional, physiological, and psychological. This kind of an evaluation helped in determining what the deficiencies are in terms of lighting and what problems these deficiencies lead to both in terms of environmental conditions and experience within the space.

Functional aspects are concerned with visibility, thus safety; and task performance in relation to the amount of light, lighting systems or lamp types chosen, and check whether they are appropriate to the desired function or not. According to the regulations the amount of light must not exceed 50 lx, where organic-based materials such as paper prints are exhibited. Besides, the IR emissions should be controlled and UV emissions should be stopped to avoid the heating effect and photochemical reactions.

In the exhibition hall APIKAM the task surfaces are the vertical panels and there is a large variety in the amount of light they receive especially under halogen spotlighting systems. In order to make the evaluations easier, four calculation surfaces are utilized to measure the amount of light on the surfaces. The surfaces are placed on the brightest, darkest, and semi-bright locations within the exhibition. For recessed fluorescent lighting system, the amount of light on the surfaces varies between 88 lx and 293 lx, which are higher than the recommended level. Since it is too expensive to change the whole lighting system, a dimmer system could be installed which gives the ability to reduce the amount of light in the exhibition. This system should offer the ability of controlling each single fluorescent box so that it would be possible to equalize the intensity for each task surface to the recommended level. This will also generate the ability to create variety in the amount of light outside the task surfaces in the exhibition, such as walls, ceiling, and floor to achieve non-uniformity. Fluorescent light sources do not produce any heat. However, they emit too much radiation within the ultraviolet spectrum. Although the ones used in the exhibition are of low UV emitting type, they nevertheless produce some UV emission which could be dangerous for the exhibited materials. A UV shield coating could be applied on the methacrylate flat diffuser for each box.

The situation is much worse for the halogen spotlighting system in terms of light intensity. The amount of light varies between 243 lx and 882 lx, which are far higher than the recommended level. The cold-light reflector of the sources reduces the heat by 66 % but at this intensity it will not be enough. The amount of light must be lowered with a dimmer system which is proposed for recessed fluorescent systems, too. The UV shield in the halogen bulbs stops the UV emission, so no further protection such as a UV coating is necessary.

Because of the high intensities especially in the halogen spotlighting system, some disturbing effects such as glare occur in the exhibition. Most of the task surface is subject to sharp transitions in terms of brightness. For example, the CS1 is subject to a transition from 621 lx to 880 lx at a height of 165 cm under halogen spotlighting system. Brightness pattern, or the non-uniform distribution of light is something valuable, but special attention must be paid that these varieties do not intersect on the task surfaces. Other surfaces such as walls, ceiling, floor, and some volumetric parts of the space could be utilized for that purpose. This problem also derives from the selection of the halogen bulb which has a beam angle of 10 degrees, which is more suitable for illuminating three dimensional objects. Since this angle is too narrow, bright circles occur on the task surfaces and this tires the eye of viewer because it is hard to adapt to the bright and dark contrast at this small scale.

Another problem is the reflected glare or veiling reflections that occur on the task surfaces for both lighting systems. Most of the task surface acts like a mirror and reflects the images of light sources and even the image of the viewer on dark colored posters. This problem is also expressed in the survey. 42 subjects reported that they noticed the reflection of themselves and light sources under both lighting systems on several vertical task surfaces.

The reason is the wrong placement of the light sources without constituting the optimum angle of incidence, which is 30 degrees for vertical tasks in museums. Halogen spotlighting system is mounted on tracks and therefore provides the ability to relocate the sources, but the recessed fluorescent lighting system is fixed and repositioning means to change the whole suspended ceiling above the exhibition.

Another solution might be to relocate the vertical task surfaces according to the fluorescent lighting system and try to minimize the spots where veiling reflections occur and then cover all task surfaces with antireflective coatings of highest quality and then relocate the halogen spotlighting system with respect to the new plan scheme of the exhibition.

The reflected glare is also available on the floor. The exhibition is covered with granite tiles which have a reflectance of 68 %. The floor is like a reflective pool on a sunny day and it is possible to see the whole pattern of light sources on the floor for both lighting systems. On most of the exhibition the floor is the main source for disturbing glare and it distracts the attention from the exhibition, whereas all attention should be directed on task surfaces. As a solution the floor could be covered with an alternative material, such as vinyl or wood, which has low degree of reflectance.

Both lighting systems failed in functional aspects for several reasons as explained above.

Physiological aspects are concerned with the effects of light on human physiology. The physiological effects besides arousal are directly related to the length of the period of one’s exposal to light. On the other hand, there may be some employees, including museum security guards and others who are exposed to lighting conditions for longer periods of time. Besides, some museums are also open at night for certain days of the week, which as a result make shift-work a parameter of consideration in terms of lighting design. This particular exhibition hall generally welcomes short visits which are not enough to become physiologically affected. The exhibition hall of APIKAM is open only during the work hours and there are no employees in the exhibition hall, who are on duty whole day, so the health issue in regard to human physiology could be neglected for this particular case. Physiological aspects are considered only in terms of arousal in this exhibition hall.

As based on Eysenck’s theory (1990) and other scientific works such as Biner’s (1991) and Boyce’s (1997), arousal levels are related to the amount of light and more light triggers more arousal. However, it is also important to point out that the arousal level should be on an optimal level to result in good performance. Like low arousal levels, very high arousal levels bear negative effect on performance related to a task. The other factor is the color of light, as cooler light of high color temperature triggers more arousal than warmer light of low color temperature.

In the exhibition hall of APIKAM the arousal level is higher under the halogen spotlighting system. The illumination supplied by the recessed fluorescent lighting system varies between 88 lx and 420 lx and the average illumination is 211 lx within the space, whereas the illumination supplied by halogen spotlighting system is between 243 lx and 1185 lx at an average of 402 lx. Although the neutral white fluorescent light source with 4000 K triggers more arousal than the reddish warm halogen light source with 2900 K, the amount of light here plays the main role.

The results of survey verify this situation, too. The preferences for the two adjective pairs in the survey as “aroused-unaroused” and “sleepy-wideawake” were pointed out that halogen spotlighting systems triggers more arousal than recessed fluorescent lighting system. For the first adjective pair, the mean for recessed fluorescent lighting is 4 and the mean for halogen spotlighting system is 1.6. A p-value which is smaller than 0.001 shows that halogen spotlighting is the one that creates arousal within the space. For the pair “sleepy-wideawake” the mean for recessed fluorescent system is 1.8 and the mean for halogen spotlighting is 4. The t-test yielded result at a p-value smaller than 0.001 and verified the validity of the hypothesis which was “recessed fluorescent lighting ≠ halogen spotlighting” . Another interesting result for the arousal levels was that the decline of the arousal level related to the increase of age. The means were 3.9, 4.0, 4.3, and 5.0 respectively for the four age groups of 20-30, 30-35, 35-40, and 40-50.

Recessed fluorescent lighting system failed in physiological aspects as it triggers less arousal than halogen spotlighting system. In order to heighten the arousal level for fluorescent lighting system, the amount of light needs to increase, which comprises a mismatch with the need for preservation. However, the illumination level could be increased on certain locations without increasing the level on vertical task surfaces with the help of a dimmer system.

Psychological aspects are concerned with the psychological effect of light described under three main parts as attention, aesthetic and environmental judgments, and feelings.

Both lighting systems have failed in attention scale, because none of them supply continuity in the order of visual clues that match with the sequential order of the exhibition. The present brightness patterns supplied by lighting systems misguide the users in the exhibition in terms of attention cycle.

There is a considerable difference between the two lighting systems in their interactions with the architectural space. Recessed fluorescent lighting system supplies a uniform distribution of luminance on the task areas and a uniform horizontal illumination in the middle of space. There is significant drop in the horizontal illumination on both sides near the long walls for the large hall and near the short walls in the adjacent small hall, deriving from the location of the light sources. While the average horizontal illumination is at 360 lx in the middle of space, it drops to 270 lx and to 180 lx on both sides. This is misleading in terms of perceptual conditions as some parts of the space are perceived weaker than the rest, although it is not an intended situation. As mentioned before, non-uniform distribution of light is necessary with its contribution to space in terms of perceptual psychology, however not in this particular way. In this exhibition the recessed fluorescent lighting system creates three uniformly illuminated areas; gradually decreases in the amount of illumination, thus the level of perception decreases too, for the area where the illumination level is at minimum. The problem is that the lesser perceived area holds the larger percentage of the task area. In fact, the amount of light on darker areas is enough to see the posters and read the informative texts. However, those locations are not a point of interest anymore under this arrangement of light sources.

The illumination supplied by halogen spotlighting is much more satisfying in terms of environmental conditions. The lighting has a non-uniform character between 240 lx and 720 lx in average, and almost all of the vertical task surfaces are strongly perceived by the users in the exhibition. Moreover, the architectural information is strongly transmitted to the visitors.

The results of the survey show that subjects rated halogen spotlighting system as it creates a cozy, interesting, and inviting environment, and that they like the gallery more under halogen spotlighting system while they rated recessed fluorescent lighting system as it creates a cold, dull, and repulsive environment.

Results for feelings are more complex. Subjects rated that they feel happy, pleased, relaxed, aroused, talkative, excited, satisfied, and stable under halogen spotlighting system, while they feel sleepy, calm, and unsatisfied under recessed fluorescent lighting system.

Positive feelings are generally influenced by halogen spotlighting system. However, this does not mean that all negative feelings are influenced by recessed fluorescent lighting systems. The adjective pairs of happy-unhappy, annoyed-pleased, hopeful-despairing, relaxed-tense, talkative-shy, and stable-depressed are rated as neutral under recessed fluorescent lighting system, which means this lighting system has neither a positive effect nor a negative effect for these pairs of feelings, while some of these feelings are positively influenced under halogen spotlighting system.

According to the results there is no clear distinction between the two lighting systems for the feeling pair of important-unimportant. Subjects feel important under both lighting systems. Some subjects reported during the survey that they felt important by being involved in this study. The results may have been affected by this feeling.

For the three scales which measure the dominancy the results were confusing. The results of the scales autonomous-guided and controlling-controlled showed that lighting systems have no effect on this feeling; they both rated near 3, which means neutral. However, the results of the scale of dominant-submissive points out halogen spotlighting system as stimulating dominancy on the subjects. The inconsistency between the results is unacceptable. That is why the results for all of these adjective pairs will not be counted.

Subjects aged between 40 and 50 feel tense under recessed fluorescent lighting system, while the rest have not been affected in the same way. For the scale of arousal-unarousal it is interesting to see that as age increases unarousal level increases too, under recessed fluorescent lighting system. The reason might be the declining visual abilities as age increases, but then what could be the reason of them feeling more aroused under halogen spotlighting system?

Both lighting systems have no influence on the feeling pair of hopeful-despairing. This pair is rated as 3 under recessed fluorescent system and 2.6 under halogen spotlighting system.

For the pair of satisfied-unsatisfied, subjects rated fluorescent system as slightly unsatisfied with a general mean of 3.9. However, the mean of the subjects between the ages 35-40 is 3.1, which implies that they feel neither satisfied nor unsatisfied under fluorescent lighting. This preference of the said age group caused the general mean to drop.

5.1. Concluding Remarks and Recommendations for Further Research

The task for lighting researchers in various disciplines has been to determine what luminous conditions (e.g., illuminance, luminance, uniformity, luminance distribution, spectral power distribution, etc.) provide good lighting quality. This topic is too complex, because those conditions surely will not be universally valid, for lighting needs will be influenced by settings, tasks, and individual differences. And this complexity leads to pessimism about the likelihood of understanding lighting quality. It is true that the probability that one could develop a tool or measurement system that will combine photometric values into a single number, into a value that explains everything that the designer or engineer needs to know about lighting quality, is very low.

What this dissertation tries to point out is the necessity for quality research in lighting to be shifted to a base of interpretation where all relevant factors of quality are studied, and discussed; instead a base of mandatory prescriptions. That is why the writer of this dissertation has benefited from a qualitative research understanding, and the tools of behavioral sciences in data collection and evaluation.

Behavioral research can be defined as the study of how people behave or feel under different environmental conditions. It does possess the tools, descriptive studies, models, and theories, which are important for architects who want to influence certain behaviors by changing the peculiarities of the built environment. As lighting quality consist in the harmony between human activity and luminous conditions in a particular setting, to assess lighting quality requires accurate measurement of the relevant human activities, as well as accurately specified, and appropriate lighting conditions. Researches on lighting quality so far has failed because of researchers approach to lighting only from a technical background. In the case of lighting quality, multiple measures is needed because every lighting installation serves for multiple purposes, such as to satisfying requirements for visibility, task performance, social interaction, mood, safety and health, and aesthetics.

At this point it would be reasonable to inquire whether these tools and data evaluation methodologies of psychology would be appropriately adapted to the architectural context or not. Psychologists study on humans' interaction with the environment since the second half of the 20th century. Barker and Wrighl (1955) developed the theory that social settings influence human behavior and they founded a research station in Kansas. These studies formed a new channel in psychology, which is environmental psychology, and through participations from other disciplines, such as sociology, anthropology, and history it lead today to a vast knowledge, which is a massive source to benefit from. There are a lot of studies in environmental psychology, which deals with the effects of architectural context on behaviors. Environmental psychologists believe that environment influences behavior at different levels (Delong 2005). Immediate behavior is a function of the setting in which it occurs. They investigate how architectural styles reflect the needs and preferences of people and how different designs shape behavior. There are also some studies that deal with architectural lighting and its effects on human psychology which has been cited in this dissertation before. Environmental psychology developed several tools for measuring the effects of the environment (setting, architectural space) on behaviors. PAD, developed by Mehrabian is one of them, which is used for data collection in this dissertation.

This evaluation methodology could be improved as it will be able to determine lighting quality for spaces where daylight is also present alongside artificial lighting. The parameters related to the architectural components could be revised and enhanced in order to get consistent results in explaining the effects of lighting on form, structure, material, texture, etc. Some inconsistent results in the psychological and physiological aspects have opened up new questions and topics to study, such as the impact of lighting on the feeling of dominancy, and the impact of lighting on arousal in relation to lamb characteristics and age differences.

Lighting researchers in the past had a narrow perspective, considering the luminous environment only as a provider of visual abilities. This study has demonstrated that quality in lighting is the sum of multiple factors besides vision, and quality is achieved only if the lighting conditions fulfill all of these multiple factors.

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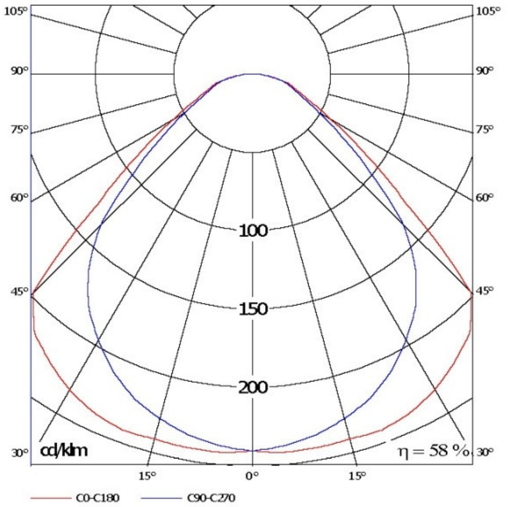
APPENDIX A

PHOTOMETRIC RESULTS FOR RECESSED FLUORESCENT LIGHTING SYSTEM

3FFilippi 2906 L 324x18 SPA / Luminaire Data Sheet

Luminous emittance 1:



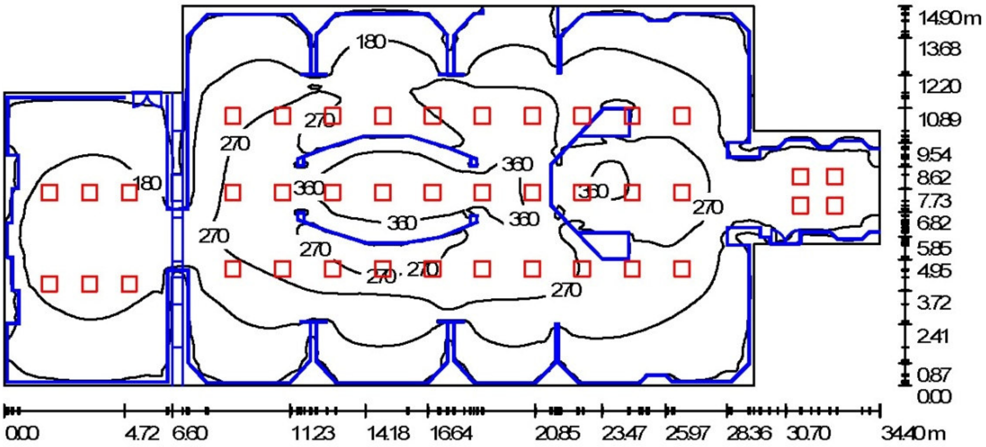
Luminaire classification according to CIE: 100
CIE flux code: 57 88 97 100 58

ILLUMINOTECHNICAL CHARACTERISTICS
Luminous efficiency >58%.
Direct symmetrical distribution.
UGR <18 (EN 12464-1).

MECHANICAL CHARACTERISTICS
SPA transparent methacrylate flat diffuser, plurilenticular, anti-glare, internal or external prismatization depending on environment's cleaning, injection moulded, resting on the structure, without frame.
Housing in hot galvanized steel, painted in white polyester.
Dimensions: 596x596 mm, height 84 mm. Weight 5.25 kg.
IP44 protection degree exposed part.
Installation also on normally inflammable surfaces. - F -
Resistance to glow wire 650°C.

ELECTRICAL CHARACTERISTICS
EEI B2 wiring with starter with low loss ballast, 230V-50Hz, power factor correction, fuse, class I.
ENEC.

APPLICATIONS
In environments requiring protection, lamp's shielding and simplified cleaning.



Height of Room: 6.500 m

Values in Lux, Scale 1:246

Surface	ρ [%]	E_{av} [lx]	E_{min} [lx]	E_{max} [lx]	u0
Workplane	/	211	15	420	0.07
Floor	68	195	6.10	398	0.03

Workplane:

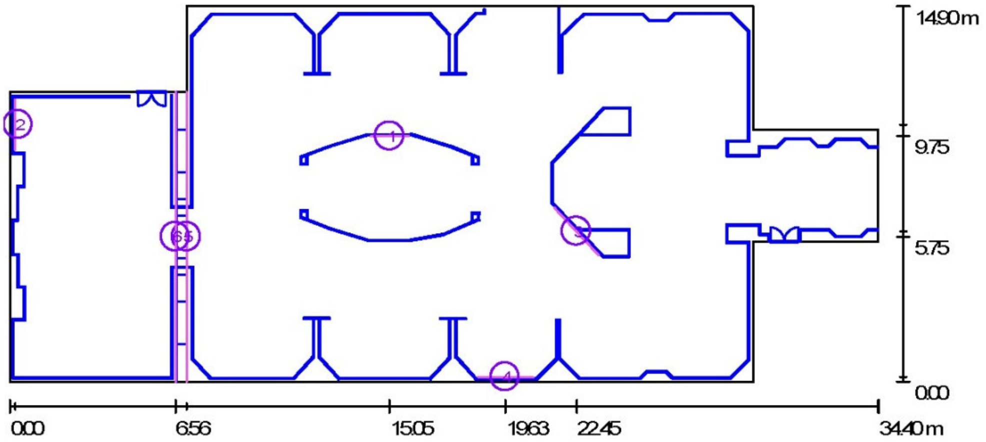
Height:	0.760 m
Grid:	128 x 128 Points

Luminaire Parts List

No.	Pieces	Designation (Correction Factor)	Φ [lm]	P [W]
1	40	3FFilippi 2906 L 324x18 SPA (1.000)	5400	86
		total:	216000	3440

Specific connected load: 7.87 W/m² = 3.73 W/m²/100 lx (Area: 436.93 m²)

Calculation surfaces (results overview)



Scale 1 : 246

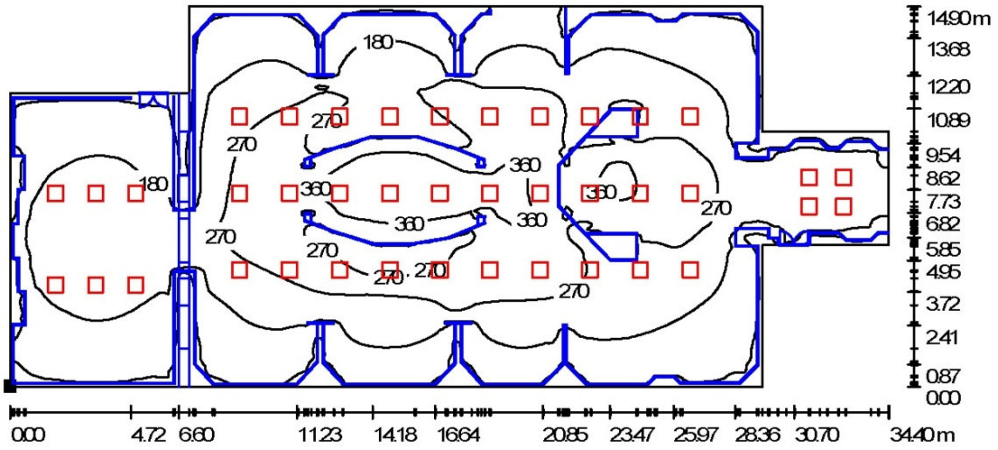
Calculation Surface List

No.	Designation	Type	Grid	E_{av} [lx]	E_{min} [lx]	E_{max} [lx]	u0	E_{min} / E_{max}
1	Calculation Surface 1	perpendicular	16 x 16	251	241	293	0.96	0.82
2	Calculation Surface 2	perpendicular	8 x 8	100	88	113	0.88	0.78
3	Calculation Surface 3	perpendicular	32 x 32	180	153	234	0.85	0.65
4	Calculation Surface 4	perpendicular	16 x 16	153	141	169	0.92	0.83
5	Calculation Surface 5	perpendicular	128 x 64	99	4.29	226	0.04	0.02
6	Calculation Surface 6	perpendicular	128 x 64	76	3.20	192	0.04	0.02

Summary of Results

Type	Quantity	Average [lx]	Min [lx]	Max [lx]	u0	E_{min} / E_{max}
perpendicular	6	99	3.20	293	0.03	0.01

Workplane / Isolines (E)



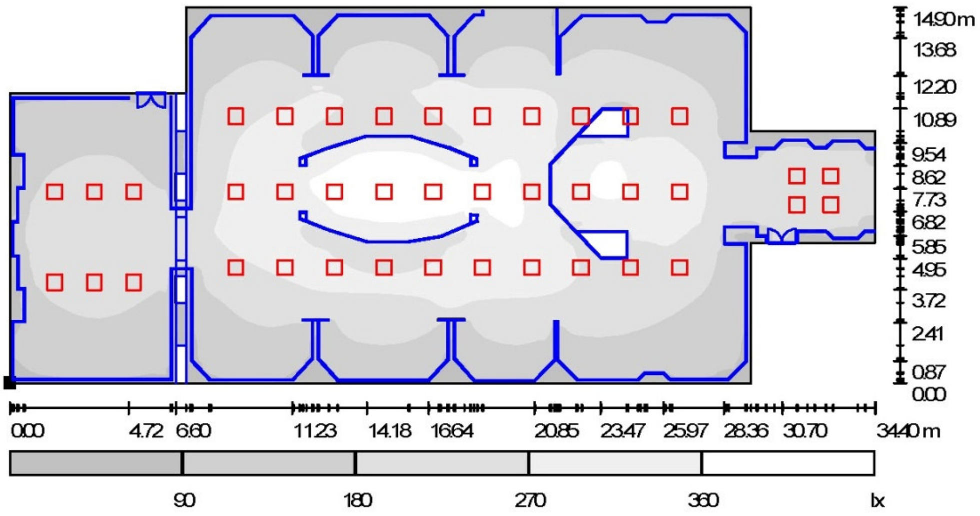
Values in Lux, Scale 1 : 246

Position of surface in room:
Marked point:
(0.000 m, 0.000 m, 0.760 m)

Grid: 128 x 128 Points

E_{av} [lx]	E_{min} [lx]	E_{max} [lx]	u0	E_{min} / E_{max}
211	15	420	0.07	0.03

Workplane / Greyscale (E)

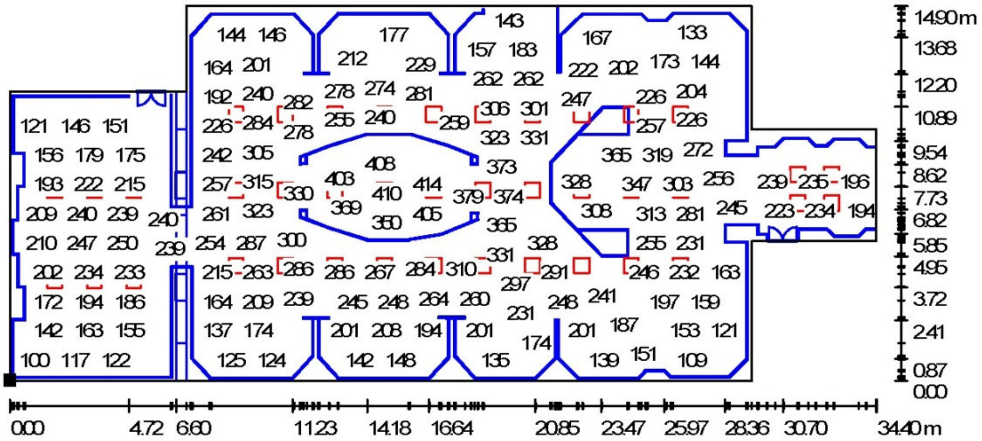


Scale 1 : 246

Position of surface in room:
Marked point:
(0.000 m, 0.000 m, 0.760 m)

Grid: 128 x 128 Points

E_{av} [lx]	E_{min} [lx]	E_{max} [lx]	u0	E_{min} / E_{max}
211	15	420	0.07	0.03



Values in Lux, Scale 1 : 246

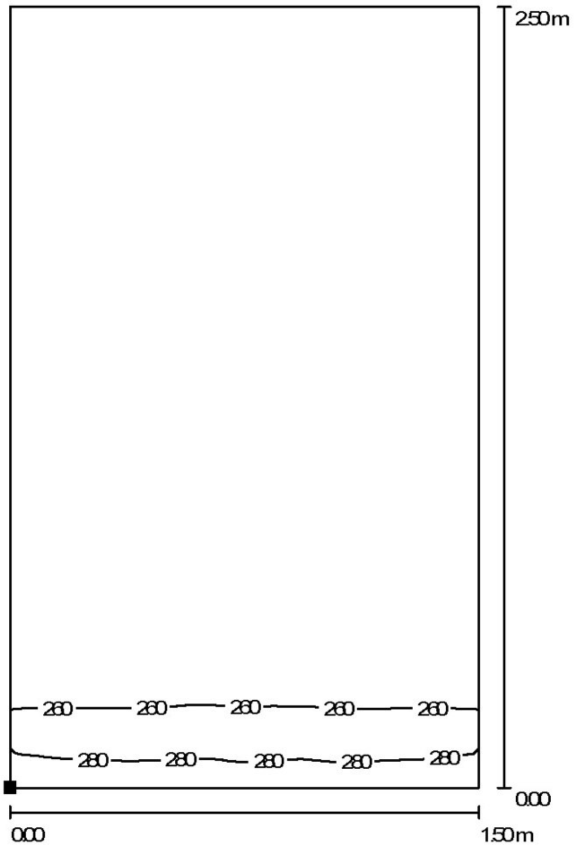
Not all calculated values could be displayed.

Position of surface in room:
Marked point:
(0.000 m, 0.000 m, 0.760 m)

Grid: 128 x 128 Points

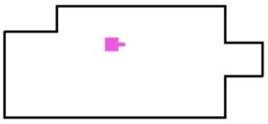
E_{av} [lx]	E_{min} [lx]	E_{max} [lx]	u0	E_{min} / E_{max}
211	15	420	0.07	0.03

Calculation Surface 1 / Isolines



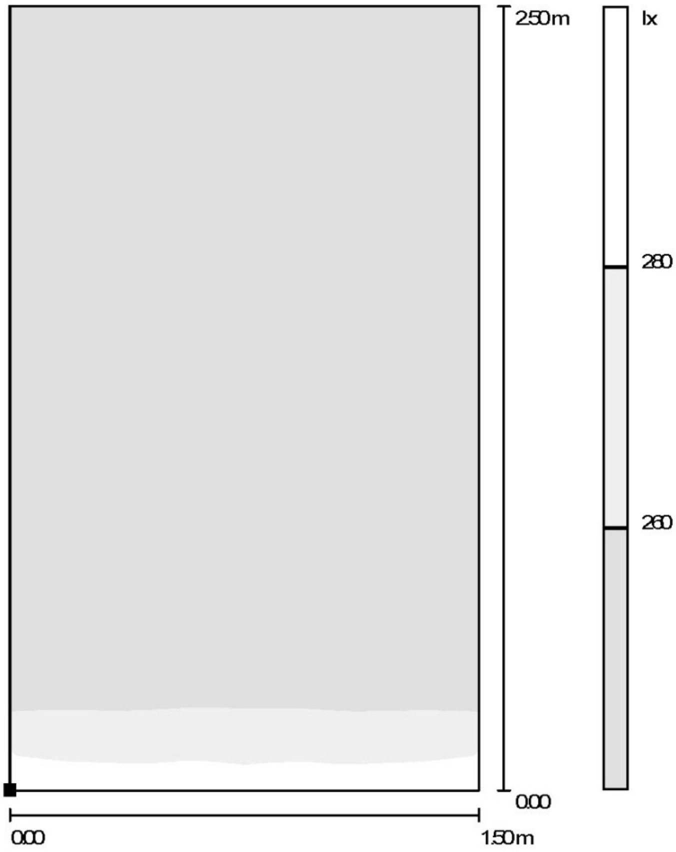
Values in Lux, Scale 1 : 20

Position of surface in room:
Marked point:
(14.300 m, 9.750 m, 0.000 m)



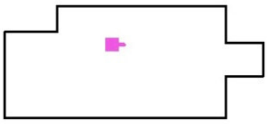
Grid: 16 x 16 Points

E_{av} [lx]	E_{min} [lx]	E_{max} [lx]	u0	E_{min} / E_{max}
251	241	293	0.96	0.82



Scale 1 : 20

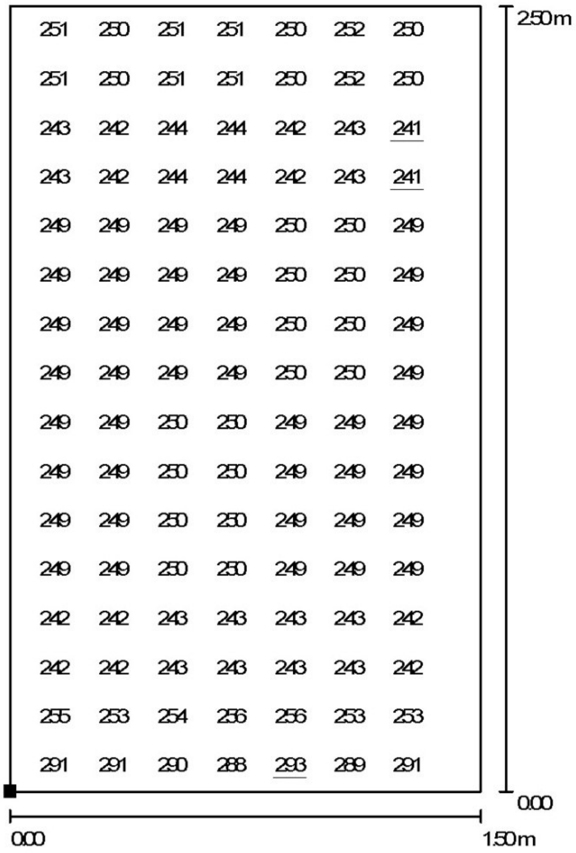
Position of surface in room:
Marked point:
(14.300 m, 9.750 m, 0.000 m)



Grid: 16 x 16 Points

E_{av} [lx]	E_{min} [lx]	E_{max} [lx]	u0	E_{min} / E_{max}
251	241	293	0.96	0.82

Calculation Surface 1 / Value Chart

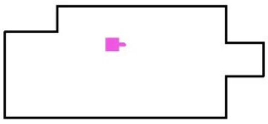


251	250	251	251	250	252	250
251	250	251	251	250	252	250
243	242	244	244	242	243	241
243	242	244	244	242	243	241
249	249	249	249	250	250	249
249	249	249	249	250	250	249
249	249	249	249	250	250	249
249	249	249	249	250	250	249
249	249	250	250	249	249	249
249	249	250	250	249	249	249
249	249	250	250	249	249	249
249	249	250	250	249	249	249
242	242	243	243	243	243	242
242	242	243	243	243	243	242
255	253	254	256	256	253	253
291	291	290	288	293	289	291

Values in Lux, Scale 1 : 20

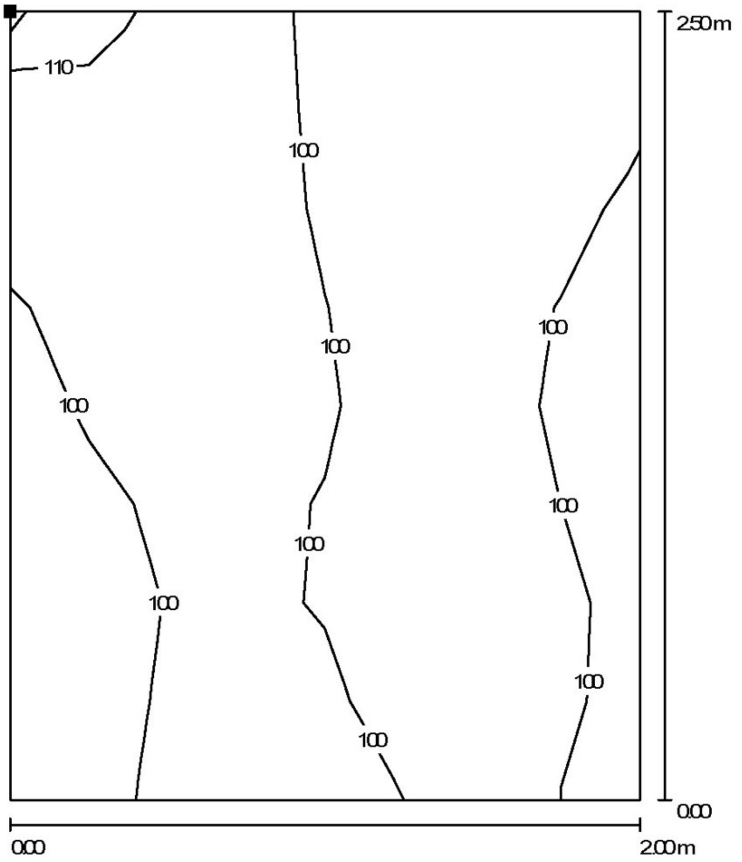
Not all calculated values could be displayed.

Position of surface in room:
Marked point:
(14.300 m, 9.750 m, 0.000 m)



Grid: 16 x 16 Points

E_{av} [lx]	E_{min} [lx]	E_{max} [lx]	u0	E_{min} / E_{max}
251	241	293	0.96	0.82

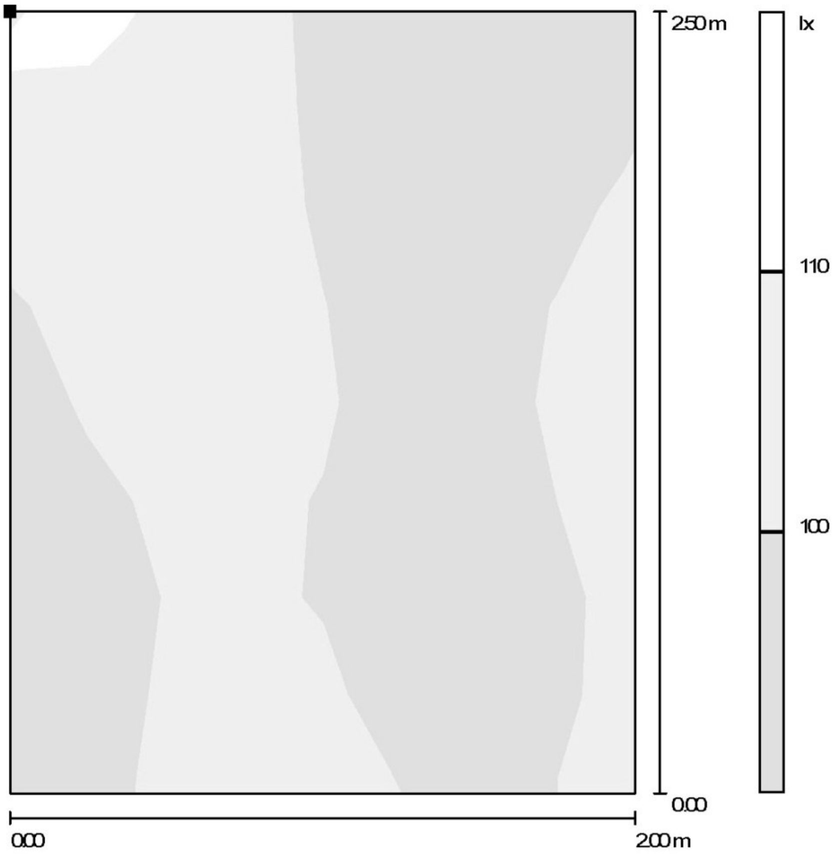


Values in Lux, Scale 1 : 20

Position of surface in room:
Marked point:
(0.205 m, 9.200 m, 2.500 m)

Grid: 8 x 8 Points

E_{av} [lx]	E_{min} [lx]	E_{max} [lx]	u0	E_{min} / E_{max}
100	88	113	0.88	0.78



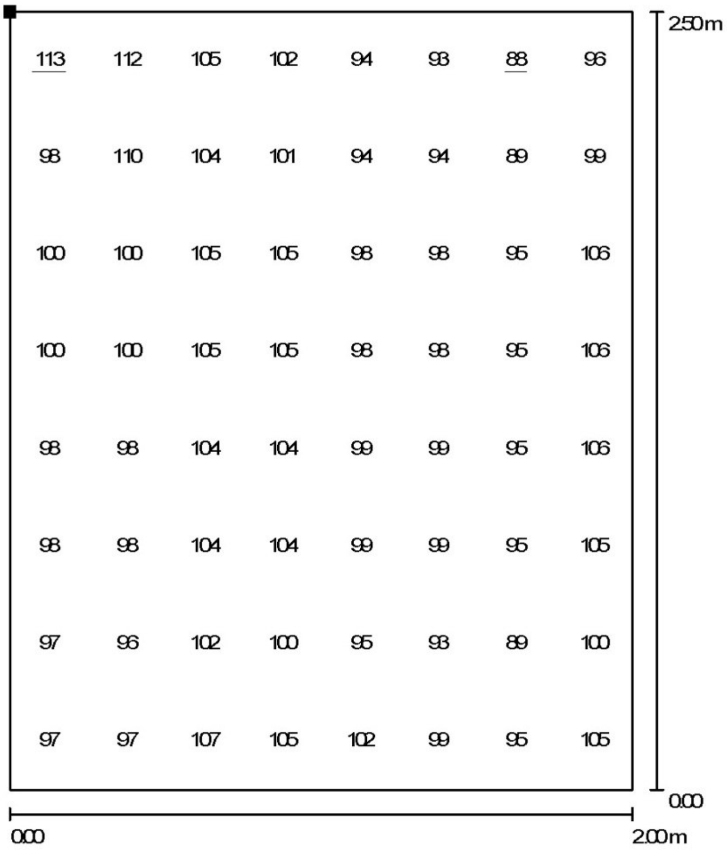
Scale 1 : 20

Position of surface in room:
Marked point:
(0.205 m, 9.200 m, 2.500 m)

Grid: 8 x 8 Points

E_{av} [lx]	E_{min} [lx]	E_{max} [lx]	u0	E_{min} / E_{max}
100	88	113	0.88	0.78

Calculation Surface 2 / Value Chart



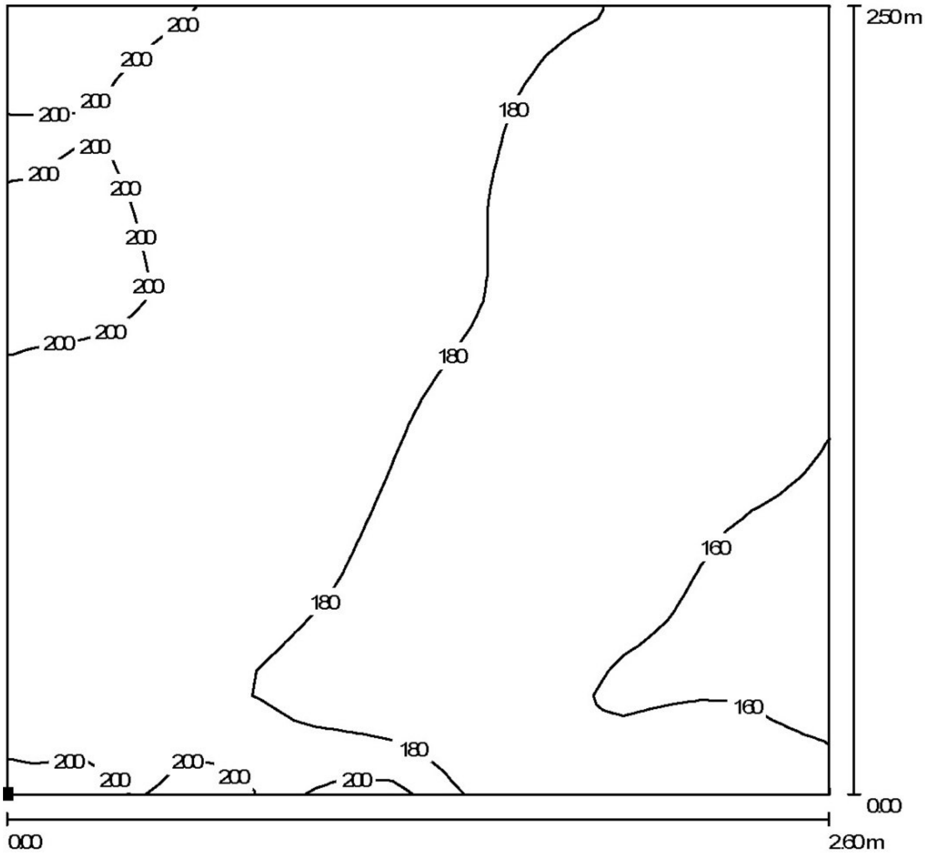
113	112	105	102	94	93	88	96
98	110	104	101	94	94	89	99
100	100	105	105	98	98	95	106
100	100	105	105	98	98	95	106
98	98	104	104	99	99	95	106
98	98	104	104	99	99	95	105
97	96	102	100	95	93	89	100
97	97	107	105	102	99	95	105

Values in Lux, Scale 1 : 20

Position of surface in room:
Marked point:
(0.205 m, 9.200 m, 2.500 m)

Grid: 8 x 8 Points

E_{av} [lx]	E_{min} [lx]	E_{max} [lx]	u0	E_{min} / E_{max}
100	88	113	0.88	0.78

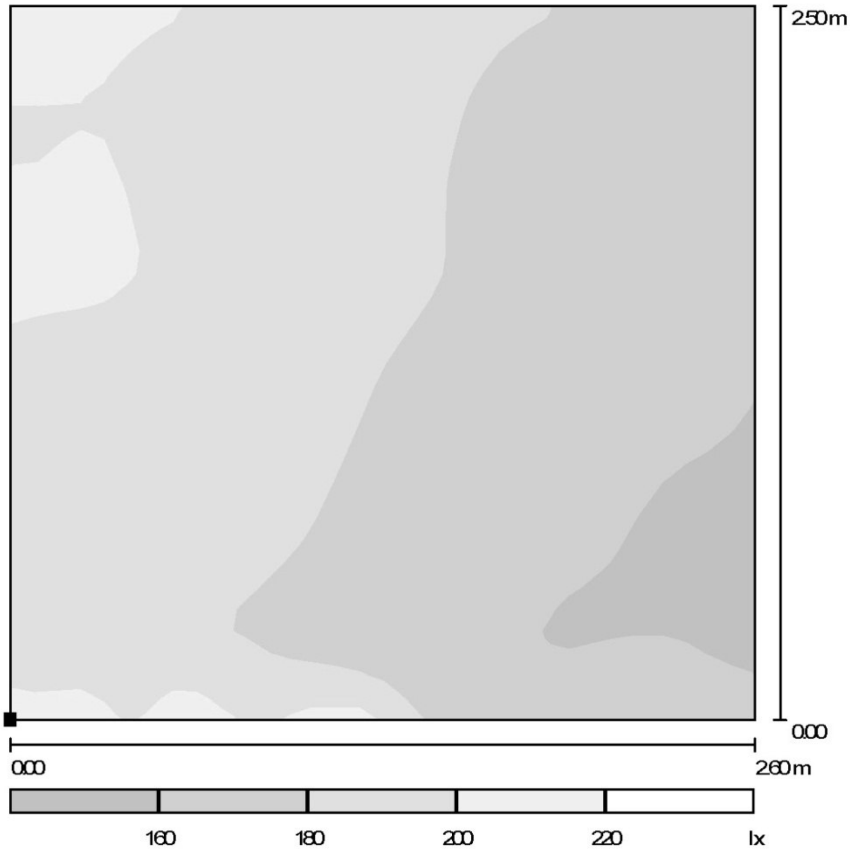


Values in Lux, Scale 1 : 20

Position of surface in room:
Marked point:
(21.558 m, 6.911 m, 0.000 m)

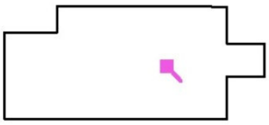
Grid: 32 x 32 Points

E_{av} [lx]	E_{min} [lx]	E_{max} [lx]	u0	E_{min} / E_{max}
180	153	234	0.85	0.65



Scale 1 : 22

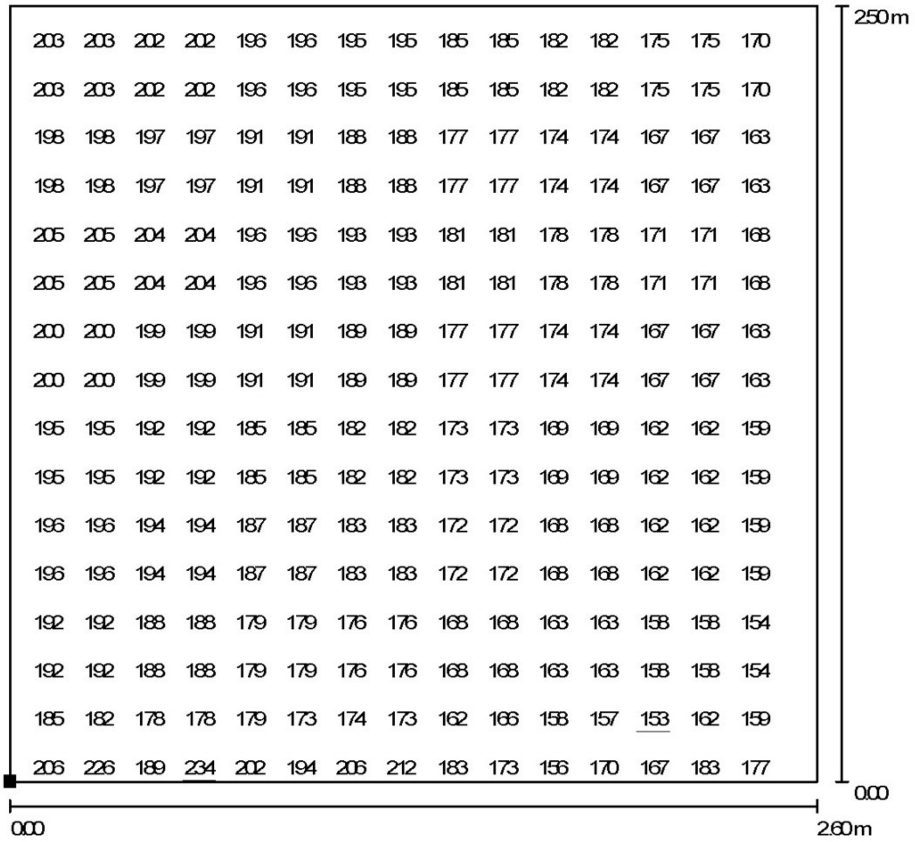
Position of surface in room:
Marked point:
(21.558 m, 6.911 m, 0.000 m)



Grid: 32 x 32 Points

E_{av} [lx]	E_{min} [lx]	E_{max} [lx]	u0	E_{min} / E_{max}
180	153	234	0.85	0.65

Calculation Surface 3 / Value Chart



203	203	202	202	196	196	195	195	185	185	182	182	175	175	170
203	203	202	202	196	196	195	195	185	185	182	182	175	175	170
198	198	197	197	191	191	188	188	177	177	174	174	167	167	163
198	198	197	197	191	191	188	188	177	177	174	174	167	167	163
205	205	204	204	196	196	193	193	181	181	178	178	171	171	168
205	205	204	204	196	196	193	193	181	181	178	178	171	171	168
200	200	199	199	191	191	189	189	177	177	174	174	167	167	163
200	200	199	199	191	191	189	189	177	177	174	174	167	167	163
195	195	192	192	185	185	182	182	173	173	169	169	162	162	159
195	195	192	192	185	185	182	182	173	173	169	169	162	162	159
196	196	194	194	187	187	183	183	172	172	168	168	162	162	159
196	196	194	194	187	187	183	183	172	172	168	168	162	162	159
192	192	188	188	179	179	176	176	168	168	163	163	158	158	154
192	192	188	188	179	179	176	176	168	168	163	163	158	158	154
185	182	178	178	179	173	174	173	162	166	158	157	153	162	159
206	226	189	234	202	194	206	212	183	173	156	170	167	183	177

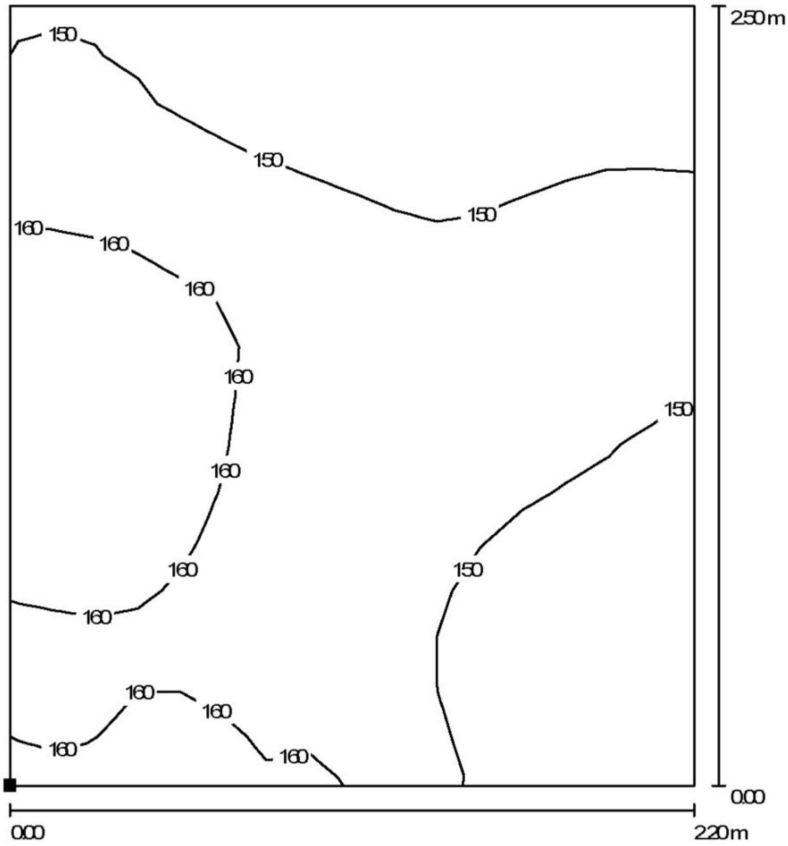
Values in Lux, Scale 1 : 20

Not all calculated values could be displayed.

Position of surface in room:
Marked point:
(21.558 m, 6.911 m, 0.000 m)

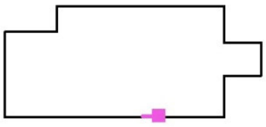
Grid: 32 x 32 Points

E_{av} [lx]	E_{min} [lx]	E_{max} [lx]	u0	E_{min} / E_{max}
180	153	234	0.85	0.65



Values in Lux, Scale 1 : 20

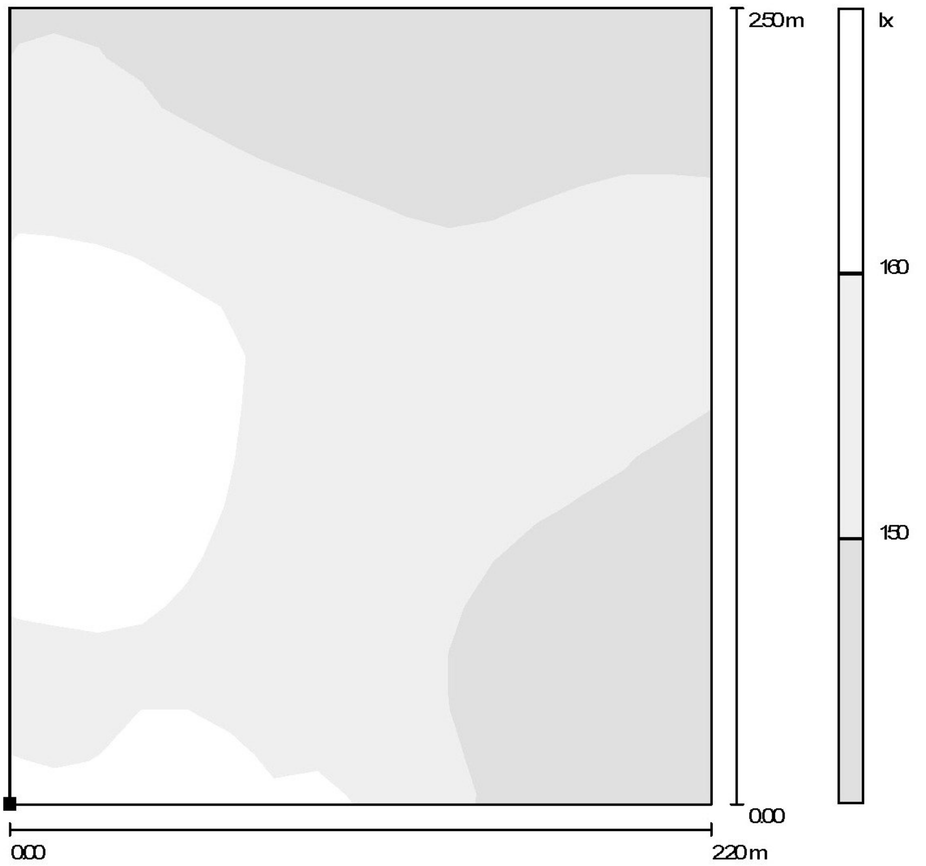
Position of surface in room:
Marked point:
(20.730 m, 0.175 m, 0.000 m)



Grid: 16 x 16 Points

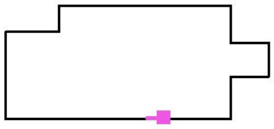
E_{av} [lx]	E_{min} [lx]	E_{max} [lx]	u0	E_{min} / E_{max}
153	141	169	0.92	0.83

Calculation Surface 4 / Greyscale



Scale 1 : 20

Position of surface in room:
Marked point:
(20.730 m, 0.175 m, 0.000 m)



Grid: 16 x 16 Points

E_{av} [lx]	E_{min} [lx]	E_{max} [lx]	u0	E_{min} / E_{max}
153	141	169	0.92	0.83

Calculation Surface 4 / Value Chart

2.50 m

150	150	150	150	145	145	145	145	141	141	141	141	145	145	145	145
150	150	150	150	145	145	145	145	141	141	141	141	145	145	145	145
152	152	152	152	147	147	147	147	143	143	143	143	147	147	147	147
152	152	152	152	147	147	147	147	143	143	143	143	147	147	147	147
163	163	163	163	158	158	158	158	154	154	154	154	158	158	158	158
163	163	163	163	158	158	158	158	154	154	154	154	158	158	158	158
164	164	165	165	161	161	160	160	154	154	152	152	155	155	151	151
164	164	165	165	161	161	160	160	154	154	152	152	155	155	151	151
162	162	162	162	158	158	158	158	153	153	151	151	150	150	148	148
162	162	162	162	158	158	158	158	153	153	151	151	150	150	148	148
164	164	164	164	160	160	159	159	155	155	150	150	151	151	149	149
164	164	164	164	160	160	159	159	155	155	150	150	151	151	149	149
158	158	159	159	157	157	156	156	149	149	145	145	146	146	143	143
158	158	159	159	157	157	156	156	149	149	145	145	146	146	143	143
156	156	161	161	158	158	158	158	154	154	149	149	148	148	149	149
163	159	161	169	167	161	158	167	154	154	149	149	148	148	149	149

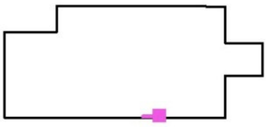
0.00

0.00

2.20 m

Values in Lux, Scale 1 : 20

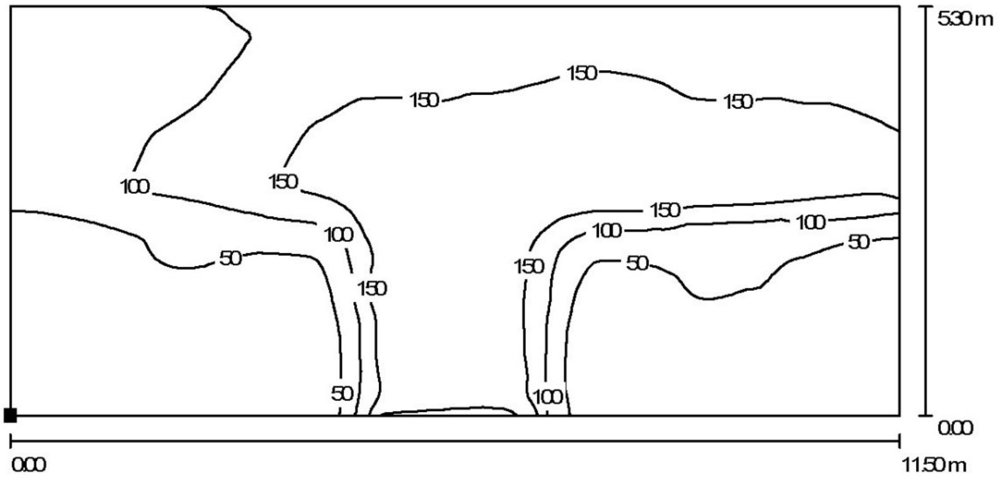
Position of surface in room:
Marked point:
(20.730 m, 0.175 m, 0.000 m)



Grid: 16 x 16 Points

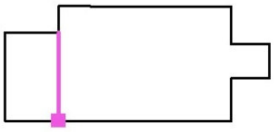
E_{av} [lx]	E_{min} [lx]	E_{max} [lx]	u0	E_{min} / E_{max}
153	141	169	0.92	0.83

Calculation Surface 5 / Isolines



Values in Lux, Scale 1 : 83

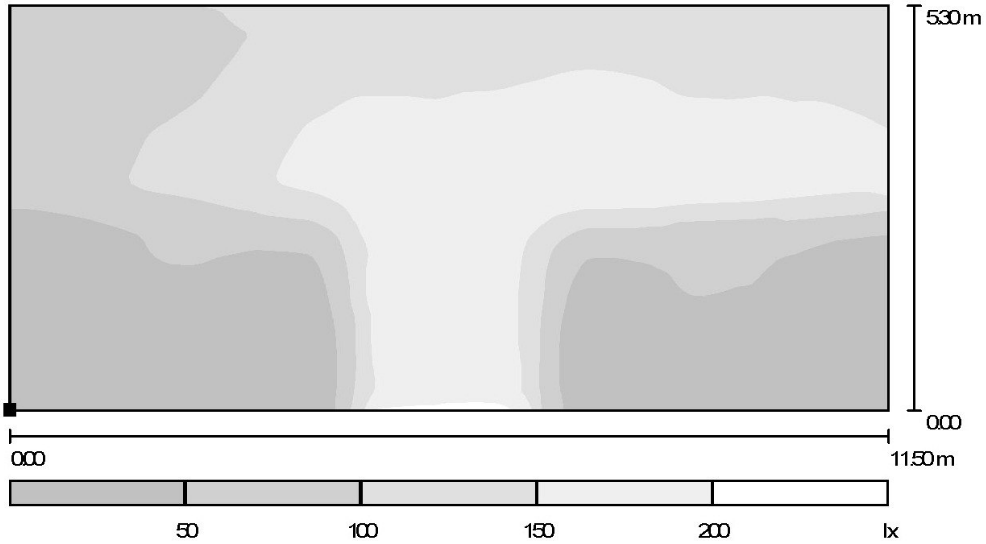
Position of surface in room:
Marked point:
(7.001 m, 0.000 m, 0.000 m)



Grid: 128 x 64 Points

E_{av} [lx]	E_{min} [lx]	E_{max} [lx]	u0	E_{min} / E_{max}
99	4.29	226	0.04	0.02

Calculation Surface 5 / Greyscale



Scale 1 : 83

Position of surface in room:
Marked point:
(7.001 m, 0.000 m, 0.000 m)

Grid: 128 x 64 Points

E_{av} [lx]	E_{min} [lx]	E_{max} [lx]	u0	E_{min} / E_{max}
99	4.29	226	0.04	0.02

Calculation Surface 5 / Value Chart

5.30 m

63	65	80	81	87	103	114	122	121	124	126	128	132	127	119	119	119	114
66	72	87	88	96	116	128	139	140	143	144	148	151	147	138	139	137	132
74	80	98	100	109	133	151	166	165	171	172	178	179	174	165	165	162	156
75	81	99	102	113	137	159	174	174	178	180	188	189	184	172	173	171	164
71	84	106	109	119	146	164	178	183	190	191	196	194	194	183	186	176	168
71	86	109	112	126	150	165	178	184	195	196	197	197	198	195	191	178	168
27	31	48	61	55	52	59	141	171	179	152	113	59	67	81	74	60	42
16	21	36	47	39	32	33	152	176	182	148	98	32	42	62	55	38	22
15	20	32	37	28	28	29	152	173	180	145	92	28	39	47	42	32	18
5.31	11	17	19	16	17	18	165	171	178	146	18	17	24	26	23	20	11
4.29	8.43	9.93	13	12	14	19	170	169	177	157	19	17	17	20	16	16	12
4.29	8.30	11	13	12	16	23	156	164	172	156	25	18	17	18	16	16	14

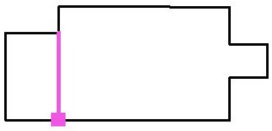
0.00

0.00 11.50 m

Values in Lux, Scale 1 : 83

Not all calculated values could be displayed.

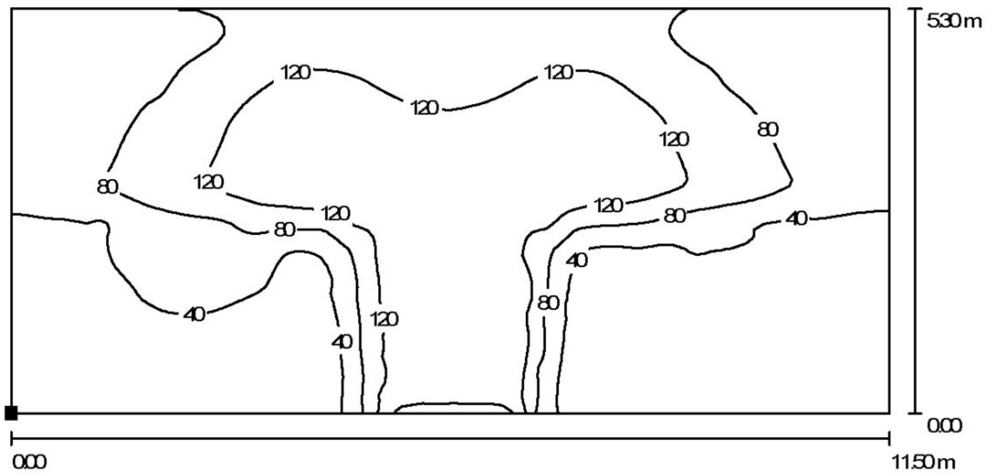
Position of surface in room:
Marked point:
(7.001 m, 0.000 m, 0.000 m)



Grid: 128 x 64 Points

E_{av} [lx]	E_{min} [lx]	E_{max} [lx]	u0	E_{min} / E_{max}
99	4.29	226	0.04	0.02

Calculation Surface 6 / Isolines



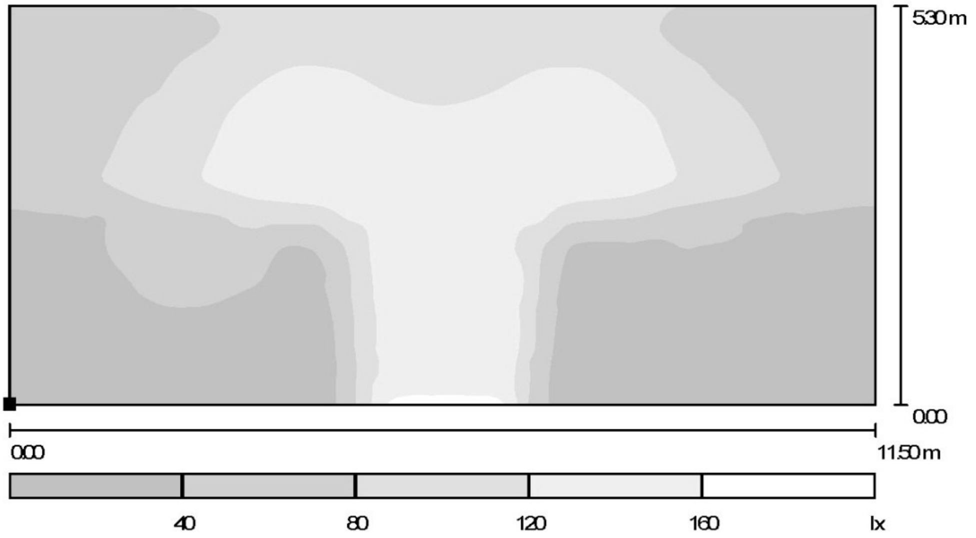
Values in Lux, Scale 1 : 83

Position of surface in room:
Marked point:
(6.559 m, 11.500 m, 0.000 m)

Grid: 128 x 64 Points

E_{av} [lx]	E_{min} [lx]	E_{max} [lx]	u0	E_{min} / E_{max}
76	3.20	192	0.04	0.02

Calculation Surface 6 / Greyscale



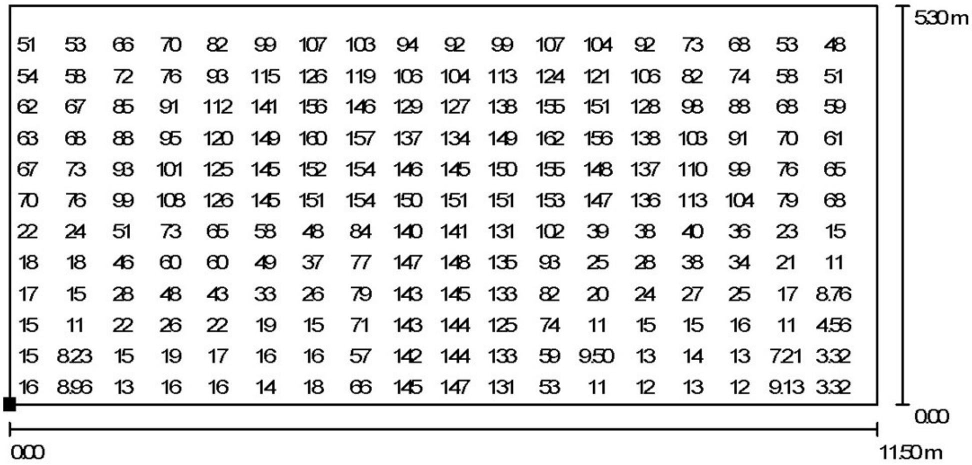
Scale 1 : 83

Position of surface in room:
Marked point:
(6.559 m, 11.500 m, 0.000 m)

Grid: 128 x 64 Points

E_{av} [lx]	E_{min} [lx]	E_{max} [lx]	u0	E_{min} / E_{max}
76	3.20	192	0.04	0.02

Calculation Surface 6 / Value Chart



51	53	66	70	82	99	107	103	94	92	99	107	104	92	73	68	53	48
54	58	72	76	93	115	126	119	106	104	113	124	121	106	82	74	58	51
62	67	85	91	112	141	156	146	129	127	138	155	151	128	98	88	68	59
63	68	88	95	120	149	160	157	137	134	149	162	156	138	103	91	70	61
67	73	93	101	125	145	152	154	146	145	150	155	148	137	110	99	76	65
70	76	99	108	126	145	151	154	150	151	151	153	147	136	113	104	79	68
22	24	51	73	65	58	48	84	140	141	131	102	39	38	40	36	23	15
18	18	46	60	60	49	37	77	147	148	135	93	25	28	38	34	21	11
17	15	28	48	43	33	26	79	143	145	133	82	20	24	27	25	17	8.76
15	11	22	26	22	19	15	71	143	144	125	74	11	15	15	16	11	4.56
15	8.23	15	19	17	16	16	57	142	144	133	59	9.50	13	14	13	7.21	3.32
16	8.96	13	16	16	14	18	66	145	147	131	53	11	12	13	12	9.13	3.32

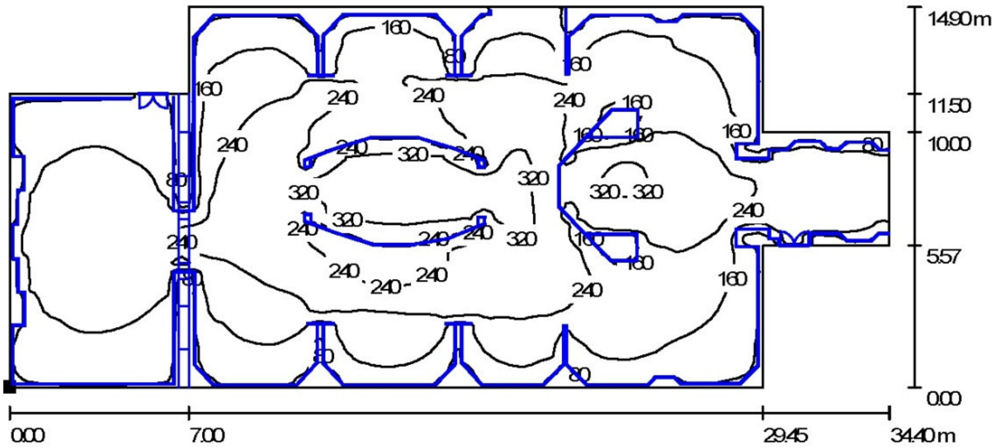
Values in Lux, Scale 1 : 83

Not all calculated values could be displayed.

Position of surface in room:
Marked point:
(6.559 m, 11.500 m, 0.000 m)

Grid: 128 x 64 Points

E_{av} [lx]	E_{min} [lx]	E_{max} [lx]	u0	E_{min} / E_{max}
76	3.20	192	0.04	0.02

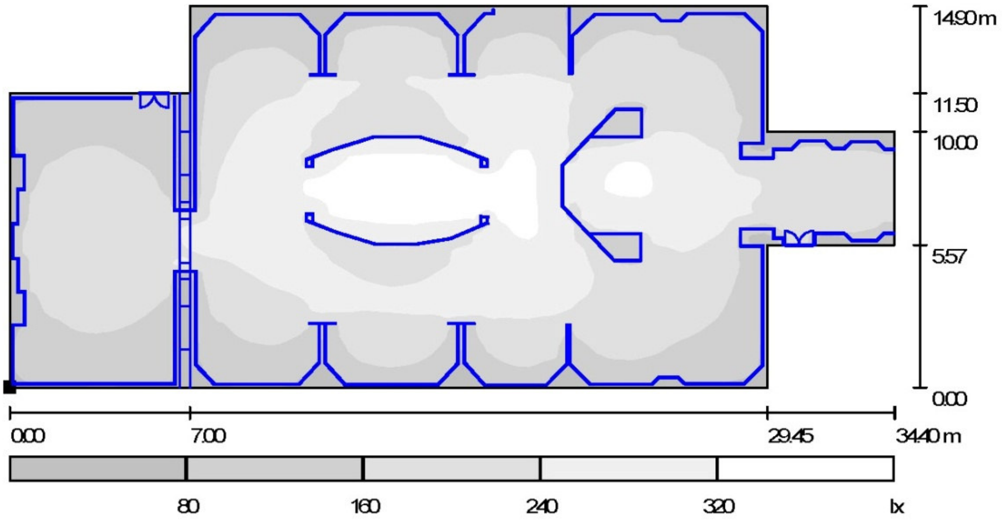


Values in Lux, Scale 1 : 246

Position of surface in room:
Marked point:
(0.000 m, 0.000 m, 0.000 m)

Grid: 128 x 128 Points

E_{av} [lx]	E_{min} [lx]	E_{max} [lx]	u0	E_{min} / E_{max}
195	6.10	398	0.03	0.02



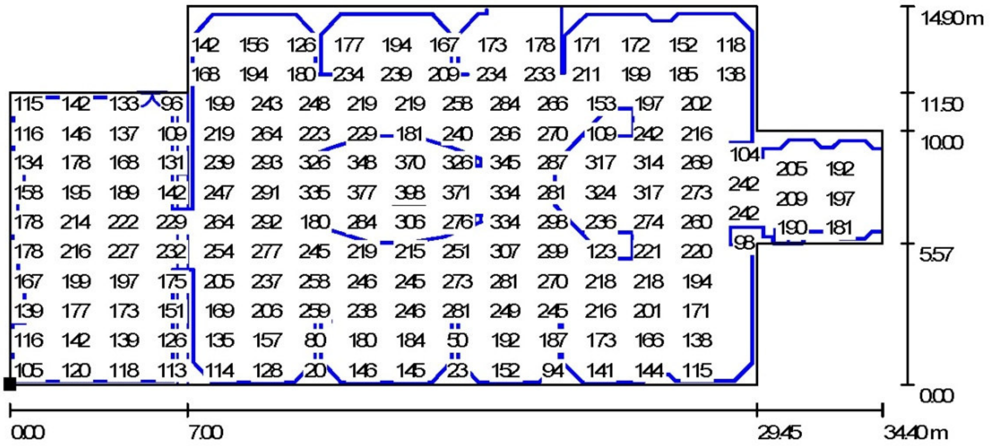
Scale 1 : 246

Position of surface in room:
Marked point:
(0.000 m, 0.000 m, 0.000 m)

Grid: 128 x 128 Points

E_{av} [lx]	E_{min} [lx]	E_{max} [lx]	u0	E_{min} / E_{max}
195	6.10	398	0.03	0.02

Floor / Value Chart (E)



Values in Lux, Scale 1 : 246

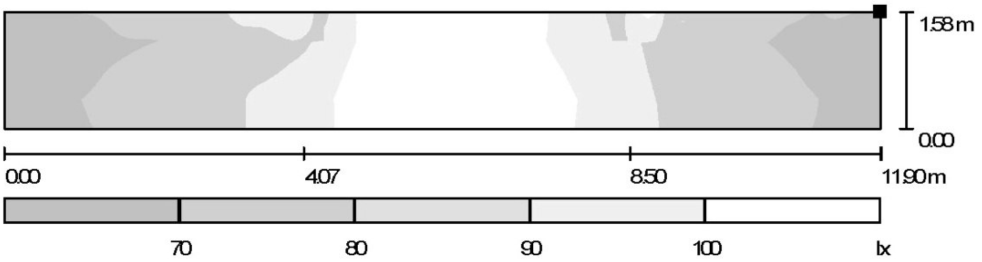
Not all calculated values could be displayed.

Position of surface in room:
Marked point:
(0.000 m, 0.000 m, 0.000 m)

Grid: 128 x 128 Points

E_{av} [lx]	E_{min} [lx]	E_{max} [lx]	u0	E_{min} / E_{max}
195	6.10	398	0.03	0.02

Ceiling / Greyscale (E)



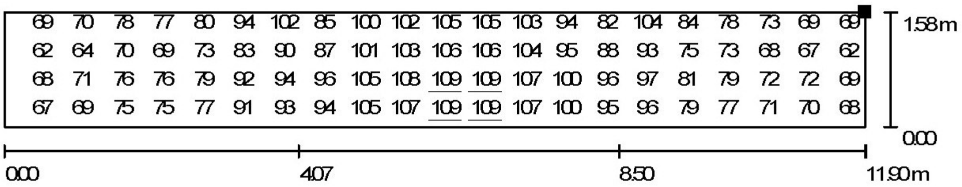
Scale 1 : 86

Position of surface in room:
Marked point:
(29.450 m, 13.400 m, 5.800 m)

Grid: 128 x 128 Points

E_{av} [lx]	E_{min} [lx]	E_{max} [lx]	u0	E_{min} / E_{max}
85	61	109	0.71	0.56

Ceiling / Value Chart (E)



69	70	78	77	80	94	102	85	100	102	105	105	103	94	82	104	84	78	73	69	69
62	64	70	69	73	83	90	87	101	103	106	106	104	95	88	93	75	73	68	67	62
68	71	76	76	79	92	94	96	105	108	109	109	107	100	96	97	81	79	72	72	69
67	69	75	75	77	91	93	94	105	107	109	109	107	100	95	96	79	77	71	70	68

Values in Lux, Scale 1 : 86

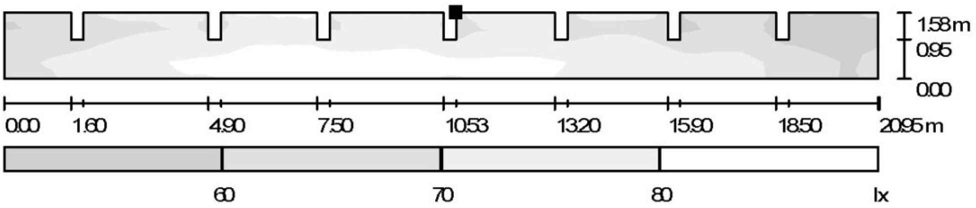
Not all calculated values could be displayed.

Position of surface in room:
Marked point:
(29.450 m, 13.400 m, 5.800 m)

Grid: 128 x 128 Points

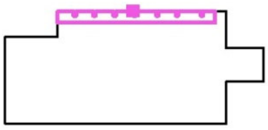
E_{av} [lx]	E_{min} [lx]	E_{max} [lx]	u0	E_{min} / E_{max}
85	61	109	0.71	0.56

Ceiling / Greyscale (E)



Scale 1 : 150

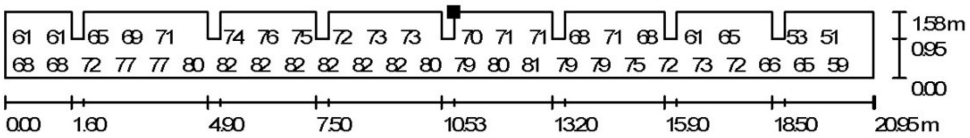
Position of surface in room:
Marked point:
(17.120 m, 14.900 m, 5.800 m)



Grid: 128 x 128 Points

E_{av} [lx]	E_{min} [lx]	E_{max} [lx]	u0	E_{min} / E_{max}
72	49	87	0.68	0.56

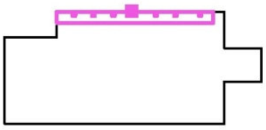
Ceiling / Value Chart (E)



Values in Lux, Scale 1 : 150

Not all calculated values could be displayed.

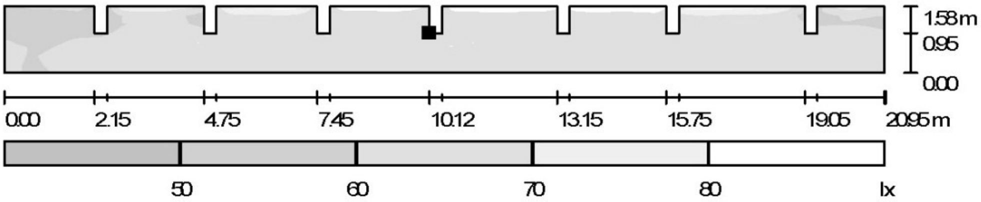
Position of surface in room:
Marked point:
(17.120 m, 14.900 m, 5.800 m)



Grid: 128 x 128 Points

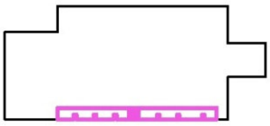
E_{av} [lx]	E_{min} [lx]	E_{max} [lx]	u0	E_{min} / E_{max}
72	49	87	0.68	0.56

Ceiling / Greyscale (E)



Scale 1 : 150

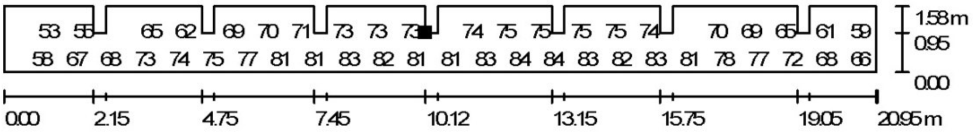
Position of surface in room:
Marked point:
(17.120 m, 0.600 m, 5.600 m)



Grid: 128 x 128 Points

E_{av} [lx]	E_{min} [lx]	E_{max} [lx]	u0	E_{min} / E_{max}
73	45	90	0.61	0.50

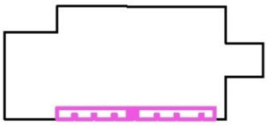
Ceiling / Value Chart (E)



Values in Lux, Scale 1 : 150

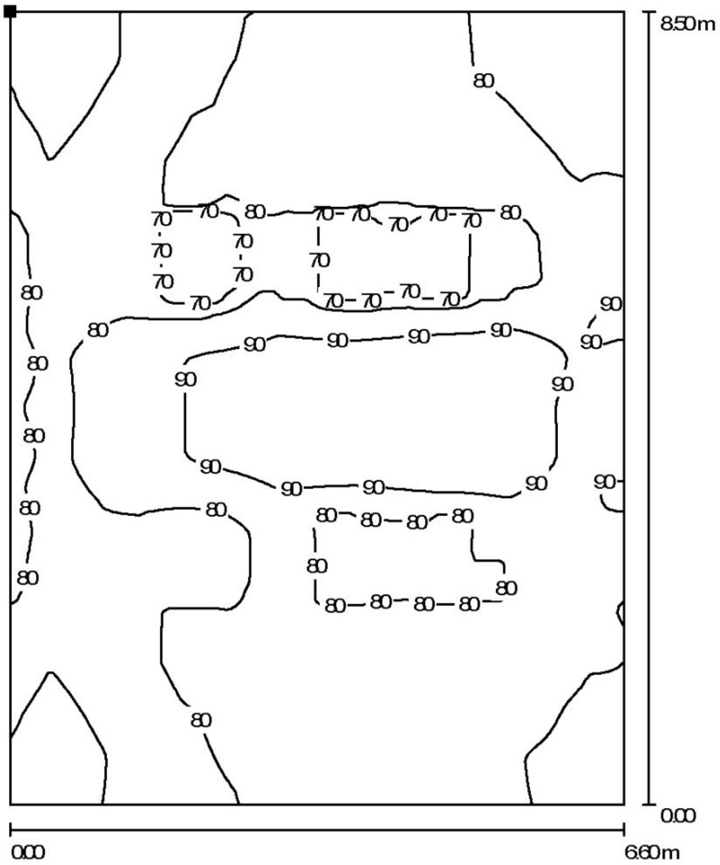
Not all calculated values could be displayed.

Position of surface in room:
Marked point:
(17.120 m, 0.600 m, 5.600 m)



Grid: 128 x 128 Points

E_{av} [lx]	E_{min} [lx]	E_{max} [lx]	u0	E_{min} / E_{max}
73	45	90	0.61	0.50



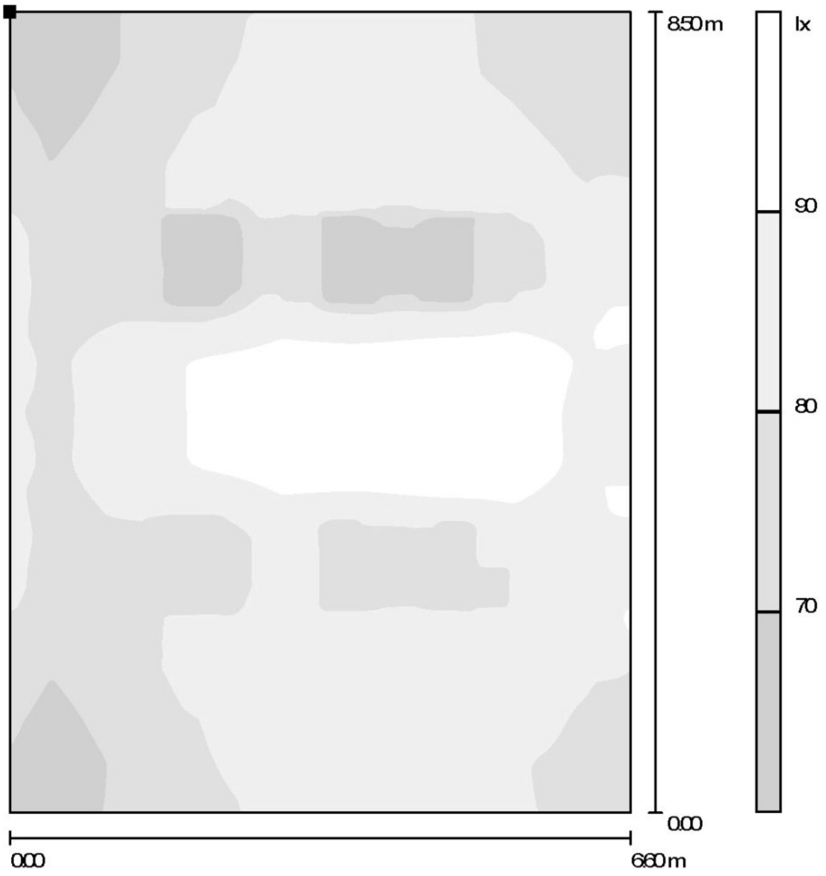
Values in Lux, Scale 1 : 67

Position of surface in room:
Marked point:
(0.000 m, 1.500 m, 5.300 m)

Grid: 128 x 128 Points

E_{av} [lx]	E_{min} [lx]	E_{max} [lx]	u0	E_{min} / E_{max}
81	61	98	0.75	0.63

Ceiling / Greyscale (E)



Scale 1 : 67

Position of surface in room:
Marked point:
(0.000 m, 1.500 m, 5.300 m)

Grid: 128 x 128 Points

E_{av} [lx]	E_{min} [lx]	E_{max} [lx]	u0	E_{min} / E_{max}
81	61	98	0.75	0.63

8.50m

69	64	64	70	71	78	78	78	80	80	80	82	82	82	82	82	77	76	76	72	70
69	64	64	70	71	78	78	78	80	80	80	82	82	82	82	82	77	76	76	72	71
71	66	66	70	71	78	78	78	80	80	80	82	82	82	82	82	77	77	77	72	70
72	68	68	75	76	83	83	83	85	85	85	88	88	88	88	88	84	84	84	75	74
75	68	68	75	76	83	83	83	85	85	85	88	88	88	88	88	84	84	84	75	74
76	71	71	76	77	83	83	84	85	85	85	88	88	88	88	88	85	86	86	80	81
84	76	76	73	71	61	61	63	78	78	78	65	65	66	66	66	76	79	79	83	84
83	76	76	73	71	61	61	63	78	78	78	65	65	66	66	66	76	79	79	83	83
83	77	77	73	73	62	62	63	78	78	78	65	65	66	66	66	77	79	79	82	85
83	77	77	73	73	62	62	63	78	78	78	65	65	66	66	66	77	79	79	82	84
82	78	78	85	85	91	91	92	94	94	94	96	96	98	98	98	95	96	96	90	90
85	78	78	85	86	91	91	91	94	94	94	96	96	98	98	98	95	96	96	87	86
82	78	78	85	86	91	91	91	94	94	94	96	96	98	98	98	95	96	96	87	86
82	78	78	85	86	91	91	91	94	94	94	96	96	98	98	98	94	95	95	86	85
82	78	78	85	85	91	91	91	94	94	94	96	96	98	98	98	94	95	95	88	88
81	78	78	85	85	91	91	91	94	94	94	96	96	98	98	98	94	95	95	88	94
83	77	77	77	78	72	72	72	83	83	83	75	75	76	76	76	83	84	84	82	83
83	77	77	77	78	72	72	72	83	83	83	75	75	76	76	76	83	84	84	82	85
82	77	77	77	73	70	70	72	83	83	83	75	75	76	76	76	79	84	84	83	85
76	71	71	77	77	84	84	85	86	86	86	88	88	88	88	88	87	88	88	84	89
76	71	71	77	77	84	84	85	86	86	86	88	88	88	88	88	87	88	88	84	86
74	69	69	76	76	84	84	84	86	86	86	88	88	88	88	88	87	88	88	80	79
71	66	66	72	72	79	79	79	81	81	81	83	83	83	83	83	81	81	81	78	76
70	66	66	72	72	79	79	79	81	81	81	83	83	83	83	83	81	81	81	78	76
70	64	64	71	71	79	79	79	81	81	81	83	83	83	83	83	80	81	81	77	76

0.00

0.00

6.60m

Values in Lux, Scale 1 : 67

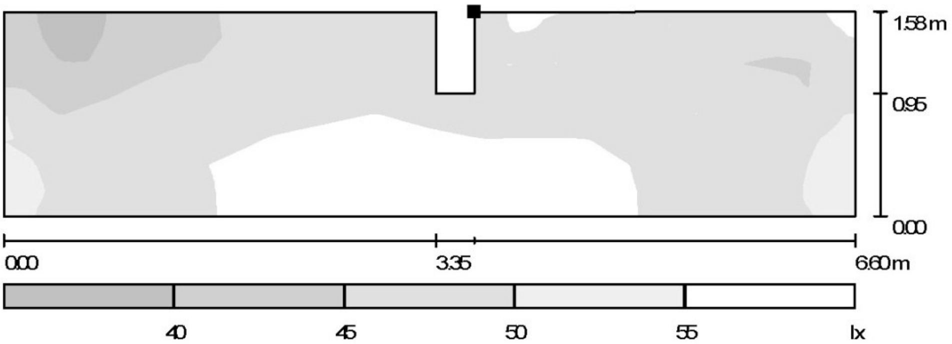
Not all calculated values could be displayed.

Position of surface in room:
Marked point:
(0.000 m, 1.500 m, 5.300 m)

Grid: 128 x 128 Points

E_{av} [lx]	E_{min} [lx]	E_{max} [lx]	u0	E_{min} / E_{max}
81	61	98	0.75	0.63

Ceiling / Greyscale (E)



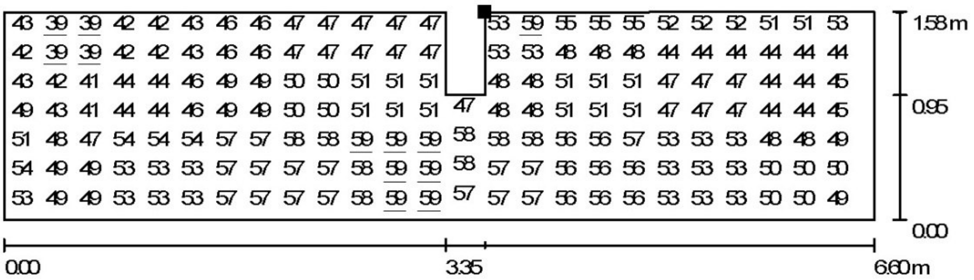
Scale 1 : 48

Position of surface in room:
Marked point:
(2.950 m, 11.500 m, 5.800 m)

Grid: 128 x 128 Points

E_{av} [lx]	E_{min} [lx]	E_{max} [lx]	u0	E_{min} / E_{max}
51	39	59	0.76	0.65

Ceiling / Value Chart (E)



43	39	39	42	42	43	46	46	47	47	47	47	47		53	59	55	55	55	52	52	52	51	51	53
42	39	39	42	42	43	46	46	47	47	47	47	47		53	53	48	48	48	44	44	44	44	44	44
43	42	41	44	44	46	49	49	50	50	51	51	51		48	48	51	51	51	47	47	47	44	44	45
49	43	41	44	44	46	49	49	50	50	51	51	51	47	48	48	51	51	51	47	47	47	44	44	45
51	48	47	54	54	54	57	57	58	58	59	59	59	58	58	58	56	56	57	53	53	53	48	48	49
54	49	49	53	53	53	57	57	57	57	58	59	59	58	57	57	56	56	56	53	53	53	50	50	50
53	49	49	53	53	53	57	57	57	57	58	59	59	57	57	57	56	56	56	53	53	53	50	50	49

Values in Lux, Scale 1 : 48

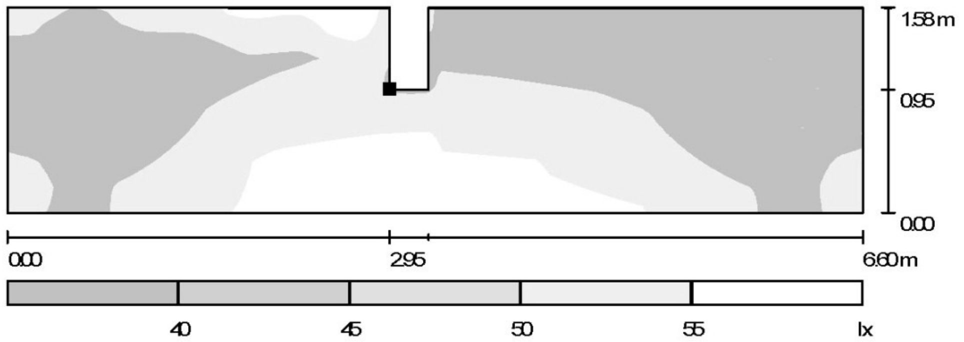
Not all calculated values could be displayed.

Position of surface in room:
Marked point:
(2.950 m, 11.500 m, 5.800 m)

Grid: 128 x 128 Points

E_{av} [lx]	E_{min} [lx]	E_{max} [lx]	u0	E_{min} / E_{max}
51	39	59	0.76	0.65

Ceiling / Greyscale (E)



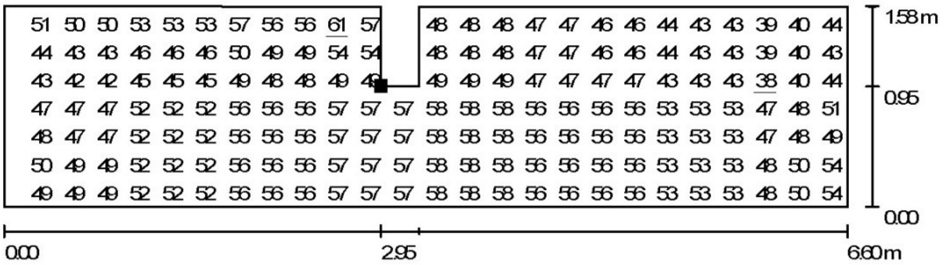
Scale 1 : 48

Position of surface in room:
Marked point:
(2.950 m, 0.600 m, 5.600 m)

Grid: 128 x 128 Points

E_{av} [lx]	E_{min} [lx]	E_{max} [lx]	u0	E_{min} / E_{max}
50	38	61	0.75	0.62

Ceiling / Value Chart (E)



51	50	50	53	53	53	57	56	56	61	57		48	48	48	47	47	46	46	44	43	43	39	40	44
44	43	43	46	46	46	50	49	49	54	54		48	48	48	47	47	46	46	44	43	43	39	40	43
43	42	42	45	45	45	49	48	48	49	49		49	49	49	47	47	47	47	43	43	43	38	40	44
47	47	47	52	52	52	56	56	56	57	57	57	58	58	58	56	56	56	56	53	53	53	47	48	51
48	47	47	52	52	52	56	56	56	57	57	57	58	58	58	56	56	56	56	53	53	53	47	48	49
50	49	49	52	52	52	56	56	56	57	57	57	58	58	58	56	56	56	56	53	53	53	48	50	54
49	49	49	52	52	52	56	56	56	57	57	57	58	58	58	56	56	56	56	53	53	53	48	50	54

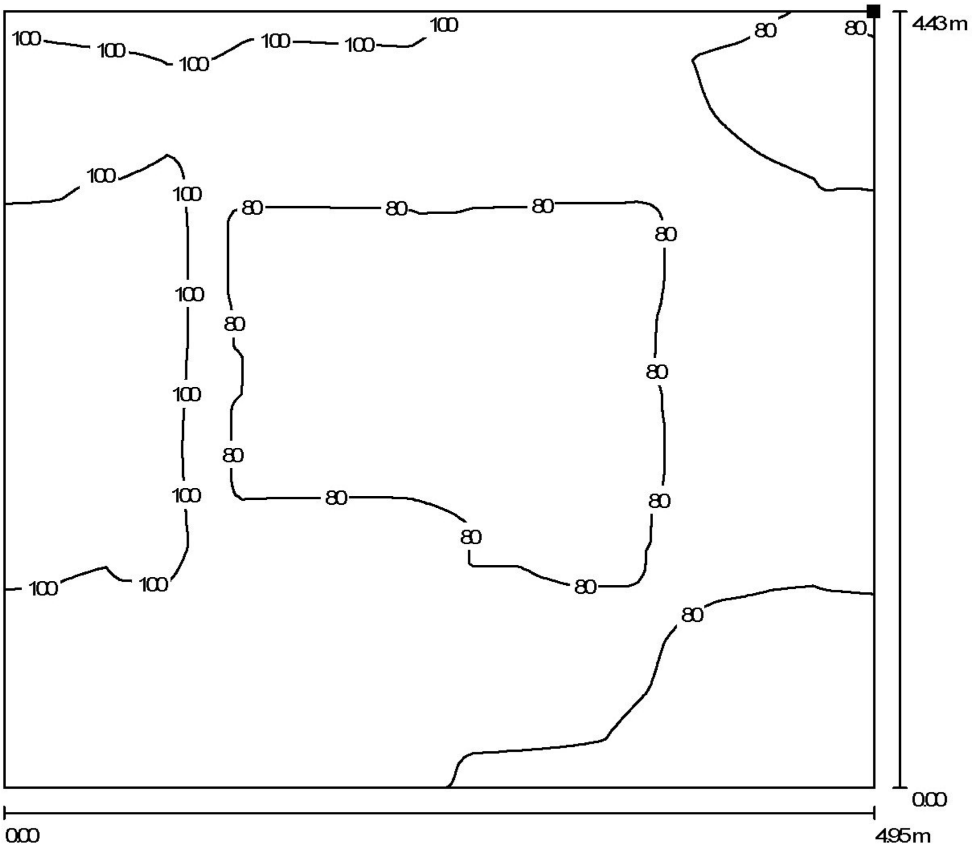
Values in Lux, Scale 1 : 48

Not all calculated values could be displayed.

Position of surface in room:
Marked point:
(2.950 m, 0.600 m, 5.600 m)

Grid: 128 x 128 Points

E_{av} [lx]	E_{min} [lx]	E_{max} [lx]	u0	E_{min} / E_{max}
50	38	61	0.75	0.62



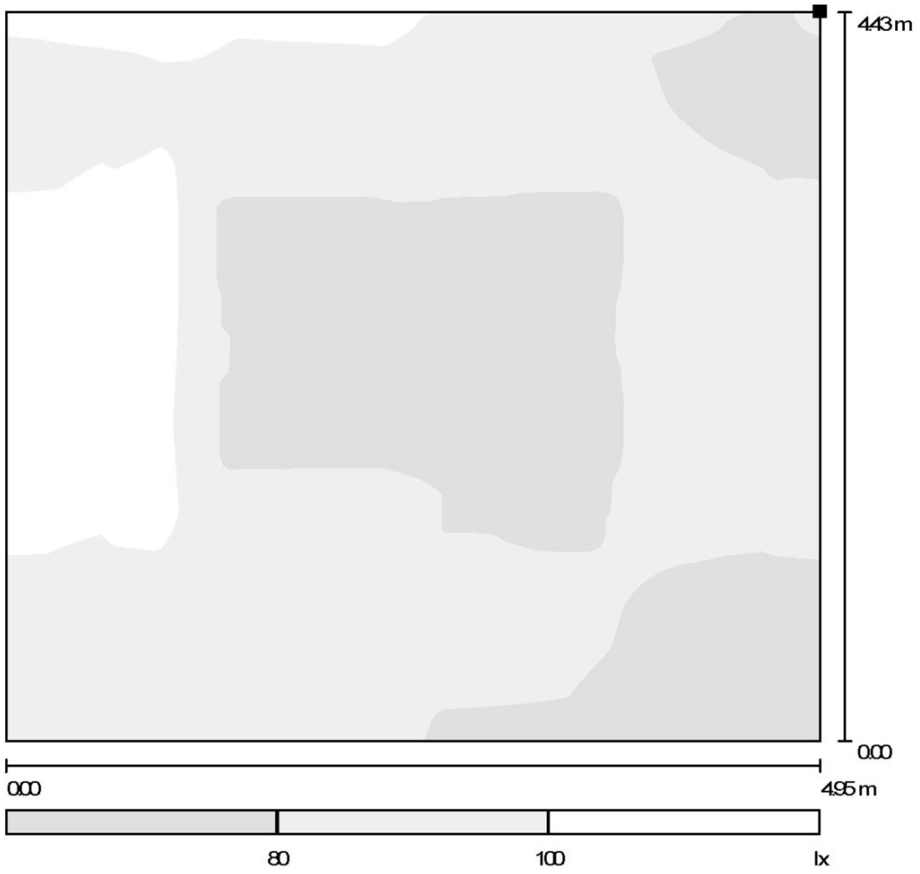
Values in Lux, Scale 1 : 36

Position of surface in room:
Marked point:
(34.400 m, 5.570 m, 5.800 m)

Grid: 128 x 128 Points

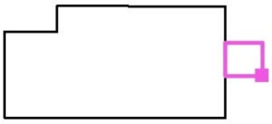
E_{av} [lx]	E_{min} [lx]	E_{max} [lx]	u0	E_{min} / E_{max}
87	62	112	0.71	0.55

Ceiling / Greyscale (E)



Scale 1 : 38

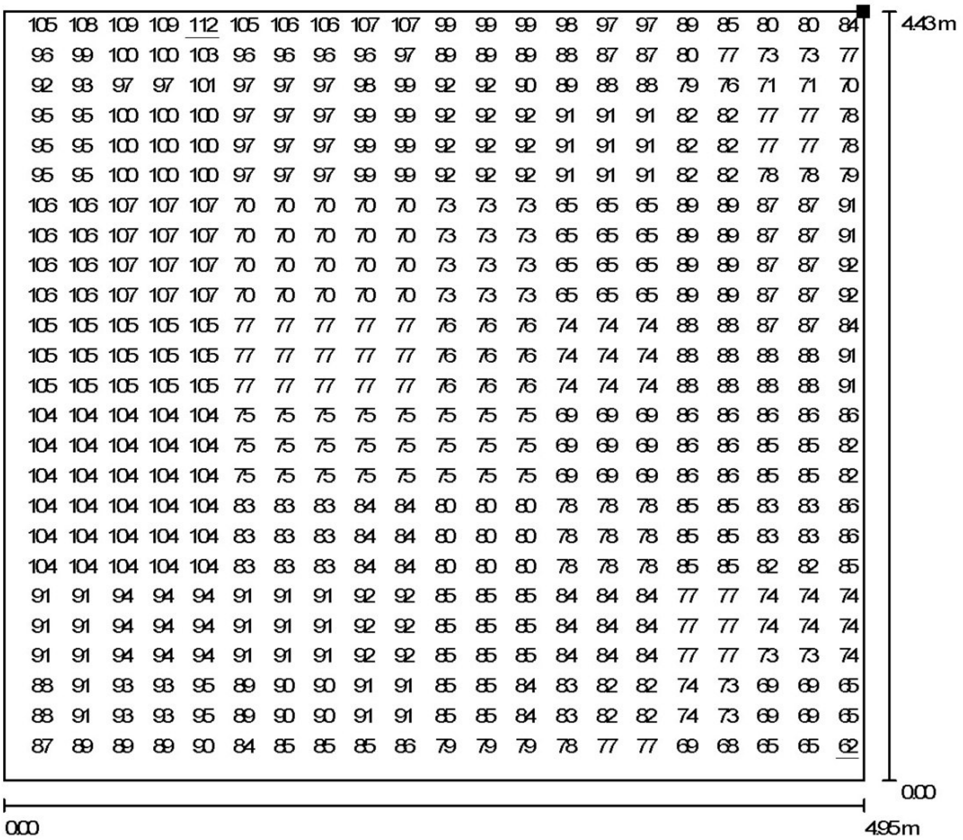
Position of surface in room:
Marked point:
(34.400 m, 5.570 m, 5.800 m)



Grid: 128 x 128 Points

E_{av} [lx]	E_{min} [lx]	E_{max} [lx]	u0	E_{min} / E_{max}
87	62	112	0.71	0.55

Ceiling / Value Chart (E)



105	108	109	109	112	105	106	106	107	107	99	99	99	98	97	97	89	85	80	80	84
96	99	100	100	103	96	96	96	96	97	89	89	89	88	87	87	80	77	73	73	77
92	93	97	97	101	97	97	97	98	99	92	92	90	89	88	88	79	76	71	71	70
95	95	100	100	100	97	97	97	99	99	92	92	92	91	91	91	82	82	77	77	78
95	95	100	100	100	97	97	97	99	99	92	92	92	91	91	91	82	82	77	77	78
95	95	100	100	100	97	97	97	99	99	92	92	92	91	91	91	82	82	78	78	79
106	106	107	107	107	70	70	70	70	70	73	73	73	65	65	65	89	89	87	87	91
106	106	107	107	107	70	70	70	70	70	73	73	73	65	65	65	89	89	87	87	91
106	106	107	107	107	70	70	70	70	70	73	73	73	65	65	65	89	89	87	87	92
106	106	107	107	107	70	70	70	70	70	73	73	73	65	65	65	89	89	87	87	92
105	105	105	105	105	77	77	77	77	77	76	76	76	74	74	74	88	88	87	87	84
105	105	105	105	105	77	77	77	77	77	76	76	76	74	74	74	88	88	88	88	91
105	105	105	105	105	77	77	77	77	77	76	76	76	74	74	74	88	88	88	88	91
104	104	104	104	104	75	75	75	75	75	75	75	75	69	69	69	86	86	86	86	86
104	104	104	104	104	75	75	75	75	75	75	75	75	69	69	69	86	86	85	85	82
104	104	104	104	104	75	75	75	75	75	75	75	75	69	69	69	86	86	85	85	82
104	104	104	104	104	83	83	83	84	84	80	80	80	78	78	78	85	85	83	83	86
104	104	104	104	104	83	83	83	84	84	80	80	80	78	78	78	85	85	83	83	86
104	104	104	104	104	83	83	83	84	84	80	80	80	78	78	78	85	85	82	82	85
91	91	94	94	94	91	91	91	92	92	85	85	85	84	84	84	77	77	74	74	74
91	91	94	94	94	91	91	91	92	92	85	85	85	84	84	84	77	77	74	74	74
91	91	94	94	94	91	91	91	92	92	85	85	85	84	84	84	77	77	73	73	74
88	91	93	93	95	89	90	90	91	91	85	85	84	83	82	82	74	73	69	69	65
88	91	93	93	95	89	90	90	91	91	85	85	84	83	82	82	74	73	69	69	65
87	89	89	89	90	84	85	85	85	86	79	79	79	78	77	77	69	68	65	65	62

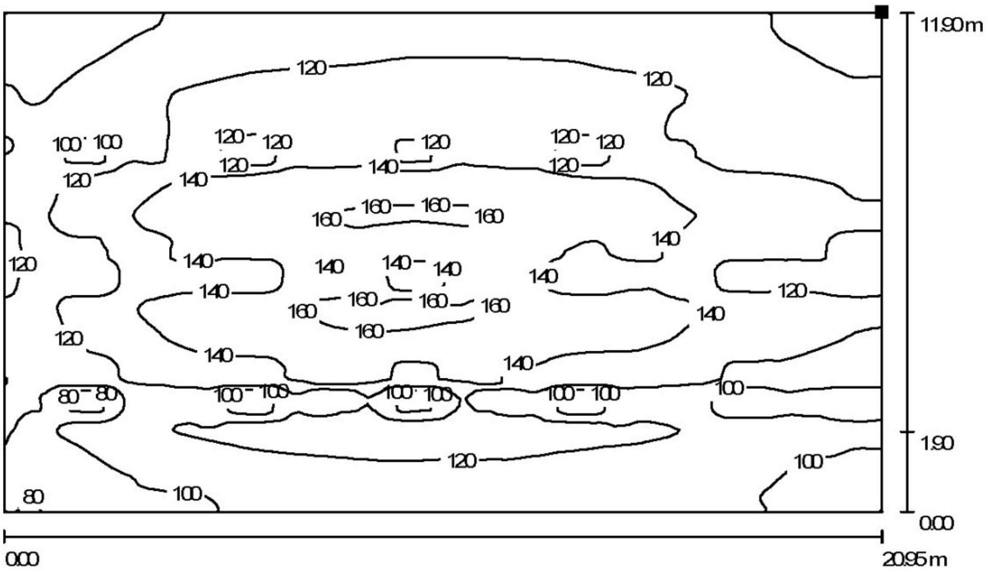
Values in Lux, Scale 1 : 36

Not all calculated values could be displayed.

Position of surface in room:
Marked point:
(34.400 m, 5.570 m, 5.800 m)

Grid: 128 x 128 Points

E_{av} [lx]	E_{min} [lx]	E_{max} [lx]	u0	E_{min} / E_{max}
87	62	112	0.71	0.55



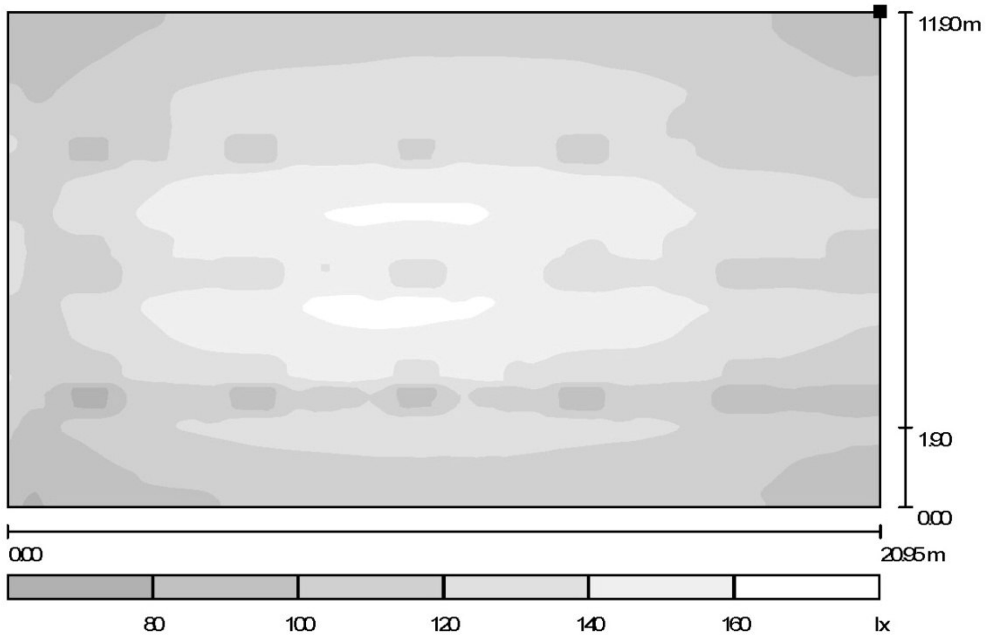
Values in Lux, Scale 1 : 150

Position of surface in room:
Marked point:
(27.950 m, 1.500 m, 5.300 m)

Grid: 128 x 128 Points

E_{av} [lx]	E_{min} [lx]	E_{max} [lx]	u0	E_{min} / E_{max}
123	77	165	0.62	0.47

Ceiling / Greyscale (E)



Scale 1 : 150

Position of surface in room:
Marked point:
(27.950 m, 1.500 m, 5.300 m)

Grid: 128 x 128 Points

E_{av} [lx]	E_{min} [lx]	E_{max} [lx]	u0	E_{min} / E_{max}
123	77	165	0.62	0.47

Ceiling / Value Chart (E)

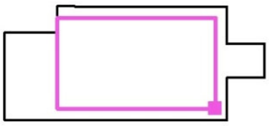
83	93	99	99	102	106	110	110	110	112	111	113	113	114	110	111	106	104	95	95	90
87	98	105	105	109	114	116	116	118	121	120	121	120	120	115	117	110	108	100	100	95
94	107	116	117	122	127	129	129	131	133	133	133	130	130	126	126	120	118	109	109	103
101	103	118	118	124	122	130	130	132	126	135	134	131	122	126	125	118	110	107	108	102
110	98	119	118	125	114	134	132	136	118	136	134	133	114	126	124	120	104	108	107	103
113	126	137	137	144	151	155	156	157	157	157	157	151	148	144	143	136	131	124	124	118
114	130	142	142	149	153	157	158	160	161	162	161	157	155	148	148	140	135	126	126	122
114	118	136	137	144	142	154	155	157	149	156	154	150	142	142	145	136	124	122	123	118
115	103	127	127	136	123	148	140	150	128	148	144	143	124	135	133	128	110	117	115	113
114	128	141	142	151	157	161	162	164	165	164	162	156	155	149	153	142	138	128	128	123
111	125	136	136	145	152	158	159	160	160	157	157	151	149	144	147	138	134	125	125	119
108	111	126	126	132	133	142	142	145	137	143	143	139	130	132	132	128	118	116	116	110
100	78	104	104	112	94	118	115	120	96	121	117	116	95	112	109	105	86	96	96	92
96	106	116	117	123	128	129	129	130	132	133	132	128	127	124	123	119	117	109	109	104
87	95	105	105	109	114	117	117	117	119	118	119	117	115	112	114	108	107	99	100	95
82	89	98	98	98	104	107	107	109	109	109	110	109	109	106	108	103	102	95	95	91

11.90m
1.90
0.00
0.00
20.95m

Values in Lux, Scale 1 : 150

Not all calculated values could be displayed.

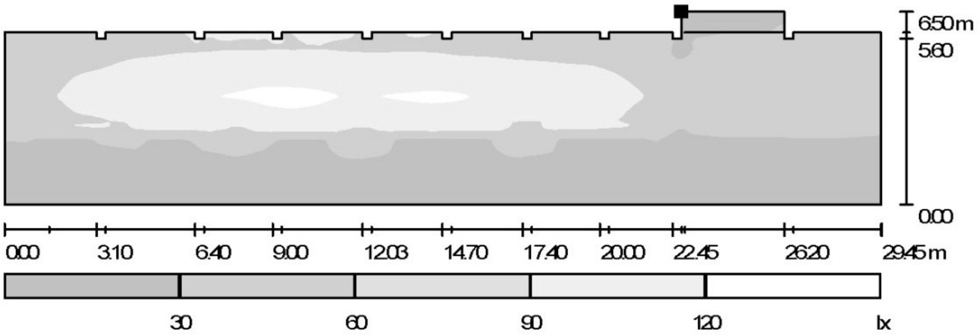
Position of surface in room:
Marked point:
(27.950 m, 1.500 m, 5.300 m)



Grid: 128 x 128 Points

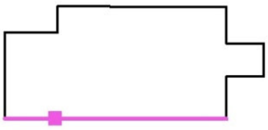
E_{av} [lx]	E_{min} [lx]	E_{max} [lx]	u0	E_{min} / E_{max}
123	77	165	0.62	0.47

Wall / Greyscale (E)



Scale 1 : 211

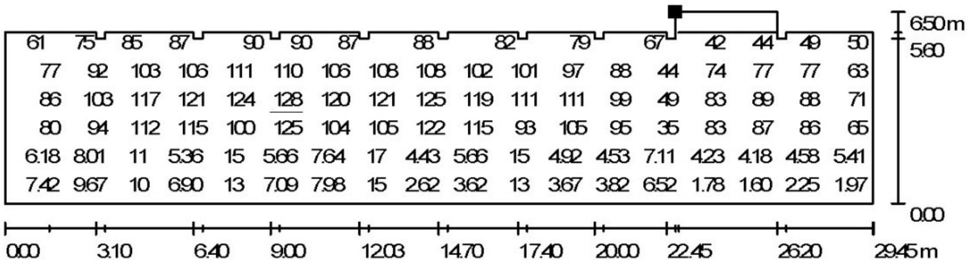
Position of surface in room:
Marked point:
(6.700 m, 0.000 m, 6.500 m)



Grid: 128 x 128 Points

E_{av} [lx]	E_{min} [lx]	E_{max} [lx]	u0	E_{min} / E_{max}
56	1.44	128	0.03	0.01

Wall / Value Chart (E)

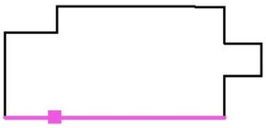


61	75	85	87	90	90	87		88		82	79		67	42	44	49	50
77	92	103	106	111	110	106	108	108	102	101	97	88	44	74	77	77	63
86	103	117	121	124	128	120	121	125	119	111	111	99	49	83	89	88	71
80	94	112	115	100	125	104	105	122	115	93	105	95	35	83	87	86	65
6.18	8.01	11	5.36	15	5.66	7.64	17	4.43	5.66	15	4.92	4.53	7.11	4.23	4.18	4.58	5.41
7.42	9.67	10	6.90	13	7.09	7.98	15	2.62	3.62	13	3.67	3.82	6.52	1.78	1.60	2.25	1.97

Values in Lux, Scale 1 : 211

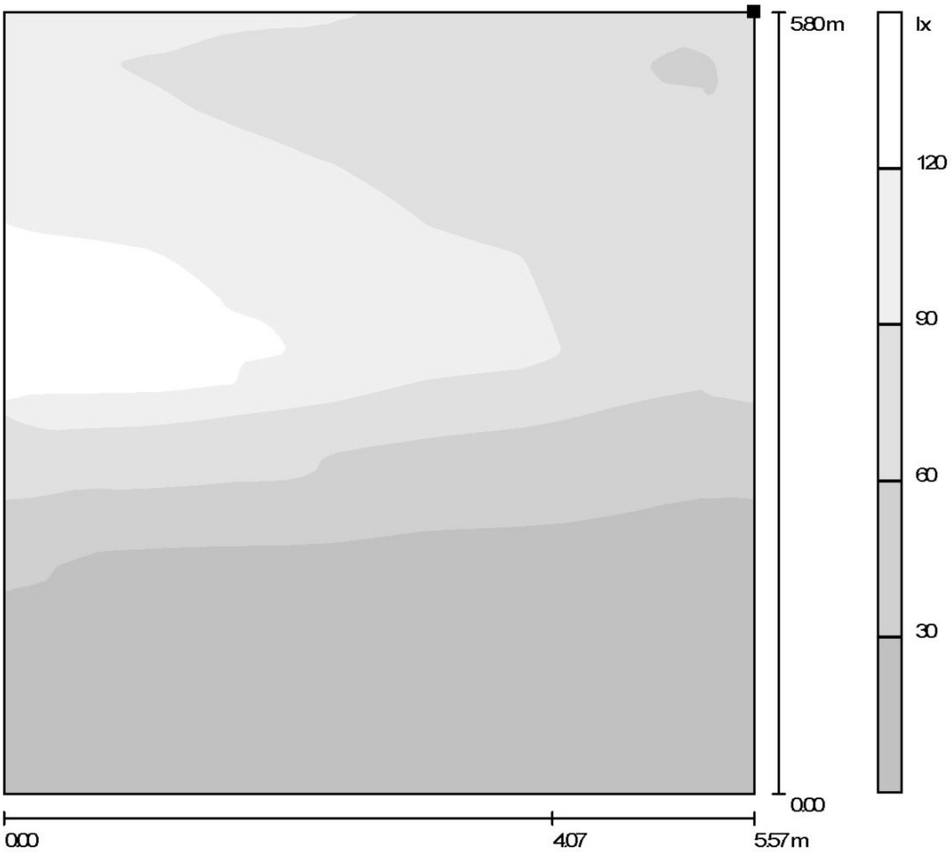
Not all calculated values could be displayed.

Position of surface in room:
Marked point:
(6.700 m, 0.000 m, 6.500 m)



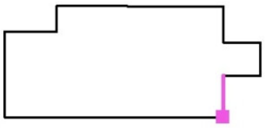
Grid: 128 x 128 Points

E_{av} [lx]	E_{min} [lx]	E_{max} [lx]	u0	E_{min} / E_{max}
56	1.44	128	0.03	0.01



Scale 1 : 46

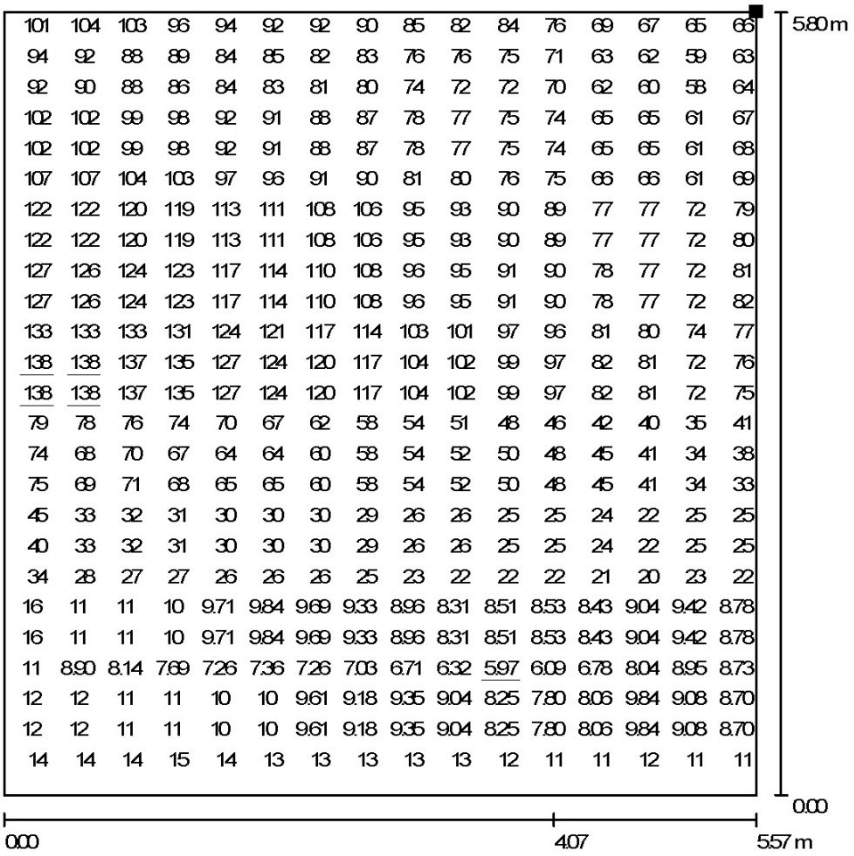
Position of surface in room:
Marked point:
(29.450 m, 0.000 m, 5.800 m)



Grid: 128 x 128 Points

E_{av} [lx]	E_{min} [lx]	E_{max} [lx]	u0	E_{min} / E_{max}
59	5.97	138	0.10	0.04

Wall / Value Chart (E)



101	104	103	96	94	92	92	90	85	82	84	76	69	67	65	66
94	92	88	89	84	85	82	83	76	76	75	71	63	62	59	63
92	90	88	86	84	83	81	80	74	72	72	70	62	60	58	64
102	102	99	98	92	91	88	87	78	77	75	74	65	65	61	67
102	102	99	98	92	91	88	87	78	77	75	74	65	65	61	68
107	107	104	103	97	96	91	90	81	80	76	75	66	66	61	69
122	122	120	119	113	111	108	106	95	93	90	89	77	77	72	79
122	122	120	119	113	111	108	106	95	93	90	89	77	77	72	80
127	126	124	123	117	114	110	108	96	95	91	90	78	77	72	81
127	126	124	123	117	114	110	108	96	95	91	90	78	77	72	82
133	133	133	131	124	121	117	114	103	101	97	96	81	80	74	77
138	138	137	135	127	124	120	117	104	102	99	97	82	81	72	76
138	138	137	135	127	124	120	117	104	102	99	97	82	81	72	75
79	78	76	74	70	67	62	58	54	51	48	46	42	40	35	41
74	68	70	67	64	64	60	58	54	52	50	48	45	41	34	38
75	69	71	68	65	65	60	58	54	52	50	48	45	41	34	33
45	33	32	31	30	30	30	29	26	26	25	25	24	22	25	25
40	33	32	31	30	30	30	29	26	26	25	25	24	22	25	25
34	28	27	27	26	26	26	25	23	22	22	22	21	20	23	22
16	11	11	10	9.71	9.84	9.69	9.33	8.96	8.31	8.51	8.53	8.43	9.04	9.42	8.78
16	11	11	10	9.71	9.84	9.69	9.33	8.96	8.31	8.51	8.53	8.43	9.04	9.42	8.78
11	8.90	8.14	7.69	7.26	7.36	7.26	7.03	6.71	6.32	5.97	6.09	6.78	8.04	8.95	8.73
12	12	11	11	10	10	9.61	9.18	9.35	9.04	8.25	7.80	8.06	9.84	9.08	8.70
12	12	11	11	10	10	9.61	9.18	9.35	9.04	8.25	7.80	8.06	9.84	9.08	8.70
14	14	14	15	14	13	13	13	13	13	12	11	11	12	11	11

Values in Lux, Scale 1 : 46

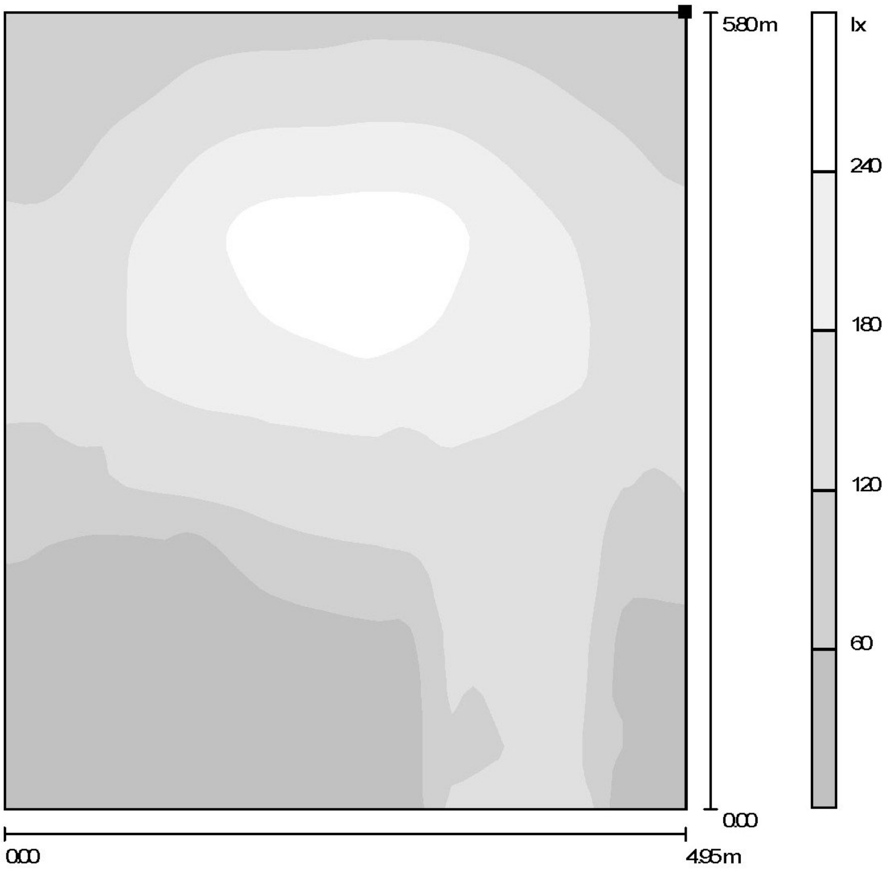
Not all calculated values could be displayed.

Position of surface in room:
Marked point:
(29.450 m, 0.000 m, 5.800 m)

Grid: 128 x 128 Points

E_{av} [lx]	E_{min} [lx]	E_{max} [lx]	u0	E_{min} / E_{max}
59	5.97	138	0.10	0.04

Wall / Greyscale (E)

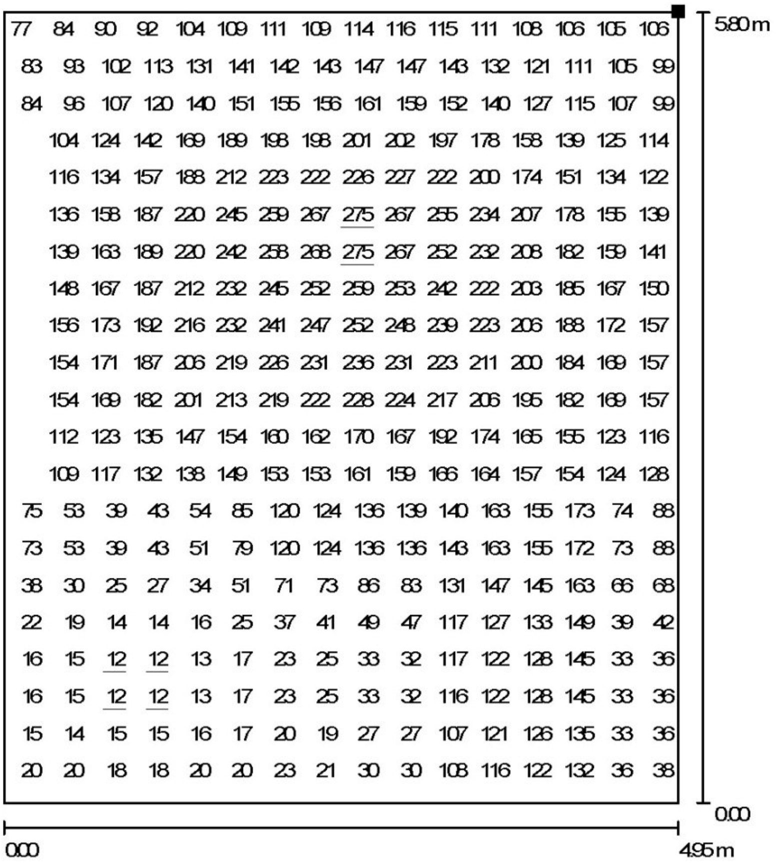


Scale 1 : 46

Position of surface in room:
Marked point:
(29.450 m, 5.570 m, 5.800 m)

Grid: 64 x 64 Points

E_{av} [lx]	E_{min} [lx]	E_{max} [lx]	u0	E_{min} / E_{max}
128	12	275	0.09	0.04



77	84	90	92	104	109	111	109	114	116	115	111	108	106	105	106
83	93	102	113	131	141	142	143	147	147	143	132	121	111	105	99
84	96	107	120	140	151	155	156	161	159	152	140	127	115	107	99
	104	124	142	169	189	198	198	201	202	197	178	158	139	125	114
	116	134	157	188	212	223	222	226	227	222	200	174	151	134	122
	136	158	187	220	245	259	267	275	267	255	234	207	178	155	139
	139	163	189	220	242	258	268	275	267	252	232	208	182	159	141
	148	167	187	212	232	245	252	259	253	242	222	203	185	167	150
	156	173	192	216	232	241	247	252	248	239	223	206	188	172	157
	154	171	187	206	219	226	231	236	231	223	211	200	184	169	157
	154	169	182	201	213	219	222	228	224	217	206	195	182	169	157
	112	123	135	147	154	160	162	170	167	192	174	165	155	123	116
	109	117	132	138	149	153	153	161	159	166	164	157	154	124	128
75	53	39	43	54	85	120	124	136	139	140	163	155	173	74	88
73	53	39	43	51	79	120	124	136	136	143	163	155	172	73	88
38	30	25	27	34	51	71	73	86	83	131	147	145	163	66	68
22	19	14	14	16	25	37	41	49	47	117	127	133	149	39	42
16	15	12	12	13	17	23	25	33	32	117	122	128	145	33	36
16	15	12	12	13	17	23	25	33	32	116	122	128	145	33	36
15	14	15	15	16	17	20	19	27	27	107	121	126	135	33	36
20	20	18	18	20	20	23	21	30	30	108	116	122	132	36	38

Values in Lux, Scale 1 : 46

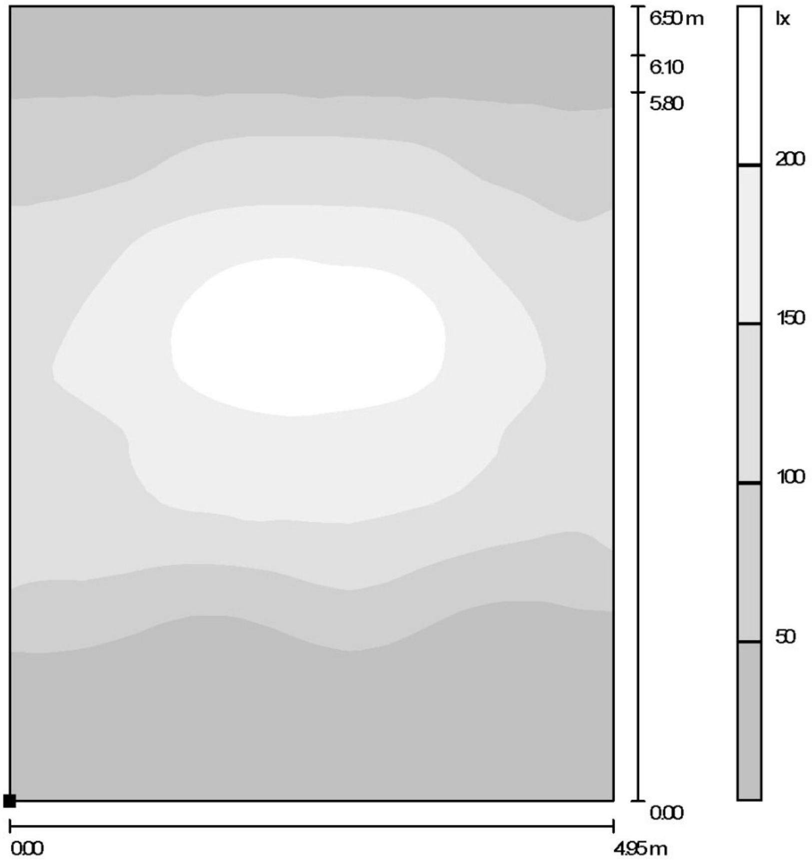
Not all calculated values could be displayed.

Position of surface in room:
Marked point:
(29.450 m, 5.570 m, 5.800 m)

Grid: 64 x 64 Points

E_{av} [lx]	E_{min} [lx]	E_{max} [lx]	u0	E_{min} / E_{max}
128	12	275	0.09	0.04

Wall / Greyscale (E)

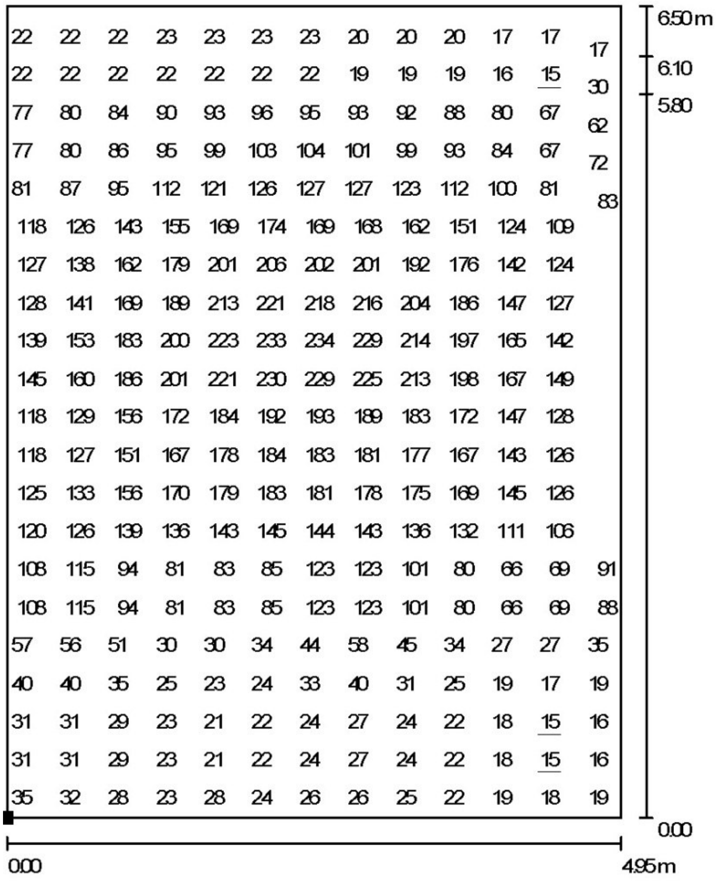


Scale 1 : 51

Position of surface in room:
Marked point:
(29.450 m, 10.000 m, 0.000 m)

Grid: 64 x 64 Points

E_{av} [lx]	E_{min} [lx]	E_{max} [lx]	u0	E_{min} / E_{max}
100	15	240	0.15	0.06



22	22	22	23	23	23	23	20	20	20	17	17	17
22	22	22	22	22	22	22	19	19	19	16	15	30
77	80	84	90	93	96	95	93	92	88	80	67	62
77	80	86	95	99	103	104	101	99	93	84	67	72
81	87	95	112	121	126	127	127	123	112	100	81	83
118	126	143	155	169	174	169	168	162	151	124	109	
127	138	162	179	201	206	202	201	192	176	142	124	
128	141	169	189	213	221	218	216	204	186	147	127	
139	153	183	200	223	233	234	229	214	197	165	142	
145	160	186	201	221	230	229	225	213	198	167	149	
118	129	156	172	184	192	193	189	183	172	147	128	
118	127	151	167	178	184	183	181	177	167	143	126	
125	133	156	170	179	183	181	178	175	169	145	126	
120	126	139	136	143	145	144	143	136	132	111	106	
108	115	94	81	83	85	123	123	101	80	66	69	91
108	115	94	81	83	85	123	123	101	80	66	69	88
57	56	51	30	30	34	44	58	45	34	27	27	35
40	40	35	25	23	24	33	40	31	25	19	17	19
31	31	29	23	21	22	24	27	24	22	18	15	16
31	31	29	23	21	22	24	27	24	22	18	15	16
35	32	28	23	28	24	26	26	25	22	19	18	19

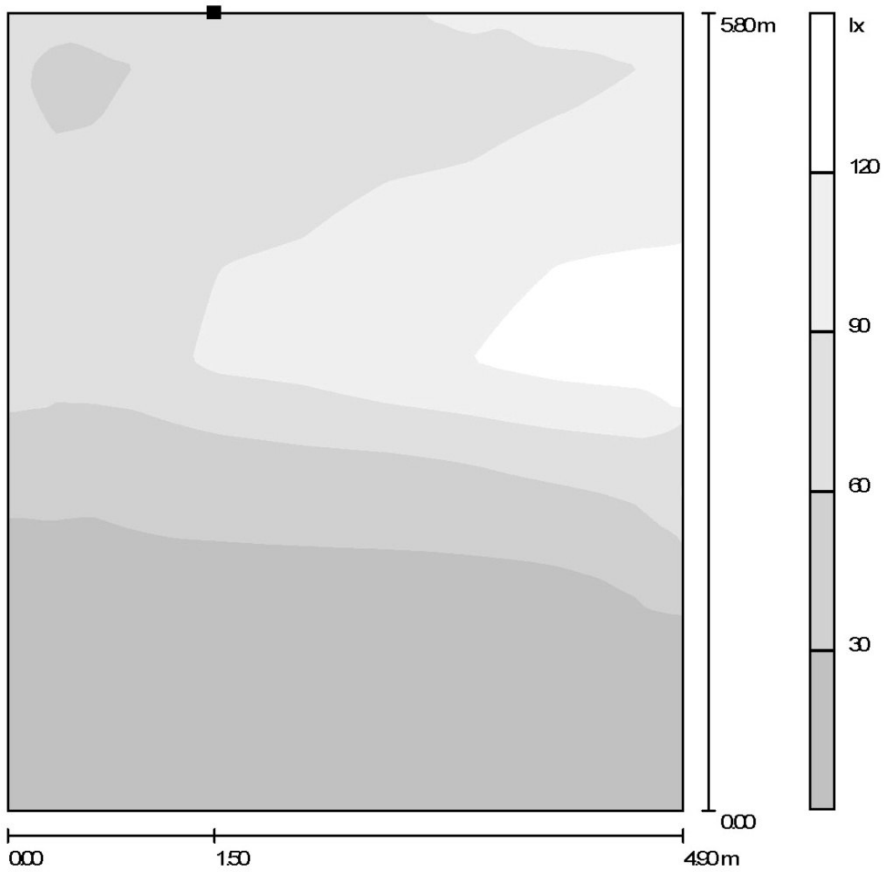
Values in Lux, Scale 1 : 51

Not all calculated values could be displayed.

Position of surface in room:
Marked point:
(29.450 m, 10.000 m, 0.000 m)

Grid: 64 x 64 Points

E_{av} [lx]	E_{min} [lx]	E_{max} [lx]	u0	E_{min} / E_{max}
100	15	240	0.15	0.06



Scale 1 : 46

Position of surface in room:
Marked point:
(29.450 m, 13.400 m, 5.800 m)

Grid: 128 x 128 Points

E_{av} [lx]	E_{min} [lx]	E_{max} [lx]	u0	E_{min} / E_{max}
59	6.22	137	0.11	0.05

Wall / Value Chart (E)

69	64	66	67	75	83	82	90	89	92	92	96	98	101
63	58	61	61	70	74	75	80	82	81	81	88	87	92
63	56	58	60	67	70	73	78	79	80	80	84	86	88
66	59	64	64	72	72	76	84	85	88	88	94	94	97
68	59	64	64	72	72	76	84	85	88	88	94	94	97
69	60	65	65	73	73	78	87	88	92	93	99	100	104
79	72	75	76	88	89	94	105	107	110	111	117	118	121
82	72	75	76	88	89	94	105	107	110	111	117	118	121
83	72	76	76	90	91	96	107	109	112	114	121	122	125
80	72	76	76	90	91	96	107	109	112	114	121	122	125
84	74	78	79	94	96	101	112	114	117	120	127	129	132
82	73	78	79	95	97	103	114	116	120	123	131	133	137
80	73	78	79	95	97	103	114	116	120	123	131	133	137
39	38	38	40	44	46	52	53	56	60	63	69	71	75
37	35	38	42	47	48	53	52	55	58	61	65	67	72
37	35	38	42	47	48	53	52	55	58	61	65	67	72
28	24	25	27	27	27	27	29	28	30	30	32	34	38
28	24	25	27	27	27	27	29	28	30	30	32	34	38
26	24	24	24	23	23	23	25	24	25	26	28	29	33
12	11	12	9.98	8.74	8.65	8.75	9.48	9.33	9.61	10	10	12	15
12	11	12	9.98	8.74	8.65	8.75	9.48	9.33	9.61	10	10	12	15
12	11	11	7.87	6.23	6.22	6.33	6.89	6.86	7.95	8.59	8.79	11	13
12	11	12	9.07	9.30	8.42	9.15	9.19	8.91	11	11	11	13	13
12	11	12	9.07	9.30	8.42	9.15	9.19	8.91	11	11	11	13	13
13	12	13	11	11	11	15	14	12	12	12	15	16	15

5.80 m

0.00

0.00 1.50 4.90 m

Values in Lux, Scale 1 : 46

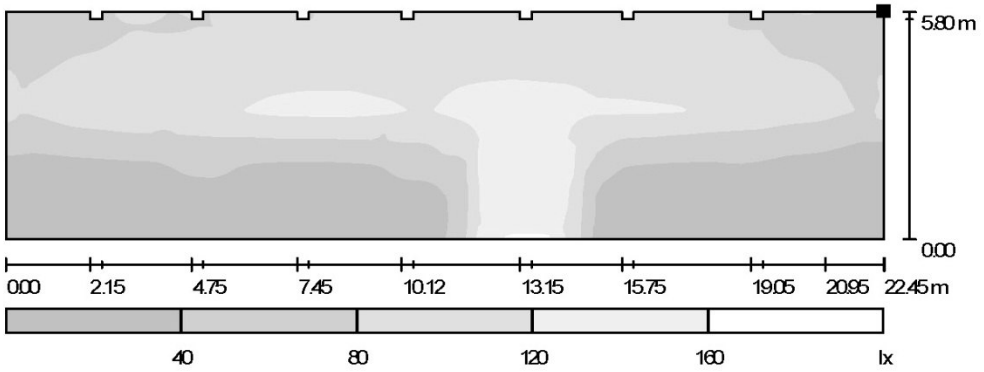
Not all calculated values could be displayed.

Position of surface in room:
Marked point:
(29.450 m, 13.400 m, 5.800 m)

Grid: 128 x 128 Points

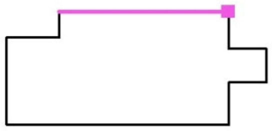
E_{av} [lx]	E_{min} [lx]	E_{max} [lx]	u0	E_{min} / E_{max}
59	6.22	137	0.11	0.05

Wall / Greyscale (E)



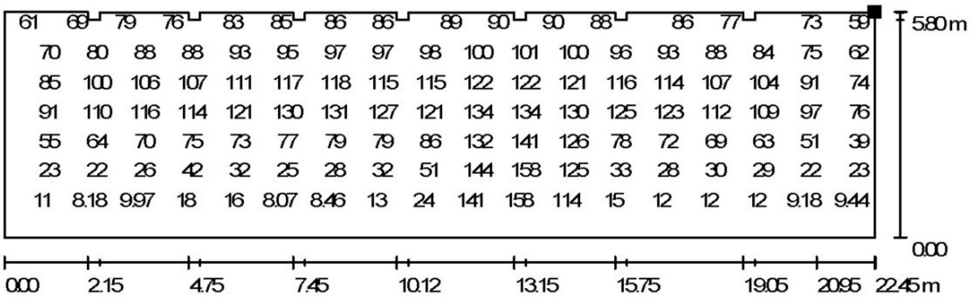
Scale 1 : 161

Position of surface in room:
Marked point:
(29.450 m, 14.900 m, 5.800 m)



Grid: 128 x 128 Points

E_{av} [lx]	E_{min} [lx]	E_{max} [lx]	u0	E_{min} / E_{max}
73	7.14	174	0.10	0.04

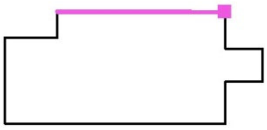


61	69	79	76	83	85	86	86	89	90	90	88	86	77	73	59		
70	80	88	88	93	95	97	97	98	100	101	100	96	93	88	84	75	62
85	100	106	107	111	117	118	115	115	122	122	121	116	114	107	104	91	74
91	110	116	114	121	130	131	127	121	134	134	130	125	123	112	109	97	76
55	64	70	75	73	77	79	79	86	132	141	126	78	72	69	63	51	39
23	22	26	42	32	25	28	32	51	144	158	125	33	28	30	29	22	23
11	8.18	9.97	18	16	8.07	8.46	13	24	141	158	114	15	12	12	12	9.18	9.44

Values in Lux, Scale 1 : 161

Not all calculated values could be displayed.

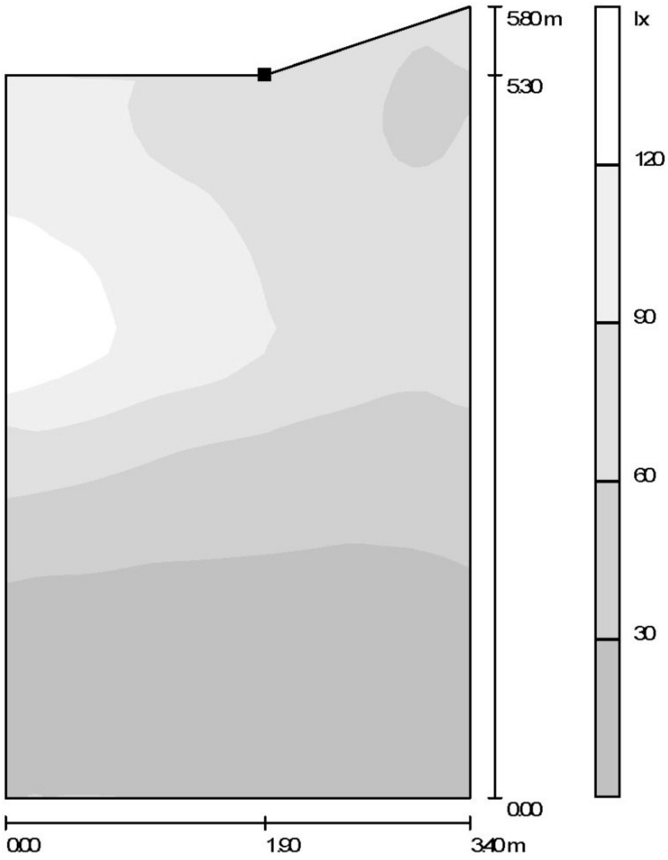
Position of surface in room:
Marked point:
(29.450 m, 14.900 m, 5.800 m)



Grid: 128 x 128 Points

E_{av} [lx]	E_{min} [lx]	E_{max} [lx]	u0	E_{min} / E_{max}
73	7.14	174	0.10	0.04

Wall / Greyscale (E)

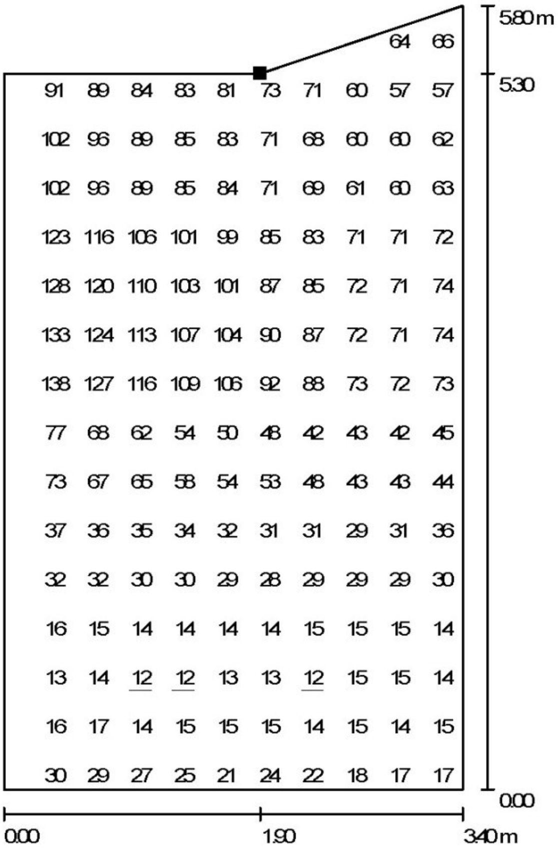


Scale 1 : 46

Position of surface in room:
Marked point:
(7.000 m, 13.400 m, 5.300 m)

Grid: 32 x 32 Points

E_{av} [lx]	E_{min} [lx]	E_{max} [lx]	u0	E_{min} / E_{max}
57	12	143	0.21	0.08

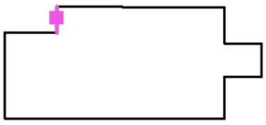


								64	66
91	89	84	83	81	73	71	60	57	57
102	96	89	85	83	71	68	60	60	62
102	96	89	85	84	71	69	61	60	63
123	116	106	101	99	85	83	71	71	72
128	120	110	103	101	87	85	72	71	74
133	124	113	107	104	90	87	72	71	74
138	127	116	109	106	92	88	73	72	73
77	68	62	54	50	48	42	43	42	45
73	67	65	58	54	53	48	43	43	44
37	36	35	34	32	31	31	29	31	36
32	32	30	30	29	28	29	29	29	30
16	15	14	14	14	14	15	15	15	14
13	14	12	12	13	13	12	15	15	14
16	17	14	15	15	15	14	15	14	15
30	29	27	25	21	24	22	18	17	17

Values in Lux, Scale 1 : 46

Not all calculated values could be displayed.

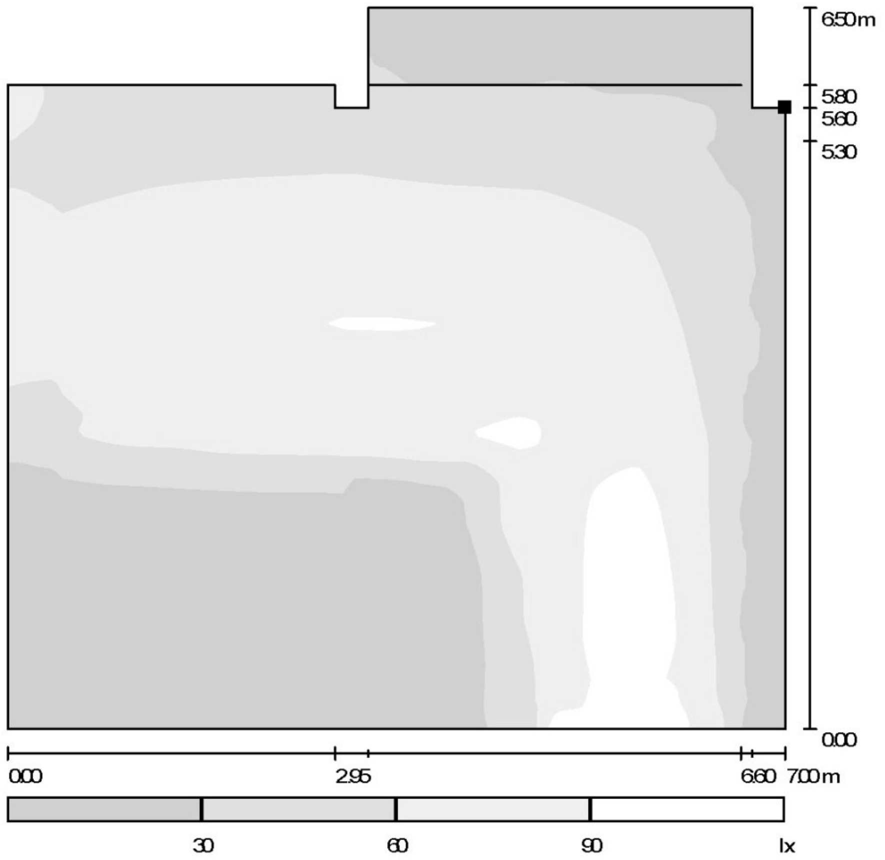
Position of surface in room:
Marked point:
(7.000 m, 13.400 m, 5.300 m)



Grid: 32 x 32 Points

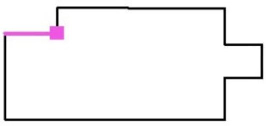
E_{av} [lx]	E_{min} [lx]	E_{max} [lx]	u0	E_{min} / E_{max}
57	12	143	0.21	0.08

Wall / Greyscale (E)



Scale 1 : 56

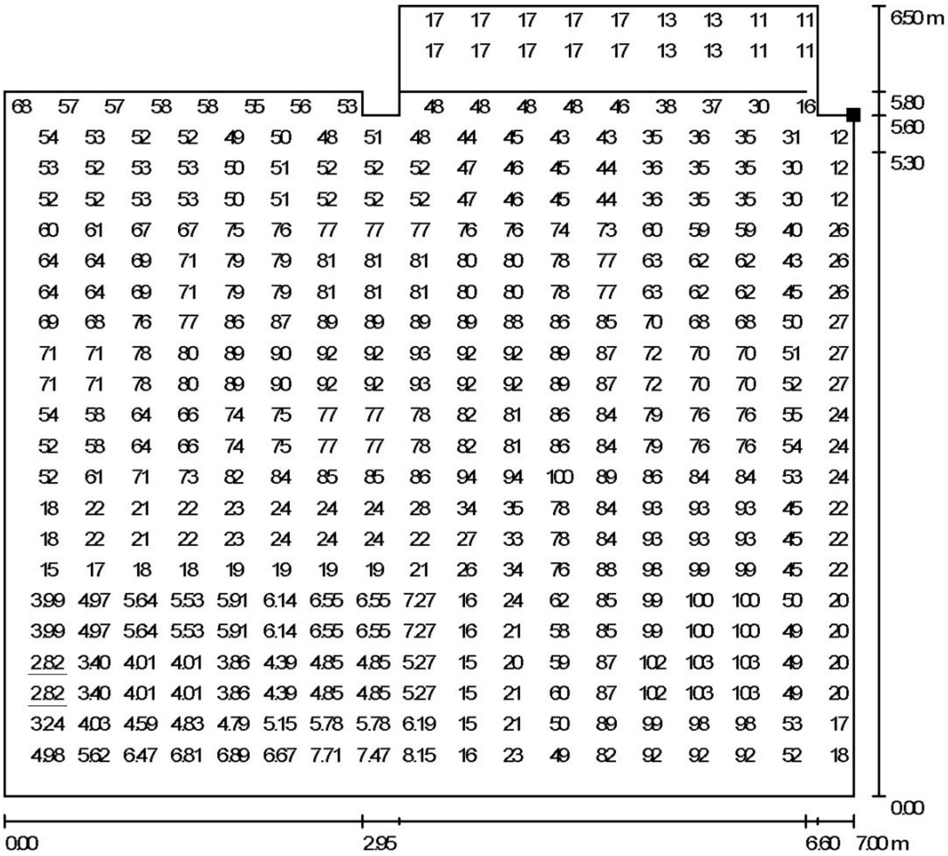
Position of surface in room:
Marked point:
(7.000 m, 11.500 m, 5.600 m)



Grid: 128 x 128 Points

E_{av} [lx]	E_{min} [lx]	E_{max} [lx]	u0	E_{min} / E_{max}
50	2.82	112	0.06	0.03

Wall / Value Chart (E)



								17	17	17	17	17	13	13	11	11
								17	17	17	17	17	13	13	11	11
68	57	57	58	58	55	56	53	48	48	48	48	46	38	37	30	16

54	53	52	52	49	50	48	51	48	44	45	43	43	35	36	35	31	12
53	52	53	53	50	51	52	52	52	47	46	45	44	36	35	35	30	12
52	52	53	53	50	51	52	52	52	47	46	45	44	36	35	35	30	12
60	61	67	67	75	76	77	77	77	76	76	74	73	60	59	59	40	26
64	64	69	71	79	79	81	81	81	80	80	78	77	63	62	62	43	26
64	64	69	71	79	79	81	81	81	80	80	78	77	63	62	62	45	26
69	68	76	77	86	87	89	89	89	89	88	86	85	70	68	68	50	27
71	71	78	80	89	90	92	92	93	92	92	89	87	72	70	70	51	27
71	71	78	80	89	90	92	92	93	92	92	89	87	72	70	70	52	27
54	58	64	66	74	75	77	77	78	82	81	86	84	79	76	76	55	24
52	58	64	66	74	75	77	77	78	82	81	86	84	79	76	76	54	24
52	61	71	73	82	84	85	85	86	94	94	100	89	86	84	84	53	24
18	22	21	22	23	24	24	24	28	34	35	78	84	93	93	93	45	22
18	22	21	22	23	24	24	24	22	27	33	78	84	93	93	93	45	22
15	17	18	18	19	19	19	19	21	26	34	76	88	98	99	99	45	22
3.99	4.97	5.64	5.53	5.91	6.14	6.55	6.55	7.27	16	24	62	85	99	100	100	50	20
3.99	4.97	5.64	5.53	5.91	6.14	6.55	6.55	7.27	16	21	58	85	99	100	100	49	20
2.82	3.40	4.01	4.01	3.86	4.39	4.85	4.85	5.27	15	20	59	87	102	103	103	49	20
2.82	3.40	4.01	4.01	3.86	4.39	4.85	4.85	5.27	15	21	60	87	102	103	103	49	20
3.24	4.03	4.59	4.83	4.79	5.15	5.78	5.78	6.19	15	21	50	89	99	98	98	53	17
4.98	5.62	6.47	6.81	6.89	6.67	7.71	7.47	8.15	16	23	49	82	92	92	92	52	18

Values in Lux, Scale 1 : 51

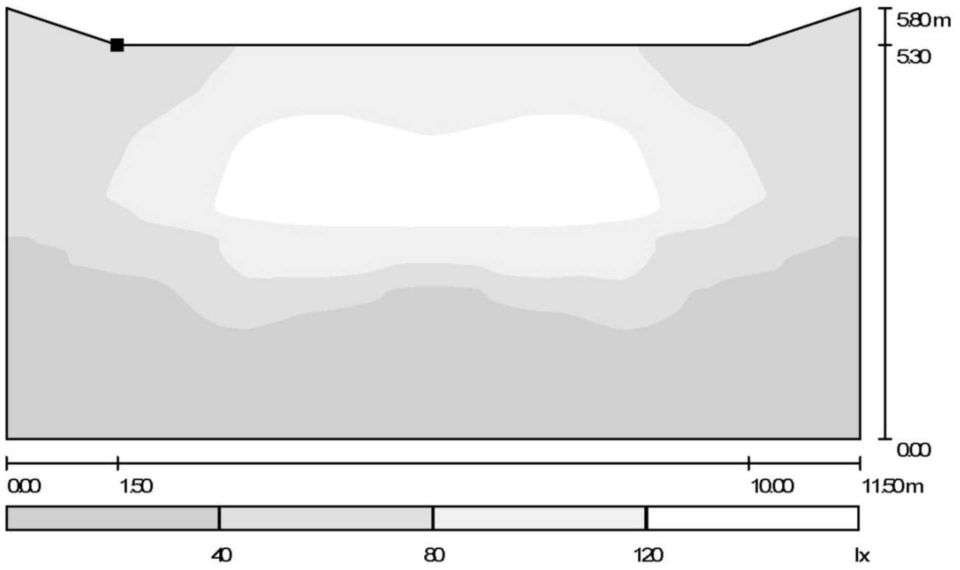
Not all calculated values could be displayed.

Position of surface in room:
Marked point:
(7.000 m, 11.500 m, 5.600 m)

Grid: 128 x 128 Points

E_{av} [lx]	E_{min} [lx]	E_{max} [lx]	u0	E_{min} / E_{max}
50	2.82	112	0.06	0.03

Wall / Greyscale (E)



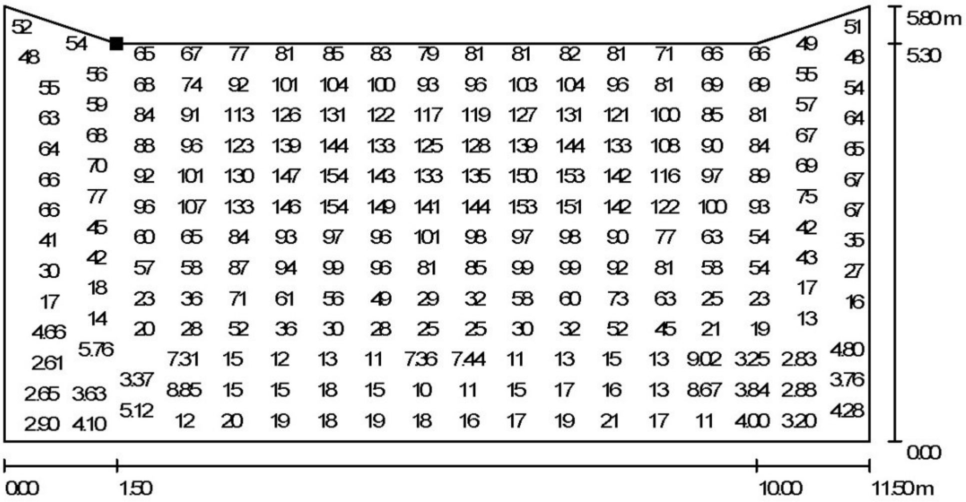
Scale 1 : 83

Position of surface in room:
Marked point:
(0.000 m, 1.500 m, 5.300 m)

Grid: 128 x 128 Points

E_{av} [lx]	E_{min} [lx]	E_{max} [lx]	u0	E_{min} / E_{max}
62	2.47	155	0.04	0.02

Wall / Value Chart (E)



Values in Lux, Scale 1 : 83

Not all calculated values could be displayed.

Position of surface in room:
Marked point:
(0.000 m, 1.500 m, 5.300 m)

Grid: 128 x 128 Points

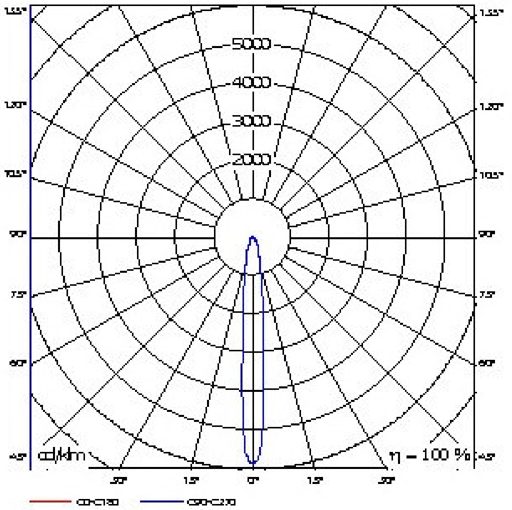
E_{av} [lx]	E_{min} [lx]	E_{max} [lx]	u0	E_{min} / E_{max}
62	2.47	155	0.04	0.02

APPENDIX B

PHOTOMETRIC RESULTS FOR HALOGEN SPOTLIGHTING SYSTEM

OSRAM GmbH 64845SP HALOPAR® 30 mit Kaltlicht-Reflektor 64845SP / **Luminaire Data Sheet**

Luminous emittance 1:

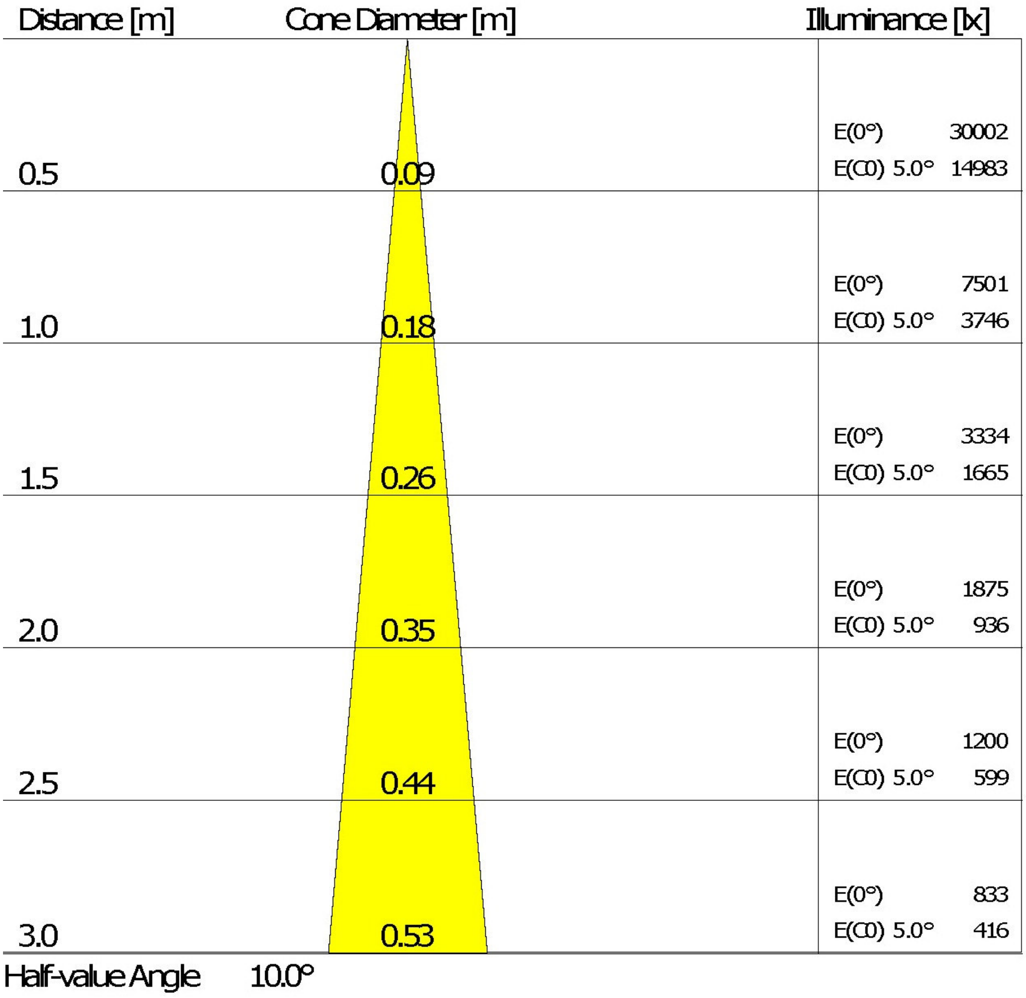


Luminaire classification according to CIE: 94
CIE flux code: 74 90 97 94 100

OSRAM HALOPAR® 20/30
- Wahlweise mit facettiertem Aluminium-Reflektor, der die entstehende Wärme nach vorne abstrahlt.
- Oder mit dekorativem Kaltlichtreflektor, der die Wärmestrahlung im Lichtbündel um bis zu 66 % reduziert. Damit sind sie auch zur Beleuchtung wärmeempfindlicher Objekte bestens geeignet.

HALOPAR® ist die halogenstarke Alternative für herkömmliche Reflektorlampen. Sie ist einfach an Netzspannung ohne Trafo zu betreiben. HALOPAR® liefert weißes, brillantes Licht. Insgesamt bietet sie eine bis zu 35 % höhere Lichtstärke als herkömmliche Reflektorlampen bzw. 15 % Energieersparnis.
- Die HALOPAR®-Lampen sind dimmbar.
- Die Lebensdauer beträgt 2.000 Stunden.
- Der Betrieb in Leuchten ohne Schutzabdeckung ist gemäß IEC 60598-1 erlaubt.
- UV-Filter-Technik (gem. IEC 60432).
- Die Farbtemperatur beträgt ca. 2.900K. &

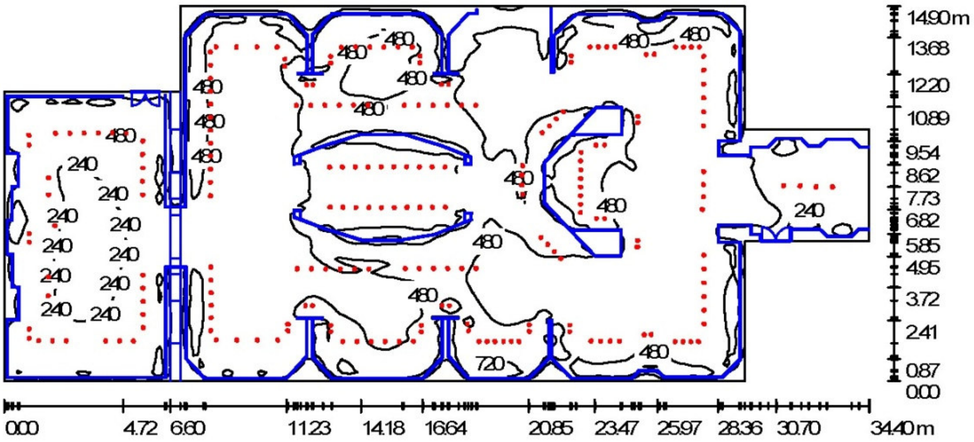
uminaire: OSRAM GmbH 64845SP HALOPAR® 30 mit Kaltlicht-Reflektor 64845SP
amps: 1 x 75W 230V 10°



Distance [m]	Cone Diameter [m]	Illuminance [lx]	
0.5	0.09	E(0°)	30002
		E(C0) 5.0°	14983
1.0	0.18	E(0°)	7501
		E(C0) 5.0°	3746
1.5	0.26	E(0°)	3334
		E(C0) 5.0°	1665
2.0	0.35	E(0°)	1875
		E(C0) 5.0°	936
2.5	0.44	E(0°)	1200
		E(C0) 5.0°	599
3.0	0.53	E(0°)	833
		E(C0) 5.0°	416

Half-value Angle 10.0°

Room with Osram 64845SP Halopar 30 Coldlight / Summary



Height of Room: 6.500 m

Values in Lux, Scale 1:246

Surface	ρ [%]	E_{av} [lx]	E_{min} [lx]	E_{max} [lx]	u0
Workplane	/	402	26	1185	0.06
Floor	68	362	20	834	0.05

Workplane:

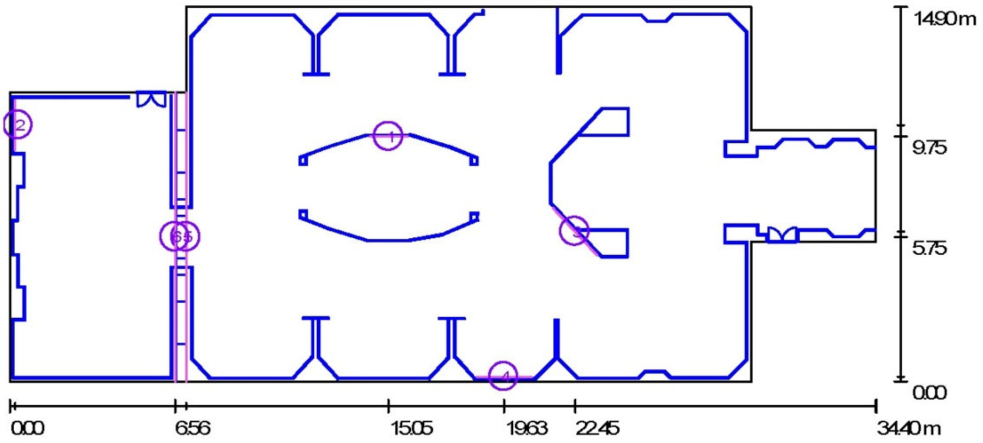
Height:	0.760 m
Grid:	128 x 128 Points

Luminaire Parts List

No.	Pieces	Designation (Correction Factor)	Φ [lm]	P [W]
1	217	OSRAM GmbH 64845SP HALOPAR® 30 mit Kaltlicht-Reflektor 64845SP (1.000)	1279	75
		total:	277543	16275

Specific connected load: 37.25 W/m² = 9.26 W/m²/100 lx (Area: 436.93 m²)

Calculation surfaces (results overview)



Scale 1 : 246

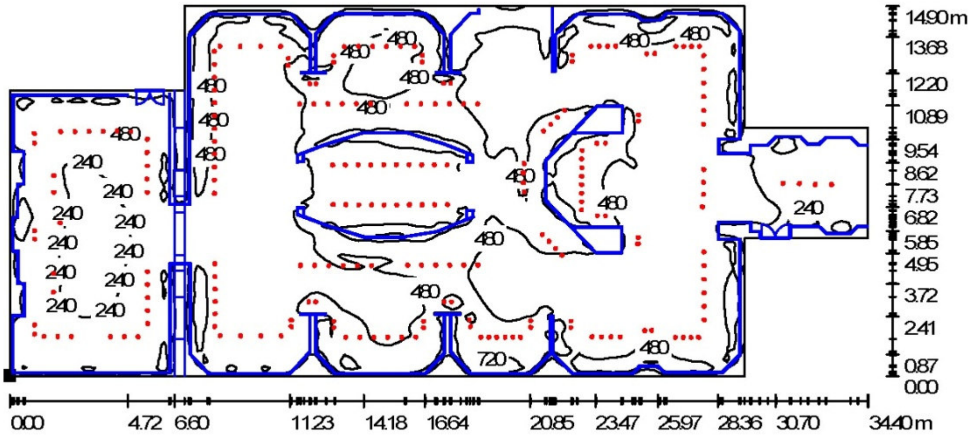
Calculation Surface List

No.	Designation	Type	Grid	E_{av} [lx]	E_{min} [lx]	E_{max} [lx]	u0	E_{min} / E_{max}
1	Calculation Surface 1	perpendicular	32 x 32	640	512	882	0.80	0.58
2	Calculation Surface 2	perpendicular	32 x 32	315	243	413	0.77	0.59
3	Calculation Surface 3	perpendicular	32 x 32	436	345	543	0.79	0.64
4	Calculation Surface 4	perpendicular	32 x 32	527	449	638	0.85	0.70
5	Calculation Surface 5	perpendicular	128 x 64	240	13	472	0.05	0.03
6	Calculation Surface 6	perpendicular	128 x 64	168	8.25	339	0.05	0.02

Summary of Results

Type	Quantity	Average [lx]	Min [lx]	Max [lx]	u0	E_{min} / E_{max}
perpendicular	6	242	8.25	882	0.03	0.01

Workplane / **Isolines (E)**



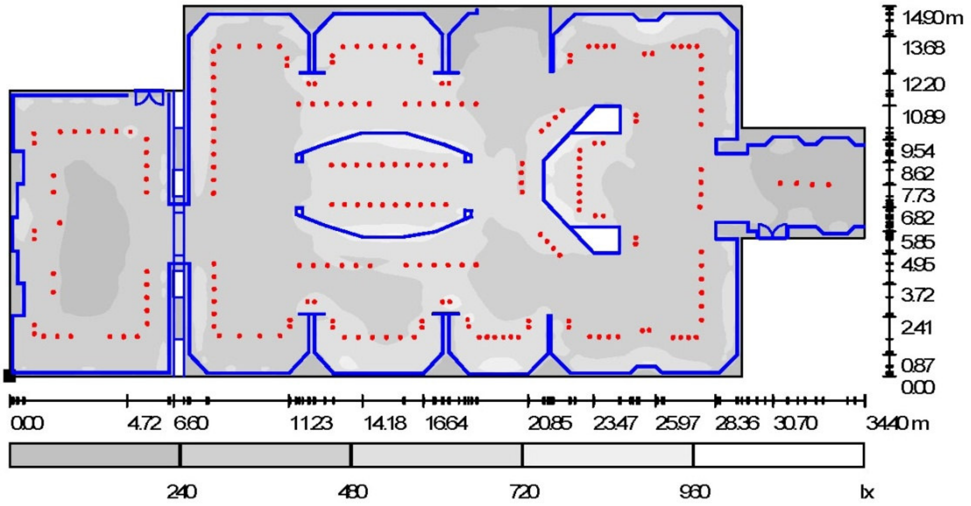
Values in Lux, Scale 1 : 246

Position of surface in room:
Marked point:
(0.000 m, 0.000 m, 0.760 m)

Grid: 128 x 128 Points

E_{av} [lx]	E_{min} [lx]	E_{max} [lx]	u0	E_{min} / E_{max}
402	26	1185	0.06	0.02

Workplane / Greyscale (E)

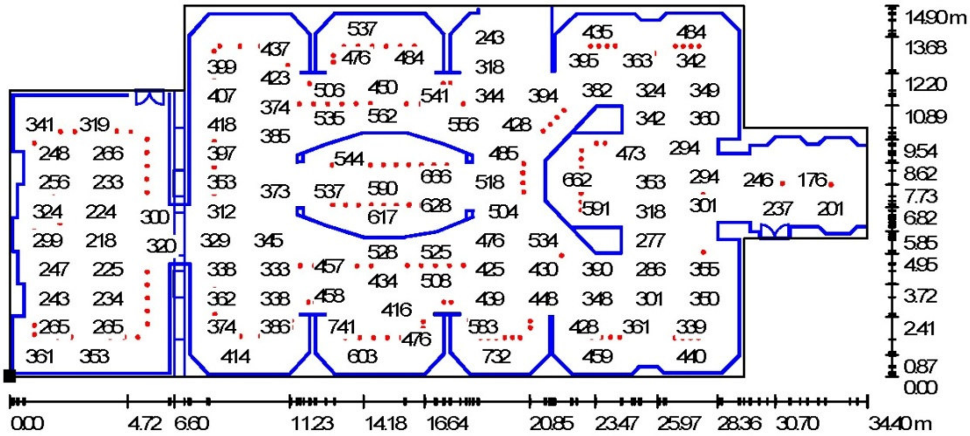


Scale 1 : 246

Position of surface in room:
Marked point:
(0.000 m, 0.000 m, 0.760 m)

Grid: 128 x 128 Points

E_{av} [lx]	E_{min} [lx]	E_{max} [lx]	u0	E_{min} / E_{max}
402	26	1185	0.06	0.02



Values in Lux, Scale 1 : 246

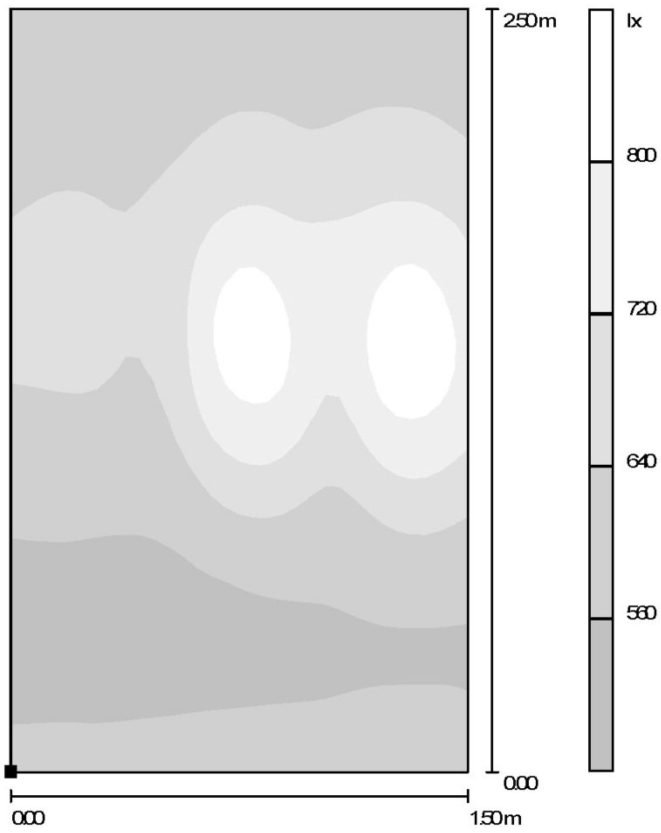
Not all calculated values could be displayed.

Position of surface in room:
Marked point:
(0.000 m, 0.000 m, 0.760 m)

Grid: 128 x 128 Points

E_{av} [lx]	E_{min} [lx]	E_{max} [lx]	u0	E_{min} / E_{max}
402	26	1185	0.06	0.02

Calculation Surface 1 / Greyscale



Scale 1 : 20

Position of surface in room:
Marked point:
(14.300 m, 9.750 m, 0.000 m)

Grid: 32 x 32 Points

E_{av} [lx]	E_{min} [lx]	E_{max} [lx]	u0	E_{min} / E_{max}
640	512	882	0.80	0.58

Calculation Surface 1 / Value Chart

2.50m

579	592	581	595	605	619	609	606	613	618
595	599	596	615	629	632	624	624	633	633
603	614	608	622	643	659	646	648	659	657
614	631	615	637	677	698	680	676	697	697
672	688	643	673	720	759	729	736	748	759
679	694	650	672	750	845	756	746	788	841
666	673	646	661	783	874	802	736	830	880
646	654	648	643	765	831	795	718	813	842
627	631	628	621	722	778	754	690	774	793
604	606	603	596	660	712	690	650	706	730
574	574	571	574	599	634	625	605	640	659
550	550	547	551	562	576	577	581	594	599
529	531	529	536	543	553	558	559	569	571
515	513	512	520	526	530	534	537	546	544
524	523	519	532	535	541	541	545	553	553
596	601	600	599	609	609	615	620	629	630

0.00

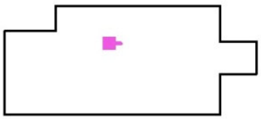
0.00

1.50m

Values in Lux, Scale 1 : 20

Not all calculated values could be displayed.

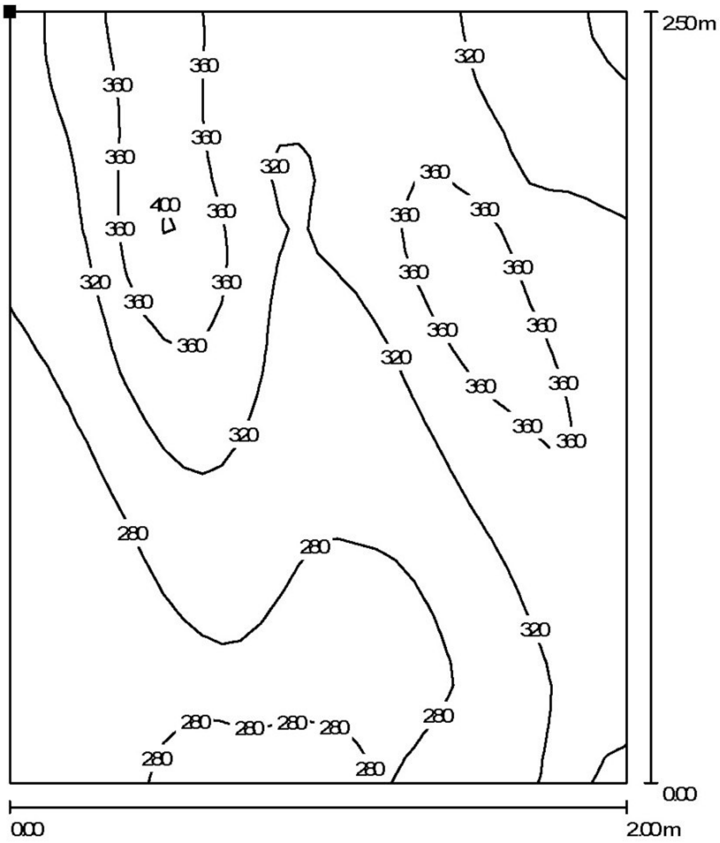
Position of surface in room:
Marked point:
(14.300 m, 9.750 m, 0.000 m)



Grid: 32 x 32 Points

E_{av} [lx]	E_{min} [lx]	E_{max} [lx]	u0	E_{min} / E_{max}
640	512	882	0.80	0.58

Calculation Surface 2 / Isolines



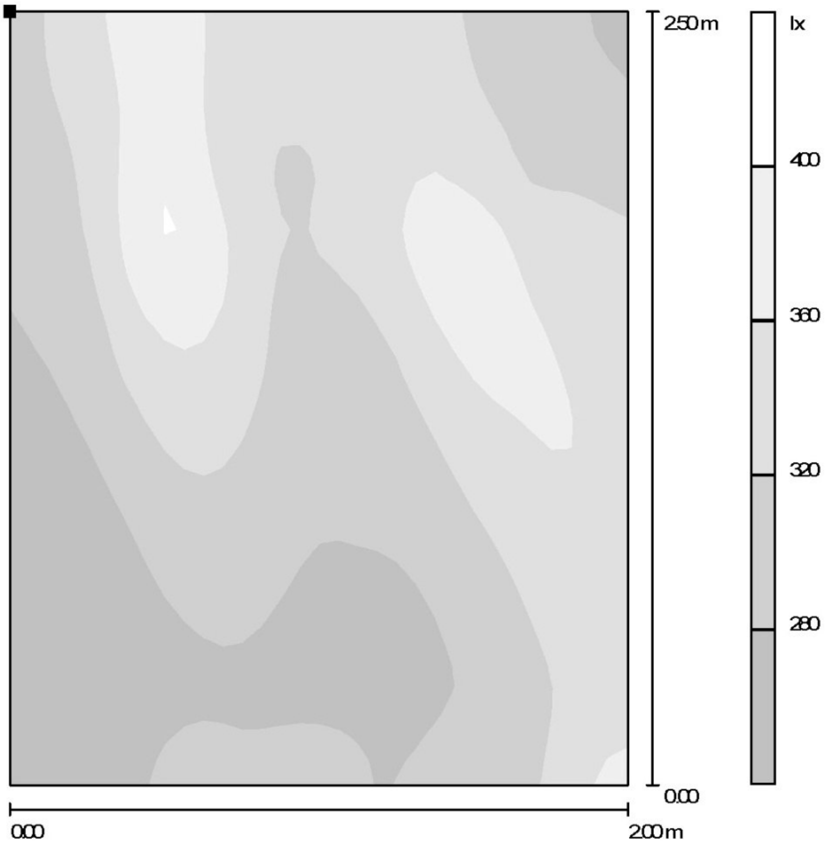
Values in Lux, Scale 1 : 20

Position of surface in room:
Marked point:
(0.205 m, 9.200 m, 2.500 m)

Grid: 32 x 32 Points

E_{av} [lx]	E_{min} [lx]	E_{max} [lx]	u0	E_{min} / E_{max}
315	243	413	0.77	0.59

Calculation Surface 2 / Greyscale



Scale 1 : 20

Position of surface in room:
Marked point:
(0.205 m, 9.200 m, 2.500 m)

Grid: 32 x 32 Points

E_{av} [lx]	E_{min} [lx]	E_{max} [lx]	u0	E_{min} / E_{max}
315	243	413	0.77	0.59

2.50 m

310	347	365	375	363	341	335	343	358	356	343	320	302	284	284
306	344	360	374	362	342	323	328	350	356	348	328	304	290	288
295	330	357	381	364	337	319	318	339	350	354	334	322	309	312
290	322	354	398	378	334	314	312	320	343	364	345	328	308	319
289	317	359	403	400	346	323	319	329	351	385	383	356	331	339
285	302	351	392	394	353	318	312	321	338	374	385	373	337	344
277	292	334	361	375	357	313	305	312	315	356	373	382	364	353
273	285	306	343	359	349	320	299	304	306	325	356	372	366	364
264	274	289	321	339	334	314	292	297	298	309	340	359	360	370
260	269	279	306	325	322	308	287	291	291	296	323	346	351	369
255	262	267	289	309	308	299	278	283	282	286	304	330	337	361
253	258	261	278	297	298	293	275	278	277	280	292	317	327	353
247	251	255	268	284	285	284	270	273	267	275	282	305	318	345
245	248	251	260	274	277	277	267	271	266	271	276	294	307	336
243	243	253	258	273	272	277	266	276	267	276	275	284	301	329
269	255	261	275	310	283	288	299	296	275	285	291	313	309	343

0.00

0.00

2.00 m

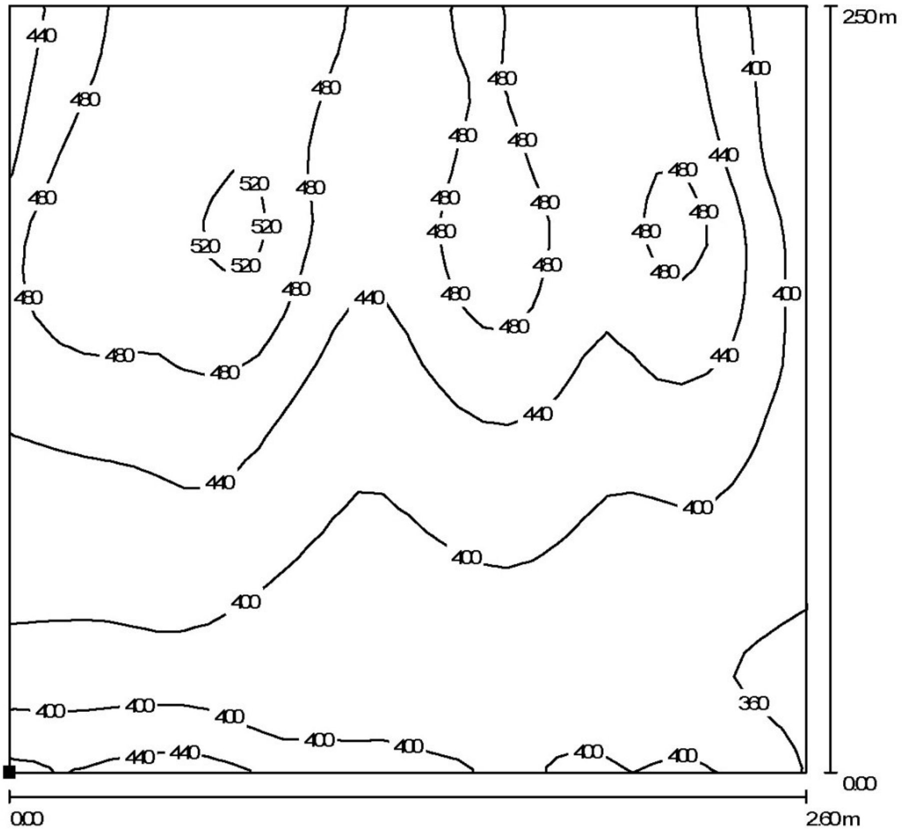
Values in Lux, Scale 1 : 20

Not all calculated values could be displayed.

Position of surface in room:
Marked point:
(0.205 m, 9.200 m, 2.500 m)

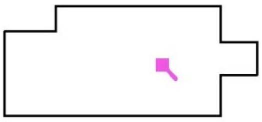
Grid: 32 x 32 Points

E_{av} [lx]	E_{min} [lx]	E_{max} [lx]	u0	E_{min} / E_{max}
315	243	413	0.77	0.59



Values in Lux, Scale 1 : 20

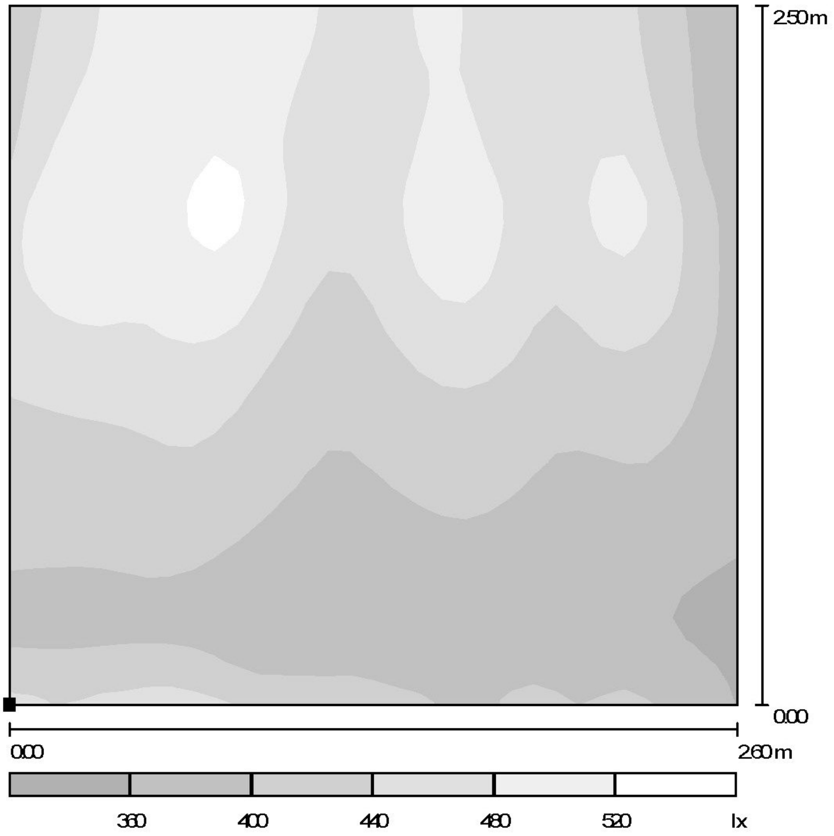
Position of surface in room:
Marked point:
(21.558 m, 6.911 m, 0.000 m)



Grid: 32 x 32 Points

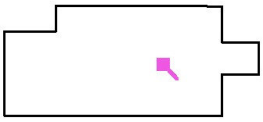
E_{av} [lx]	E_{min} [lx]	E_{max} [lx]	u0	E_{min} / E_{max}
436	345	543	0.79	0.64

Calculation Surface 3 / Greyscale



Scale 1 : 22

Position of surface in room:
Marked point:
(21.558 m, 6.911 m, 0.000 m)



Grid: 32 x 32 Points

E_{av} [lx]	E_{min} [lx]	E_{max} [lx]	u0	E_{min} / E_{max}
436	345	543	0.79	0.64

Calculation Surface 3 / Value Chart

2.50 m

441	474	496	504	502	496	477	475	482	486	475	471	466	450	408
448	483	499	502	504	491	470	469	478	486	472	469	468	457	411
456	503	497	499	524	487	460	461	473	496	470	464	472	474	413
477	514	491	503	528	486	450	460	476	508	464	456	482	489	419
498	522	500	519	541	494	454	461	489	518	481	461	490	500	445
494	510	491	514	524	483	444	451	483	505	479	451	479	486	448
481	499	481	502	506	466	432	440	469	488	469	440	462	472	442
468	481	470	490	486	449	422	430	454	470	456	426	445	455	439
445	454	438	462	463	429	409	408	431	445	443	408	421	432	420
432	437	436	446	445	425	400	400	411	429	428	409	400	417	407
431	432	432	441	438	419	397	398	404	421	417	402	391	405	400
418	417	420	427	422	405	390	391	393	407	404	392	379	391	387
404	401	403	408	401	387	377	378	380	392	388	378	369	377	371
393	390	393	396	389	377	372	373	372	383	377	370	361	366	361
397	392	394	392	389	371	370	369	362	380	376	360	364	361	360
454	463	459	464	447	434	425	449	422	396	388	429	392	423	384

0.00

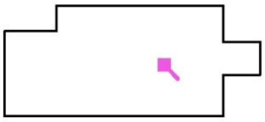
0.00

2.60 m

Values in Lux, Scale 1 : 20

Not all calculated values could be displayed.

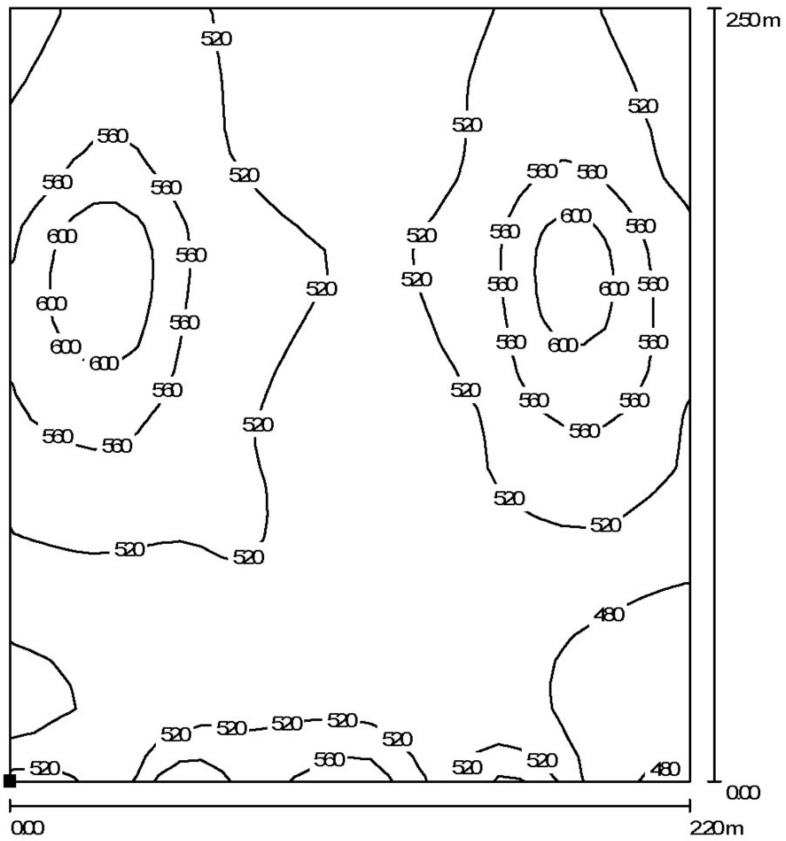
Position of surface in room:
Marked point:
(21.558 m, 6.911 m, 0.000 m)



Grid: 32 x 32 Points

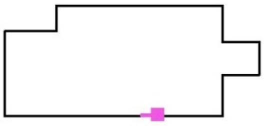
E_{av} [lx]	E_{min} [lx]	E_{max} [lx]	u0	E_{min} / E_{max}
436	345	543	0.79	0.64

Room with Osram 64845SP Halopar 30 Coldlight / Calculation Surface 4 / Isolines (E, Perpendicular)



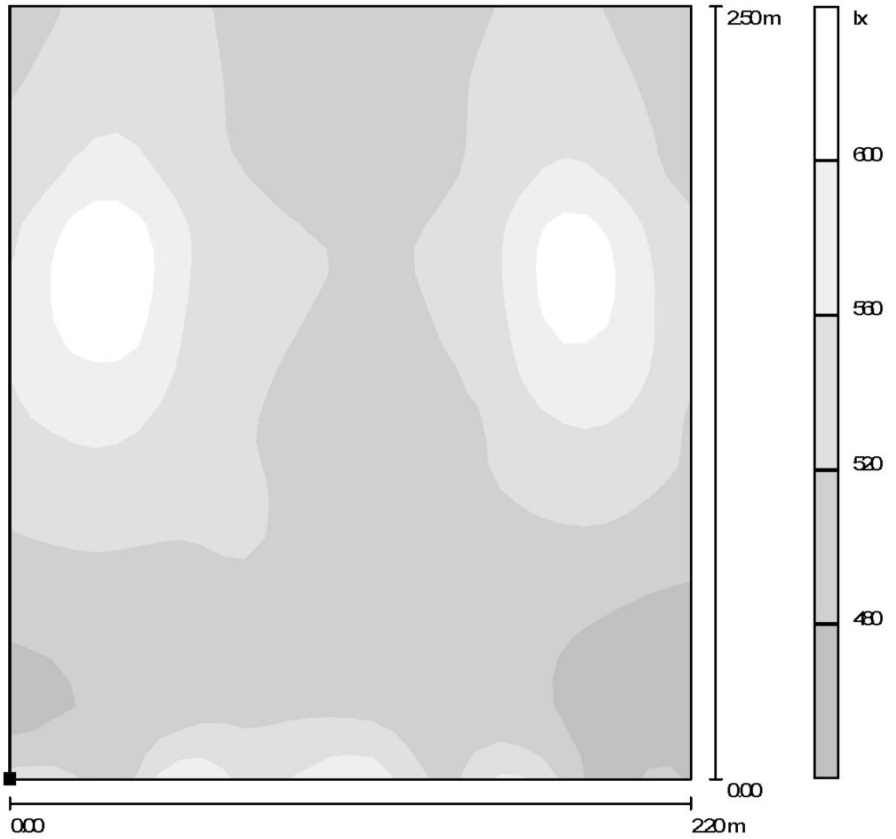
Values in Lux, Scale 1 : 20

Position of surface in room:
Marked point:
(20.730 m, 0.175 m, 0.000 m)



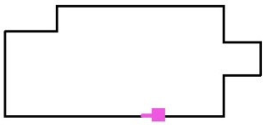
Grid: 32 x 32 Points

E_{av} [lx]	E_{min} [lx]	E_{max} [lx]	u0	E_{min} / E_{max}
527	449	638	0.85	0.70



Scale 1 : 20

Position of surface in room:
Marked point:
(20.730 m, 0.175 m, 0.000 m)



Grid: 32 x 32 Points

E_{av} [lx]	E_{min} [lx]	E_{max} [lx]	u0	E_{min} / E_{max}
527	449	638	0.85	0.70

Calculation Surface 4 / Value Chart

2.50m

510	536	544	536	524	510	500	499	494	503	514	532	539	531	511
529	545	550	541	527	513	500	499	494	503	523	538	546	539	521
539	559	561	546	524	514	501	499	495	500	523	538	554	547	528
546	582	582	550	526	519	503	500	497	503	524	543	576	569	534
582	629	625	577	542	536	525	523	516	521	534	563	619	616	567
596	633	628	582	539	534	524	522	514	520	536	569	622	621	581
593	617	619	575	530	527	521	517	511	517	523	560	608	611	581
583	602	603	565	525	525	519	513	507	515	520	549	589	594	571
554	574	573	539	523	523	515	507	500	515	516	532	560	566	560
539	555	553	538	521	524	515	503	500	516	516	515	539	547	542
526	539	534	525	523	527	521	505	507	521	521	515	523	526	524
509	519	515	513	517	521	517	504	503	514	514	507	506	507	505
489	495	499	505	516	519	515	511	505	513	510	503	489	486	472
474	479	485	497	507	509	509	507	498	503	500	494	479	471	457
469	482	488	505	512	519	516	515	508	508	504	499	481	469	461
534	509	483	588	599	516	545	607	606	517	508	573	547	471	465

0.00

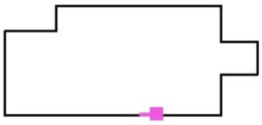
0.00

2.20m

Values in Lux, Scale 1 : 20

Not all calculated values could be displayed.

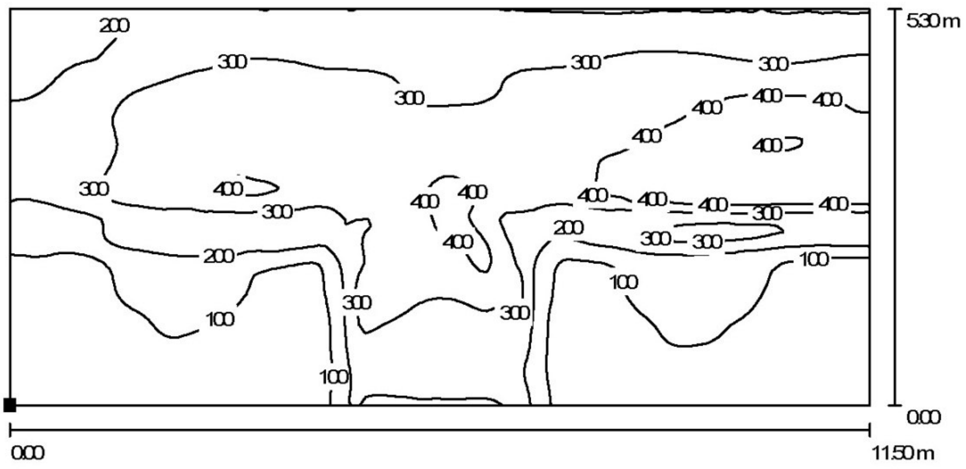
Position of surface in room:
Marked point:
(20.730 m, 0.175 m, 0.000 m)



Grid: 32 x 32 Points

E_{av} [lx]	E_{min} [lx]	E_{max} [lx]	u0	E_{min} / E_{max}
527	449	638	0.85	0.70

Calculation Surface 5 / Isolines



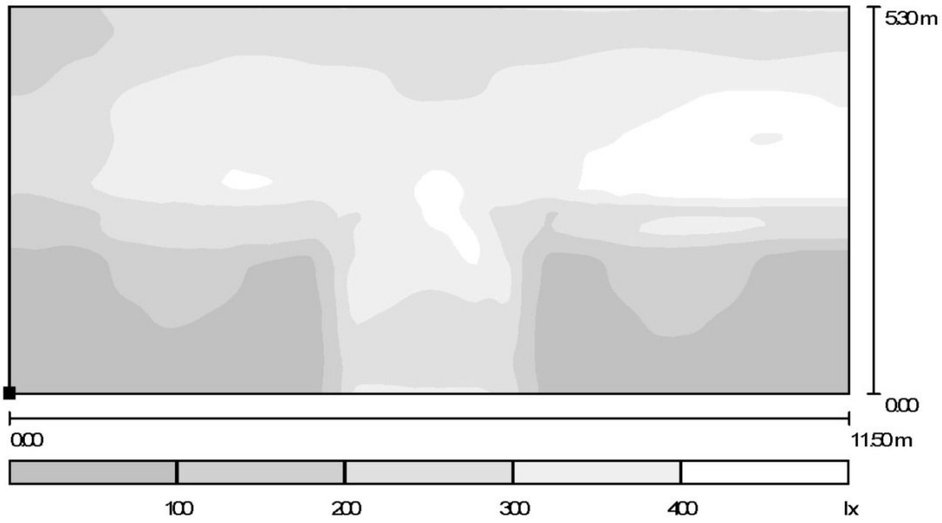
Values in Lux, Scale 1 : 83

Position of surface in room:
Marked point:
(7.001 m, 0.000 m, 0.000 m)

Grid: 128 x 64 Points

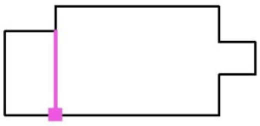
E_{av} [lx]	E_{min} [lx]	E_{max} [lx]	u0	E_{min} / E_{max}
240	13	472	0.05	0.03

Calculation Surface 5 / Greyscale



Scale 1 : 83

Position of surface in room:
Marked point:
(7.001 m, 0.000 m, 0.000 m)



Grid: 128 x 64 Points

E_{av} [lx]	E_{min} [lx]	E_{max} [lx]	u0	E_{min} / E_{max}
240	13	472	0.05	0.03

5.30 m

164	177	184	222	242	275	277	261	256	256	252	259	261	262	275	296	296	282	268	262	276
185	214	229	279	313	347	347	325	318	301	279	284	305	321	341	367	371	366	351	346	365
217	262	292	350	353	371	363	349	364	330	318	324	334	369	366	387	398	416	434	427	415
218	259	281	335	348	378	370	352	345	353	362	365	354	349	371	398	412	428	403	394	414
214	268	300	375	378	402	396	377	355	361	394	388	357	358	394	416	430	440	452	445	439
220	284	324	384	403	412	410	387	359	359	419	419	356	361	404	436	446	468	470	460	458
117	147	222	283	299	294	270	235	292	336	386	419	291	180	242	296	335	331	325	296	277
81	58	98	146	160	133	104	78	267	388	349	384	317	73	75	127	159	153	123	63	61
41	51	88	136	148	123	84	69	237	360	299	314	321	65	63	124	146	139	112	49	43
18	31	60	103	112	90	53	40	219	297	275	280	264	37	36	91	121	111	87	29	23
13	20	31	56	64	54	45	37	217	273	262	260	248	38	37	60	78	69	55	26	24
13	17	23	42	45	45	40	42	175	263	257	256	232	46	34	48	50	45	40	26	24

0.00

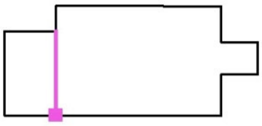
0.00

11.50 m

Values in Lux, Scale 1 : 83

Not all calculated values could be displayed.

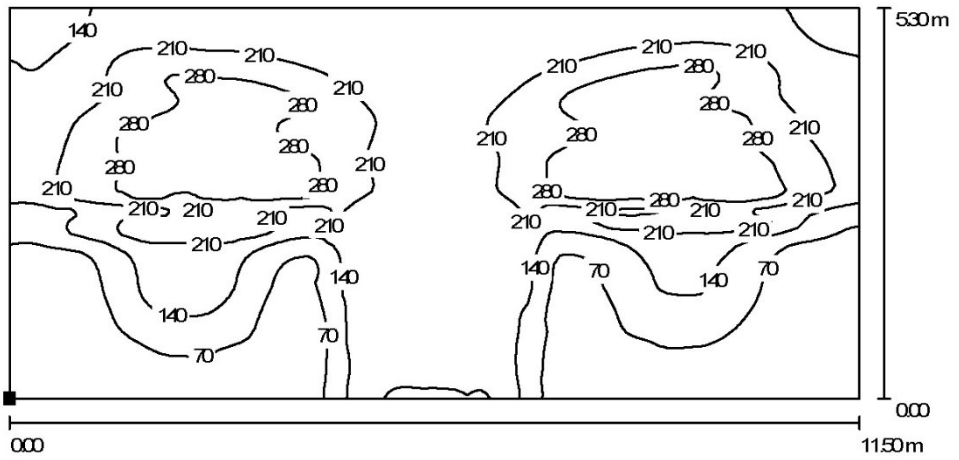
Position of surface in room:
Marked point:
(7.001 m, 0.000 m, 0.000 m)



Grid: 128 x 64 Points

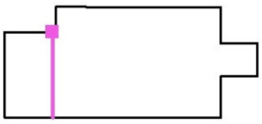
E_{av} [lx]	E_{min} [lx]	E_{max} [lx]	u0	E_{min} / E_{max}
240	13	472	0.05	0.03

Calculation Surface 6 / Isolines



Values in Lux, Scale 1 : 83

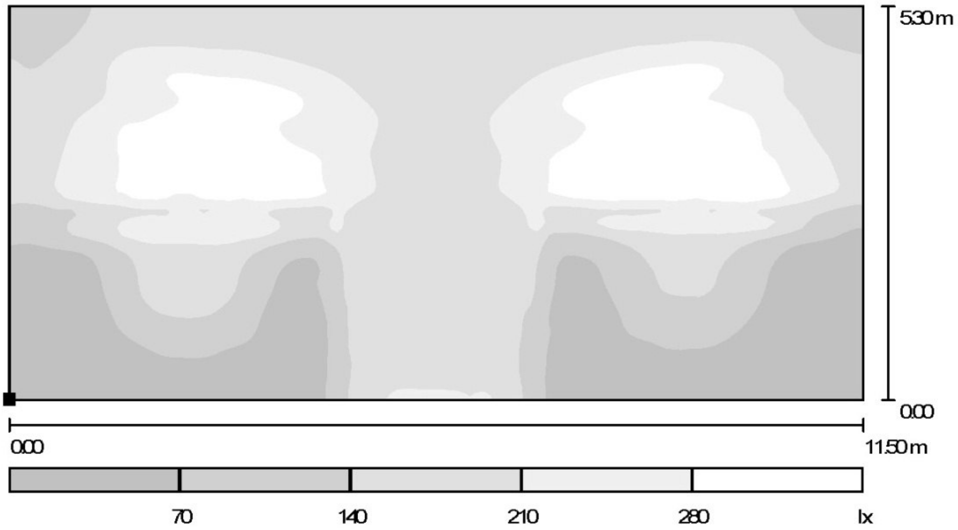
Position of surface in room:
Marked point:
(6.559 m, 11.500 m, 0.000 m)



Grid: 128 x 64 Points

E_{av} [lx]	E_{min} [lx]	E_{max} [lx]	u0	E_{min} / E_{max}
168	8.25	339	0.05	0.02

Calculation Surface 6 / Greyscale



Scale 1 : 83

Position of surface in room:
Marked point:
(6.559 m, 11.500 m, 0.000 m)

Grid: 128 x 64 Points

E_{av} [lx]	E_{min} [lx]	E_{max} [lx]	u0	E_{min} / E_{max}
168	8.25	339	0.05	0.02

Calculation Surface 6 / Value Chart

5.30 m

120	145	205	214	202	197	170	164	156	156	158	164	184	210	231	232	184	142
134	173	245	283	281	275	230	191	166	164	174	202	264	288	304	286	217	166
159	200	257	278	289	296	275	241	194	187	217	262	292	302	291	287	233	188
163	217	294	292	297	308	253	227	198	194	214	241	287	311	319	319	258	201
177	231	287	297	297	302	293	242	192	190	205	262	305	302	302	320	286	225
179	243	301	301	311	321	297	244	190	187	210	265	309	311	320	330	302	239
89	150	224	259	269	251	189	164	171	163	165	225	162	207	242	240	176	89
44	45	123	179	172	124	65	147	180	173	162	177	66	120	158	149	64	38
39	37	112	163	160	104	50	217	178	174	159	173	46	109	144	131	43	26
33	26	87	135	135	79	31	202	178	175	153	149	29	82	117	100	29	15
35	23	46	67	61	53	35	119	185	180	172	112	26	47	57	53	24	9.44
32	21	36	49	48	36	42	127	197	191	180	104	28	35	43	40	21	11

0.00

0.00

11.50 m

Values in Lux, Scale 1 : 83

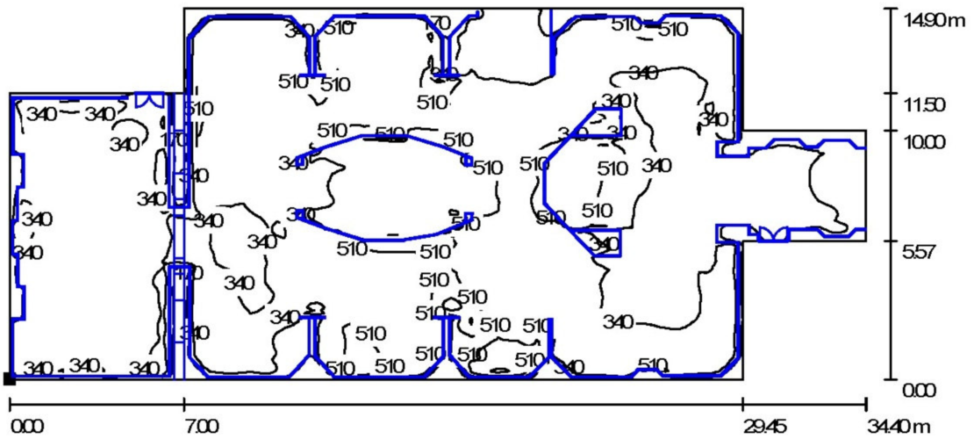
Not all calculated values could be displayed.

Position of surface in room:
Marked point:
(6.559 m, 11.500 m, 0.000 m)

Grid: 128 x 64 Points

E_{av} [lx]	E_{min} [lx]	E_{max} [lx]	u0	E_{min} / E_{max}
168	8.25	339	0.05	0.02

Floor / Isolines (E)



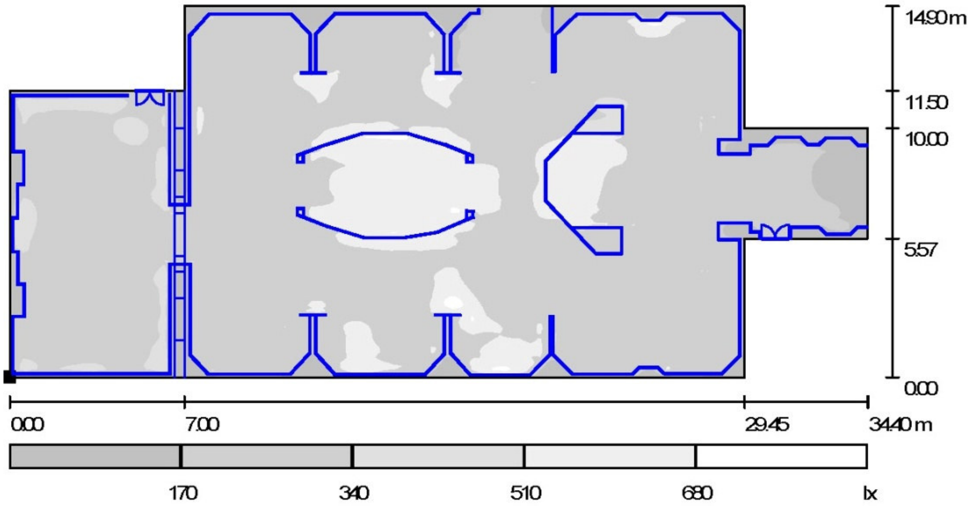
Values in Lux, Scale 1 : 246

Position of surface in room:
Marked point:
(0.000 m, 0.000 m, 0.000 m)

Grid: 128 x 128 Points

E_{av} [lx]	E_{min} [lx]	E_{max} [lx]	u0	E_{min} / E_{max}
362	20	834	0.05	0.02

Floor / Greyscale (E)

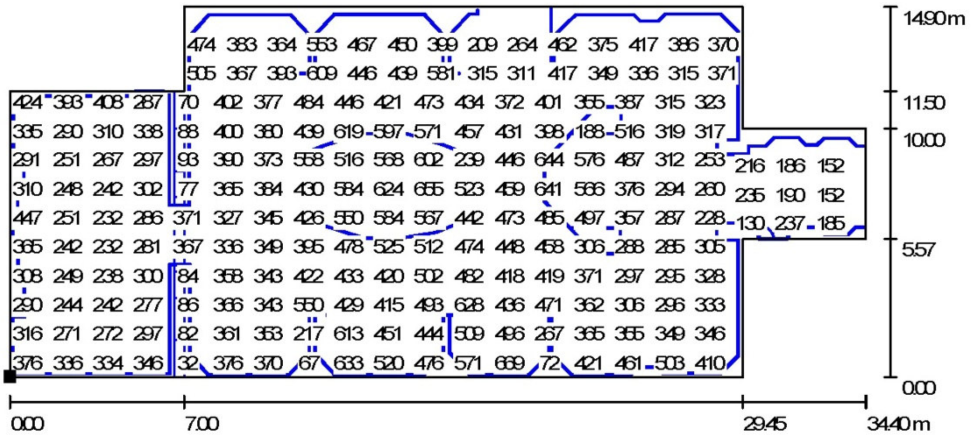


Scale 1 : 246

Position of surface in room:
Marked point:
(0.000 m, 0.000 m, 0.000 m)

Grid: 128 x 128 Points

E_{av} [lx]	E_{min} [lx]	E_{max} [lx]	u0	E_{min} / E_{max}
362	20	834	0.05	0.02



Values in Lux, Scale 1 : 246

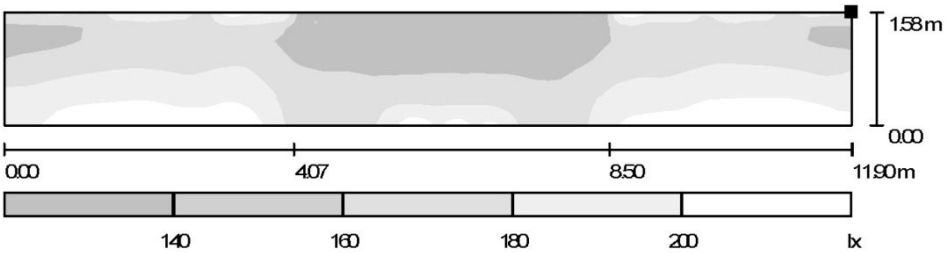
Not all calculated values could be displayed.

Position of surface in room:
Marked point:
(0.000 m, 0.000 m, 0.000 m)

Grid: 128 x 128 Points

E_{av} [lx]	E_{min} [lx]	E_{max} [lx]	u0	E_{min} / E_{max}
362	20	834	0.05	0.02

Ceiling / Greyscale (E)



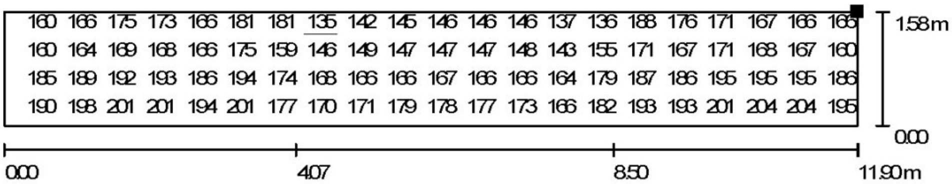
Scale 1 : 86

Position of surface in room:
Marked point:
(29.450 m, 13.400 m, 5.800 m)

Grid: 128 x 128 Points

E_{av} [lx]	E_{min} [lx]	E_{max} [lx]	u0	E_{min} / E_{max}
173	135	219	0.78	0.62

Ceiling / Value Chart (E)



160	166	175	173	166	181	181	135	142	145	146	146	146	137	136	188	176	171	167	166	165
160	164	169	168	166	175	159	146	149	147	147	147	148	143	155	171	167	171	168	167	160
185	189	192	193	186	194	174	168	166	166	167	166	166	164	179	187	186	195	195	195	186
190	198	201	201	194	201	177	170	171	179	178	177	173	166	182	193	193	201	204	204	195

Values in Lux, Scale 1 : 86

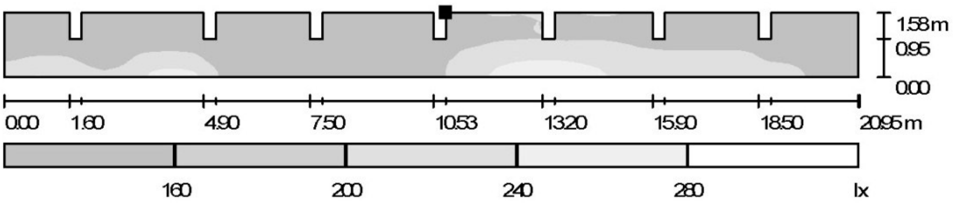
Not all calculated values could be displayed.

Position of surface in room:
Marked point:
(29.450 m, 13.400 m, 5.800 m)

Grid: 128 x 128 Points

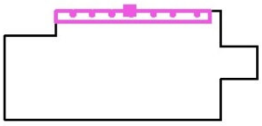
E_{av} [lx]	E_{min} [lx]	E_{max} [lx]	u0	E_{min} / E_{max}
173	135	219	0.78	0.62

Ceiling / Greyscale (E)



Scale 1 : 150

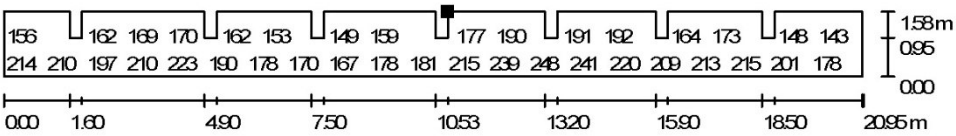
Position of surface in room:
Marked point:
(17.120 m, 14.900 m, 5.800 m)



Grid: 128 x 128 Points

E_{av} [lx]	E_{min} [lx]	E_{max} [lx]	u0	E_{min} / E_{max}
186	120	285	0.65	0.42

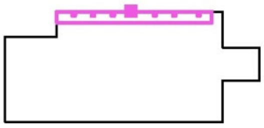
Ceiling / Value Chart (E)



Values in Lux, Scale 1 : 150

Not all calculated values could be displayed.

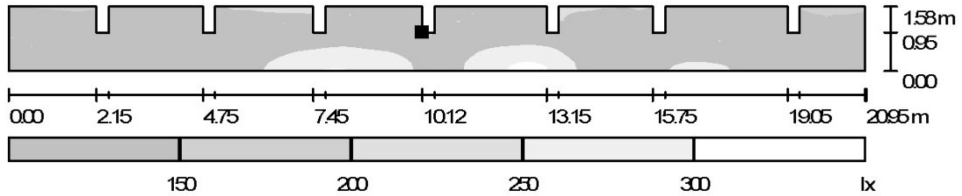
Position of surface in room:
Marked point:
(17.120 m, 14.900 m, 5.800 m)



Grid: 128 x 128 Points

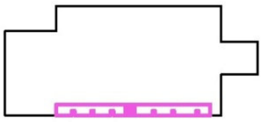
E_{av} [lx]	E_{min} [lx]	E_{max} [lx]	u0	E_{min} / E_{max}
186	120	285	0.65	0.42

Ceiling / Greyscale (E)



Scale 1 : 150

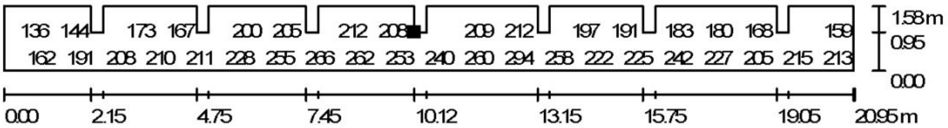
Position of surface in room:
Marked point:
(17.120 m, 0.600 m, 5.600 m)



Grid: 128 x 128 Points

E_{av} [lx]	E_{min} [lx]	E_{max} [lx]	u0	E_{min} / E_{max}
204	115	342	0.56	0.34

Ceiling / Value Chart (E)



Values in Lux, Scale 1 : 150

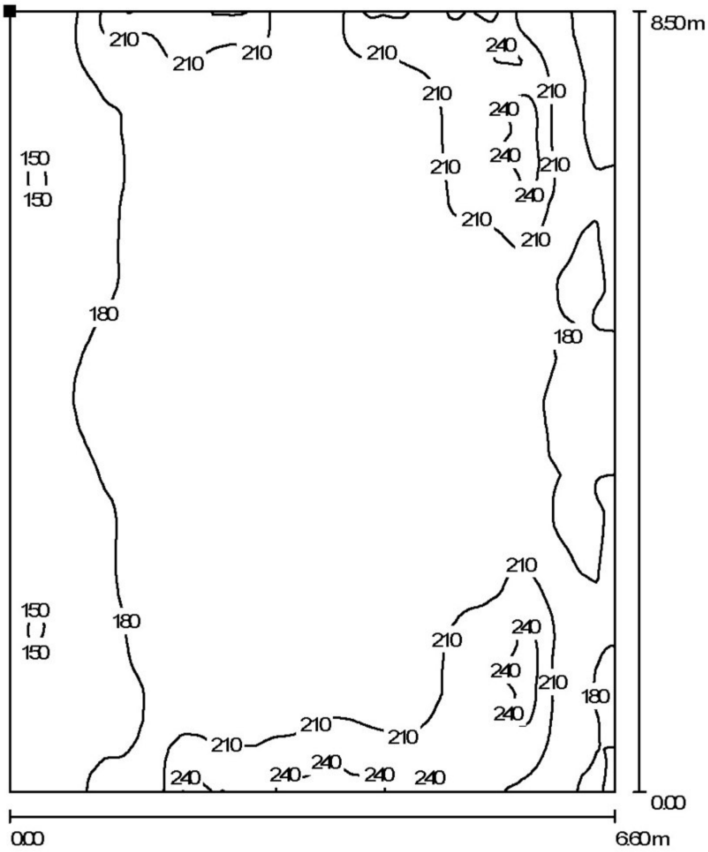
Not all calculated values could be displayed.

Position of surface in room:
Marked point:
(17.120 m, 0.600 m, 5.600 m)

Grid: 128 x 128 Points

E_{av} [lx]	E_{min} [lx]	E_{max} [lx]	u0	E_{min} / E_{max}
204	115	342	0.56	0.34

Ceiling / Isolines (E)



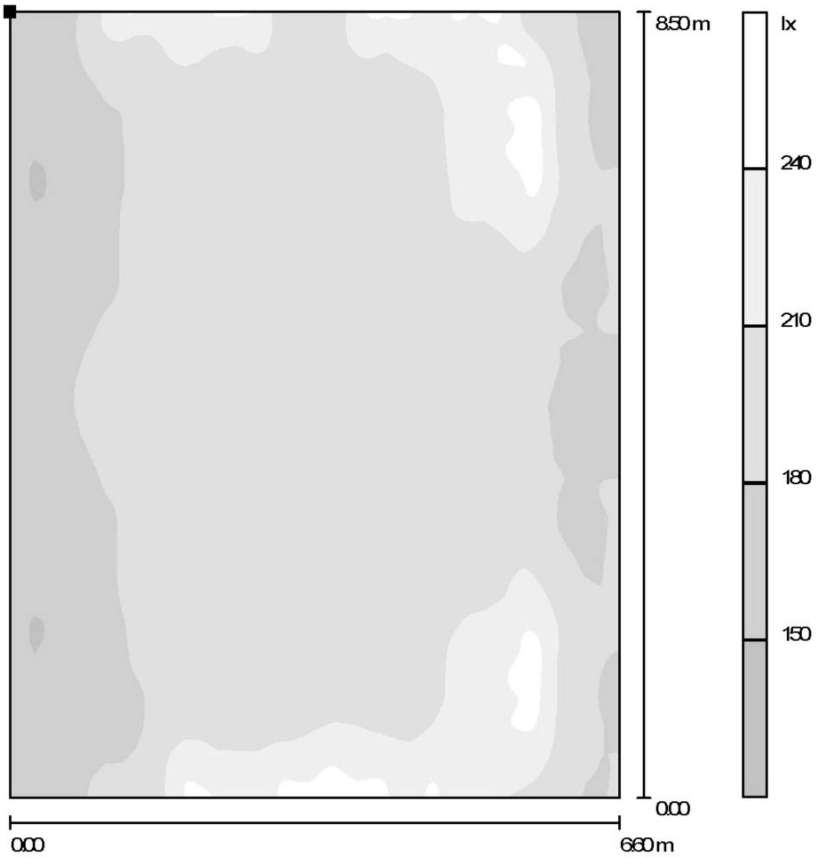
Values in Lux, Scale 1 : 67

Position of surface in room:
Marked point:
(0.000 m, 1.500 m, 5.300 m)

Grid: 128 x 128 Points

E_{av} [lx]	E_{min} [lx]	E_{max} [lx]	u0	E_{min} / E_{max}
193	146	269	0.75	0.54

Ceiling / Greyscale (E)



Scale 1 : 67

Position of surface in room:
Marked point:
(0.000 m, 1.500 m, 5.300 m)

Grid: 128 x 128 Points

E_{av} [lx]	E_{min} [lx]	E_{max} [lx]	u0	E_{min} / E_{max}
193	146	269	0.75	0.54

8.50m

153	178	222	218	230	215	196	196	231	234	235	239	198	176
156	178	198	198	219	207	195	196	213	214	220	250	220	174
153	168	178	184	199	193	188	190	194	201	215	225	236	177
150	160	178	182	198	191	187	191	192	199	216	238	256	173
154	157	178	188	206	191	187	191	192	199	216	241	254	181
149	151	174	194	197	193	187	189	190	196	215	220	252	181
151	155	178	198	201	196	191	193	194	199	213	212	228	178
154	155	177	192	199	195	191	193	194	199	209	203	220	176
154	159	179	190	197	193	191	193	194	197	204	199	205	173
155	159	177	186	198	193	191	193	194	197	202	193	199	170
159	170	187	186	198	194	191	193	193	195	197	189	190	178
160	178	184	186	200	195	192	193	193	193	194	185	187	172
161	181	181	186	205	195	192	193	193	193	194	185	187	172
163	180	182	187	207	192	191	194	194	195	196	184	185	172
158	166	184	190	208	195	192	194	194	196	198	186	187	177
156	162	181	188	208	197	192	194	194	196	198	190	190	182
155	160	177	186	206	197	193	195	196	198	203	193	196	169
156	160	179	193	204	197	193	195	196	198	203	193	201	172
156	157	179	200	203	198	193	195	196	200	210	203	223	178
151	153	174	199	200	194	189	190	191	196	210	213	222	193
149	153	173	194	198	194	189	190	191	196	212	220	250	184
153	156	176	185	205	196	192	195	195	199	217	232	254	186
153	166	174	179	199	198	198	203	202	201	216	222	248	182
154	170	175	182	211	204	208	216	214	207	227	234	234	182
152	172	177	187	221	210	227	242	223	216	239	245	221	179

0.00

0.00

6.60m

Values in Lux, Scale 1 : 67

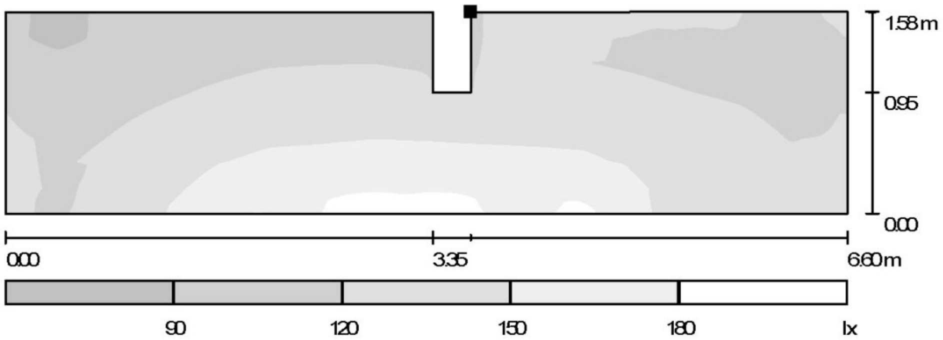
Not all calculated values could be displayed.

Position of surface in room:
Marked point:
(0.000 m, 1.500 m, 5.300 m)

Grid: 128 x 128 Points

E_{av} [lx]	E_{min} [lx]	E_{max} [lx]	u0	E_{min} / E_{max}
193	146	269	0.75	0.54

Ceiling / Greyscale (E)



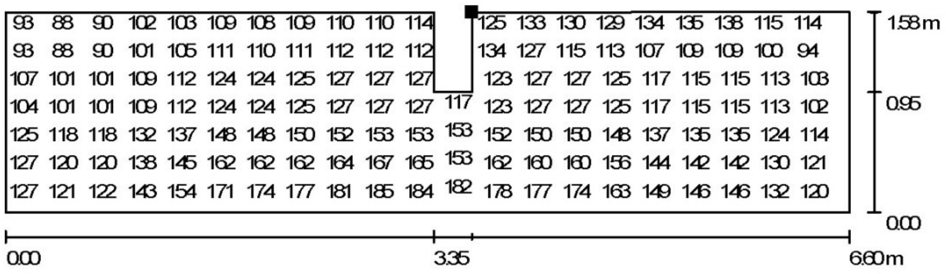
Scale 1 : 48

Position of surface in room:
Marked point:
(2.950 m, 11.500 m, 5.800 m)

Grid: 128 x 128 Points

E_{av} [lx]	E_{min} [lx]	E_{max} [lx]	u0	E_{min} / E_{max}
130	85	200	0.66	0.43

Ceiling / Value Chart (E)



93	88	90	102	103	109	108	109	110	110	114		125	133	130	129	134	135	138	115	114
93	88	90	101	105	111	110	111	112	112	112		134	127	115	113	107	109	109	100	94
107	101	101	109	112	124	124	125	127	127	127		123	127	127	125	117	115	115	113	103
104	101	101	109	112	124	124	125	127	127	127	117	123	127	127	125	117	115	115	113	102
125	118	118	132	137	148	148	150	152	153	153	153	152	150	150	148	137	135	135	124	114
127	120	120	138	145	162	162	162	164	167	165	153	162	160	160	156	144	142	142	130	121
127	121	122	143	154	171	174	177	181	185	184	182	178	177	174	163	149	146	146	132	120

Values in Lux, Scale 1 : 48

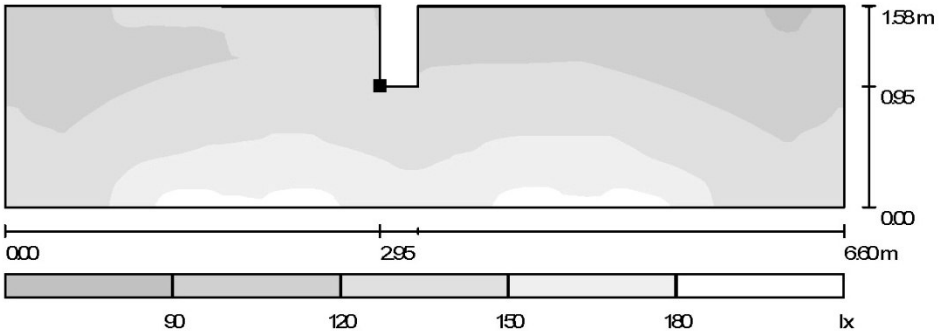
Not all calculated values could be displayed.

Position of surface in room:
Marked point:
(2.950 m, 11.500 m, 5.800 m)

Grid: 128 x 128 Points

E_{av} [lx]	E_{min} [lx]	E_{max} [lx]	u0	E_{min} / E_{max}
130	85	200	0.66	0.43

Ceiling / Greyscale (E)



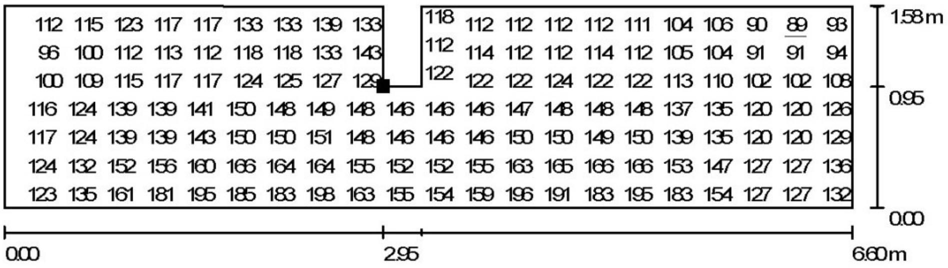
Scale 1 : 48

Position of surface in room:
Marked point:
(2.950 m, 0.600 m, 5.600 m)

Grid: 128 x 128 Points

E_{av} [lx]	E_{min} [lx]	E_{max} [lx]	u0	E_{min} / E_{max}
132	89	199	0.68	0.45

Ceiling / Value Chart (E)



112	115	123	117	117	133	133	139	133		118	112	112	112	112	111	104	106	90	89	93
96	100	112	113	112	118	118	133	143		112	114	112	112	114	112	105	104	91	91	94
100	109	115	117	117	124	125	127	129		122	122	122	124	122	122	113	110	102	102	108
116	124	139	139	141	150	148	149	148	146	146	146	147	148	148	148	137	135	120	120	126
117	124	139	139	143	150	150	151	148	146	146	146	150	150	149	150	139	135	120	120	129
124	132	152	156	160	166	164	164	155	152	152	155	163	165	166	166	153	147	127	127	136
123	135	161	181	195	185	183	198	163	155	154	159	196	191	183	195	183	154	127	127	132

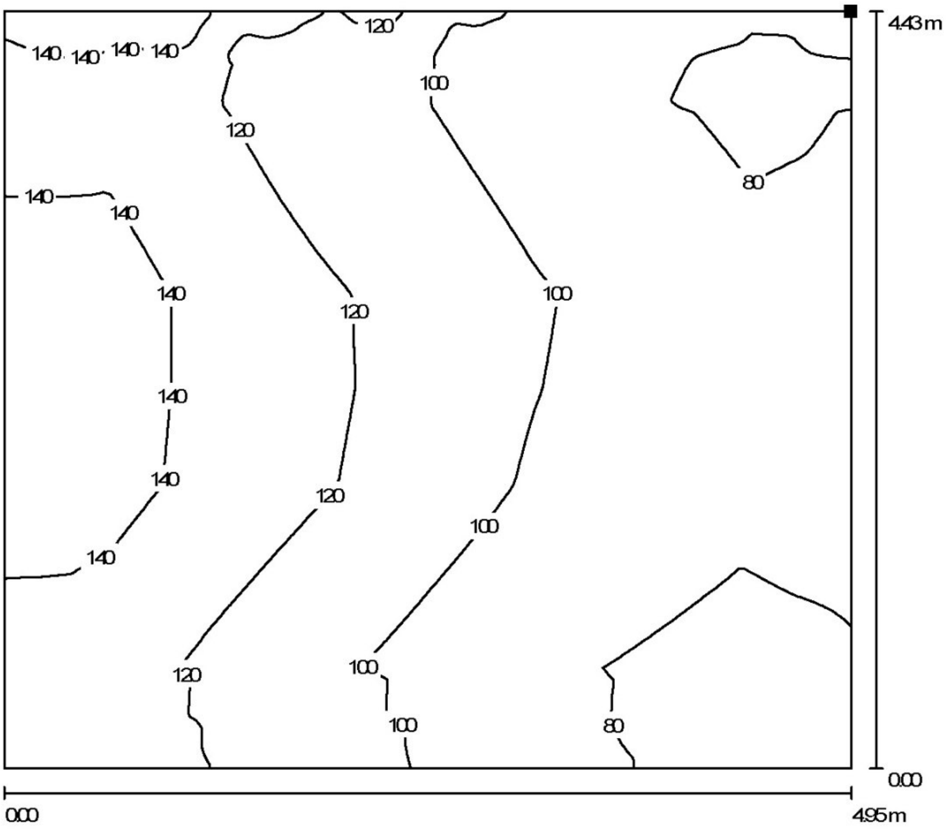
Values in Lux, Scale 1 : 48

Not all calculated values could be displayed.

Position of surface in room:
Marked point:
(2.950 m, 0.600 m, 5.600 m)

Grid: 128 x 128 Points

E_{av} [lx]	E_{min} [lx]	E_{max} [lx]	u0	E_{min} / E_{max}
132	89	199	0.68	0.45

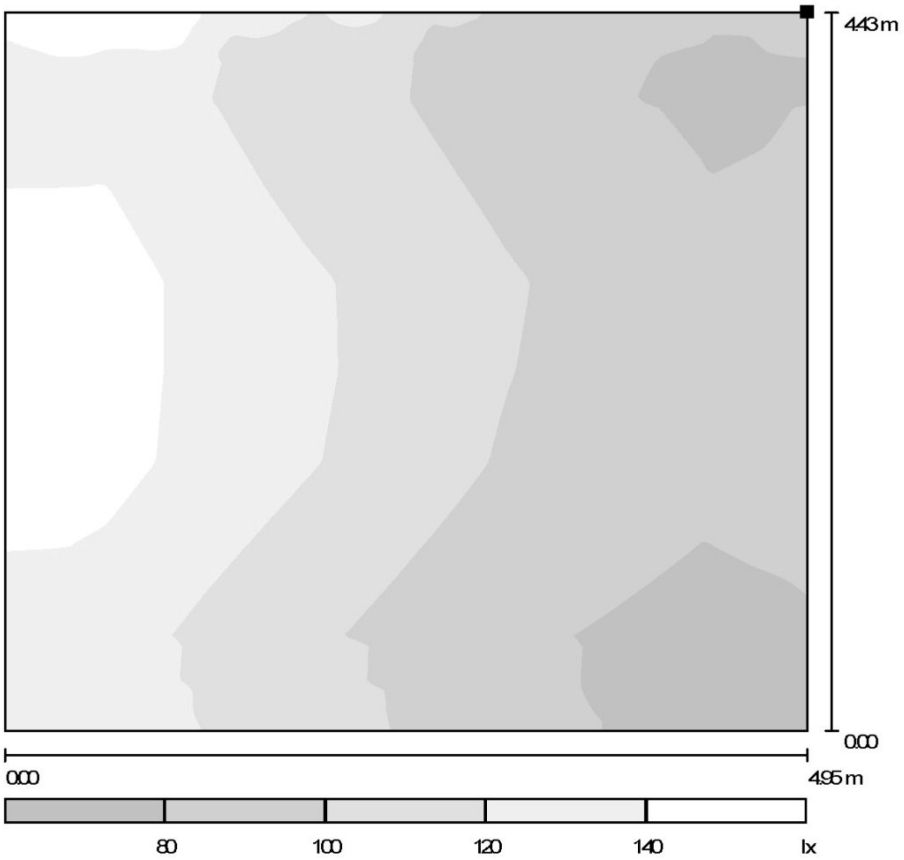


Values in Lux, Scale 1 : 36

Position of surface in room:
Marked point:
(34.400 m, 5.570 m, 5.800 m)

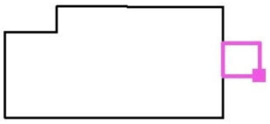
Grid: 128 x 128 Points

E_{av} [lx]	E_{min} [lx]	E_{max} [lx]	u0	E_{min} / E_{max}
107	70	155	0.66	0.45



Scale 1 : 38

Position of surface in room:
Marked point:
(34.400 m, 5.570 m, 5.800 m)



Grid: 128 x 128 Points

E_{av} [lx]	E_{min} [lx]	E_{max} [lx]	u0	E_{min} / E_{max}
107	70	155	0.66	0.45

4.43 m

151	155	147	151	146	122	125	121	123	123	100	103	98	97	100	97	83	83	80	80	84
142	146	138	142	137	114	117	113	115	114	93	96	92	91	93	91	83	83	80	80	84
133	136	133	133	133	110	109	109	108	109	92	92	90	88	88	88	77	76	75	75	75
135	135	132	132	132	110	110	110	109	109	92	92	92	89	89	89	78	78	76	76	83
135	135	132	132	132	110	110	110	109	109	92	92	92	89	89	89	78	78	76	76	83
135	135	132	132	132	110	110	110	109	109	92	92	92	89	89	89	78	78	76	76	83
151	151	145	145	145	122	122	122	122	122	102	102	102	100	100	100	86	86	85	85	92
151	151	145	145	145	122	122	122	122	122	102	102	102	100	100	100	86	86	85	85	92
151	151	145	145	145	122	122	122	122	122	102	102	102	100	100	100	86	86	85	85	92
151	151	145	145	145	122	122	122	122	122	102	102	102	100	100	100	86	86	85	85	92
150	150	146	146	146	124	124	124	124	124	104	104	104	101	101	101	87	87	86	86	87
150	150	146	146	146	124	124	124	124	124	104	104	104	101	101	101	87	87	86	86	92
150	150	146	146	146	124	124	124	124	124	104	104	104	101	101	101	87	87	86	86	92
148	148	145	145	145	123	123	123	123	123	100	100	100	98	98	98	86	86	85	85	91
148	148	145	145	145	123	123	123	123	123	100	100	100	98	98	98	86	86	85	85	86
148	148	145	145	145	123	123	123	123	123	100	100	100	98	98	98	86	86	85	85	86
148	148	144	144	144	121	121	121	120	120	98	98	98	96	96	96	84	84	83	83	90
148	148	144	144	144	121	121	121	120	120	98	98	98	96	96	96	84	84	83	83	90
148	148	144	144	144	121	121	121	120	120	98	98	98	96	96	96	84	84	83	83	90
131	131	127	127	127	104	104	104	103	103	84	84	84	83	83	83	75	75	74	74	80
131	131	127	127	127	104	104	104	103	103	84	84	84	83	83	83	75	75	74	74	80
131	131	127	127	127	104	104	104	103	103	84	84	84	83	83	83	75	75	74	74	80
127	130	125	125	125	103	103	103	102	101	84	84	82	82	82	82	72	72	71	71	72
127	130	125	125	125	103	103	103	102	101	84	84	82	82	82	82	72	72	71	71	72
129	130	126	126	125	103	104	104	103	102	84	84	83	83	83	83	73	73	70	70	72

0.00

0.00

4.95 m

Values in Lux, Scale 1 : 36

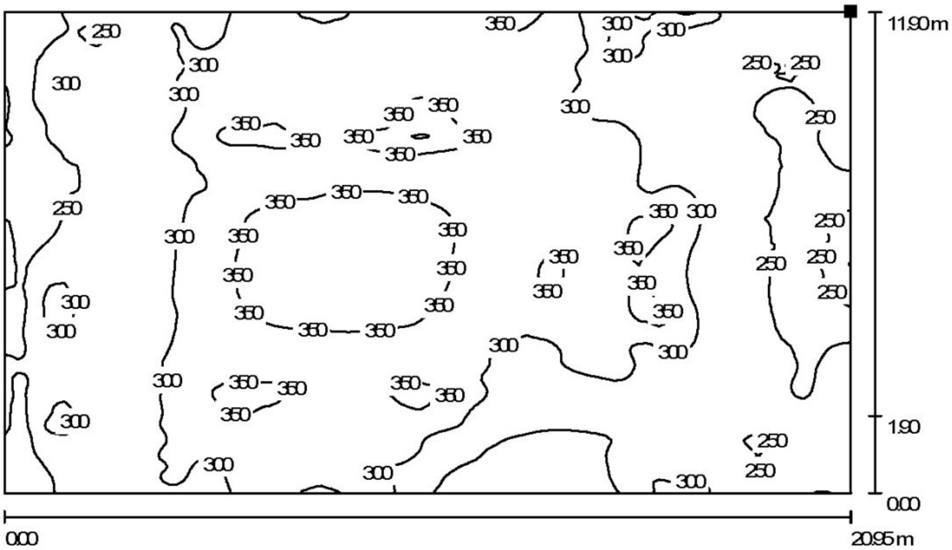
Not all calculated values could be displayed.

Position of surface in room:
Marked point:
(34.400 m, 5.570 m, 5.800 m)

Grid: 128 x 128 Points

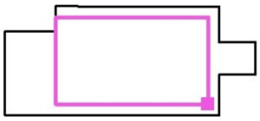
E_{av} [lx]	E_{min} [lx]	E_{max} [lx]	u0	E_{min} / E_{max}
107	70	155	0.66	0.45

Ceiling / Isolines (E)



Values in Lux, Scale 1 : 150

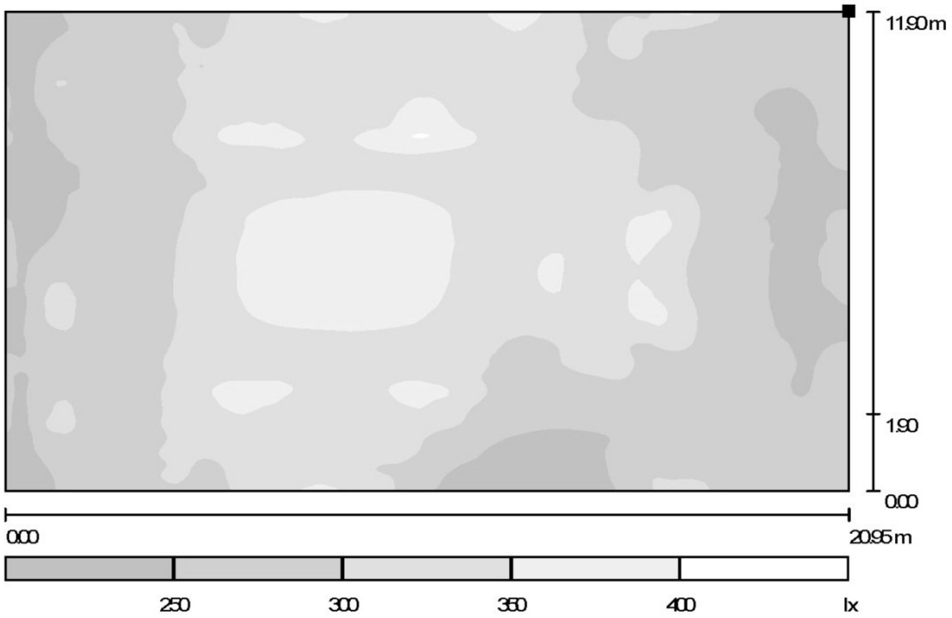
Position of surface in room:
Marked point:
(27.950 m, 1.500 m, 5.300 m)



Grid: 128 x 128 Points

E_{av} [lx]	E_{min} [lx]	E_{max} [lx]	u0	E_{min} / E_{max}
299	201	419	0.67	0.48

Ceiling / Greyscale (E)



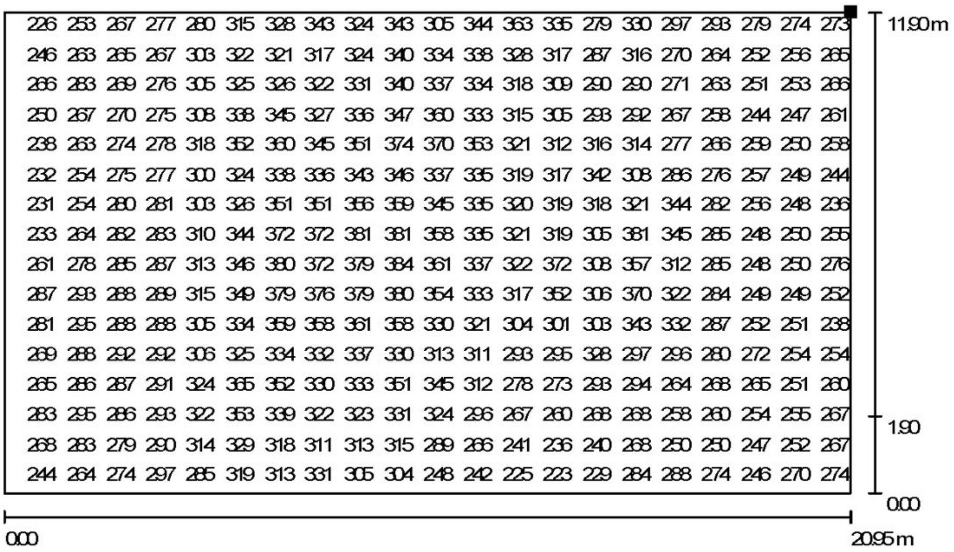
Scale 1 : 150

Position of surface in room:
Marked point:
(27.950 m, 1.500 m, 5.300 m)

Grid: 128 x 128 Points

E_{av} [lx]	E_{min} [lx]	E_{max} [lx]	u0	E_{min} / E_{max}
299	201	419	0.67	0.48

Ceiling / Value Chart (E)



226	253	267	277	280	315	328	343	324	343	305	344	363	335	279	330	297	293	279	274	273
246	263	265	267	303	322	321	317	324	340	334	338	328	317	287	316	270	264	252	256	265
266	283	269	276	305	325	326	322	331	340	337	334	318	309	290	290	271	263	251	253	266
250	267	270	275	308	338	345	327	336	347	360	333	315	305	293	292	267	258	244	247	261
238	263	274	278	318	352	360	345	351	374	370	353	321	312	316	314	277	266	259	250	258
232	254	275	277	300	324	338	336	343	346	337	335	319	317	342	308	286	276	257	249	244
231	254	280	281	303	326	351	351	356	359	345	335	320	319	318	321	344	282	256	248	236
233	264	282	283	310	344	372	372	381	381	358	335	321	319	305	381	345	285	248	250	255
261	278	285	287	313	346	380	372	379	384	361	337	322	372	308	357	312	285	248	250	276
287	293	288	289	315	349	379	376	379	380	354	333	317	352	306	370	322	284	249	249	252
281	295	288	288	305	334	359	358	361	358	330	321	304	301	303	343	332	287	252	251	238
269	288	292	292	306	325	334	332	337	330	313	311	293	295	328	297	296	280	272	254	254
265	286	287	291	324	365	352	330	333	351	345	312	278	273	293	294	264	268	265	251	260
283	295	286	293	322	353	339	322	323	331	324	296	267	260	268	268	258	260	254	255	267
268	283	279	290	314	329	318	311	313	315	289	266	241	236	240	268	250	250	247	252	267
244	264	274	297	285	319	313	331	305	304	248	242	225	223	229	284	288	274	246	270	274

Values in Lux, Scale 1 : 150

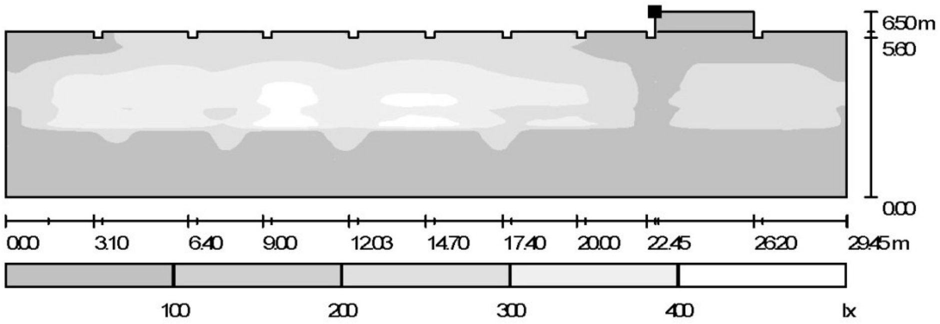
Not all calculated values could be displayed.

Position of surface in room:
Marked point:
(27.950 m, 1.500 m, 5.300 m)

Grid: 128 x 128 Points

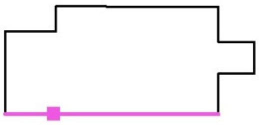
E_{av} [lx]	E_{min} [lx]	E_{max} [lx]	u0	E_{min} / E_{max}
299	201	419	0.67	0.48

Wall / Greyscale (E)



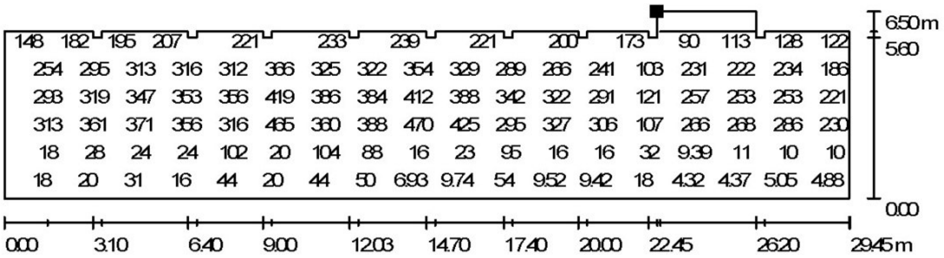
Scale 1 : 211

Position of surface in room:
Marked point:
(6.700 m, 0.000 m, 6.500 m)



Grid: 128 x 128 Points

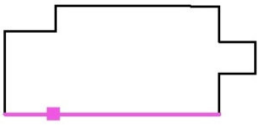
E_{av} [lx]	E_{min} [lx]	E_{max} [lx]	u0	E_{min} / E_{max}
175	3.39	481	0.02	0.01



Values in Lux, Scale 1 : 211

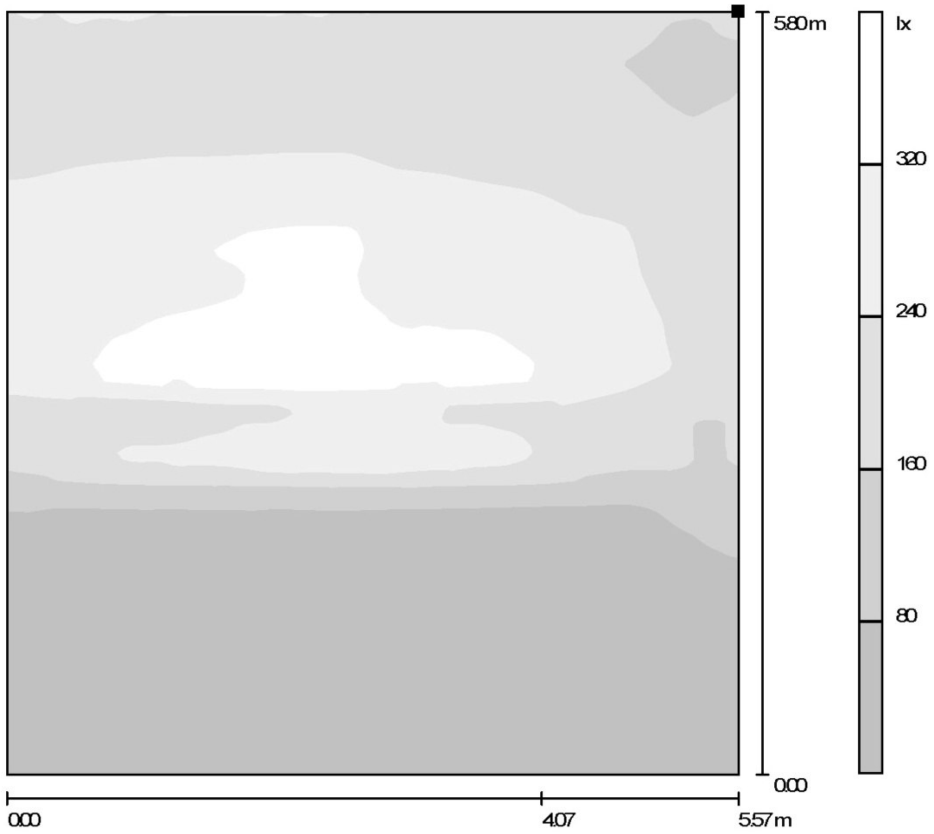
Not all calculated values could be displayed.

Position of surface in room:
Marked point:
(6.700 m, 0.000 m, 6.500 m)



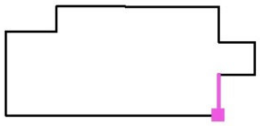
Grid: 128 x 128 Points

E_{av} [lx]	E_{min} [lx]	E_{max} [lx]	u0	E_{min} / E_{max}
175	3.39	481	0.02	0.01



Scale 1 : 46

Position of surface in room:
Marked point:
(29.450 m, 0.000 m, 5.800 m)



Grid: 128 x 128 Points

E_{av} [lx]	E_{min} [lx]	E_{max} [lx]	u0	E_{min} / E_{max}
168	17	371	0.10	0.05

5.80 m

225	228	225	222	225	224	221	223	214	204	203	201	200	180	179	175	162	167
201	205	205	207	202	201	199	206	207	189	187	184	182	169	165	162	150	157
203	205	202	205	204	203	203	204	204	190	187	184	180	164	164	158	150	159
222	223	224	223	223	222	222	222	223	209	207	204	199	183	183	181	166	173
222	227	228	230	227	230	230	230	231	219	215	209	203	183	183	181	166	176
236	240	242	245	249	249	250	252	251	238	234	226	219	202	201	196	183	192
283	293	299	308	312	317	317	318	319	302	299	290	279	250	249	238	217	221
288	299	306	316	320	322	323	325	324	308	304	294	281	255	253	241	218	226
289	300	308	317	320	323	326	326	326	308	306	299	290	261	259	247	226	232
284	295	303	312	315	317	319	320	318	303	301	295	287	260	257	245	225	234
287	305	317	322	324	332	339	337	340	320	323	321	313	277	273	260	235	236
300	317	326	340	345	351	356	360	360	344	344	337	322	291	289	269	236	233
314	323	329	344	354	358	358	369	363	354	352	341	328	300	298	277	241	236
187	192	202	206	221	228	229	238	233	241	237	229	224	212	207	186	165	164
202	224	240	246	255	266	272	271	275	270	265	257	246	214	203	181	164	163
173	206	220	223	225	237	258	244	261	244	236	235	229	201	175	160	167	159
76	79	75	77	79	81	74	82	82	76	76	76	72	68	71	65	116	126
72	64	60	61	63	64	60	63	64	59	59	59	56	56	57	55	79	123
61	54	53	52	53	53	53	53	53	49	49	48	48	50	49	49	60	59
29	23	23	22	22	23	22	22	22	21	21	21	21	23	24	24	31	29
20	23	23	22	22	23	22	22	22	21	21	21	21	23	24	24	31	29
19	19	19	18	19	19	18	18	18	18	18	17	17	19	22	22	26	25
24	25	26	24	25	25	24	24	25	25	24	24	23	24	27	27	29	28
24	25	26	24	25	25	24	24	25	25	24	24	23	24	27	27	29	28
33	37	39	36	39	38	37	37	38	40	39	36	32	35	35	31	32	28

0.00

0.00 4.07 5.57 m

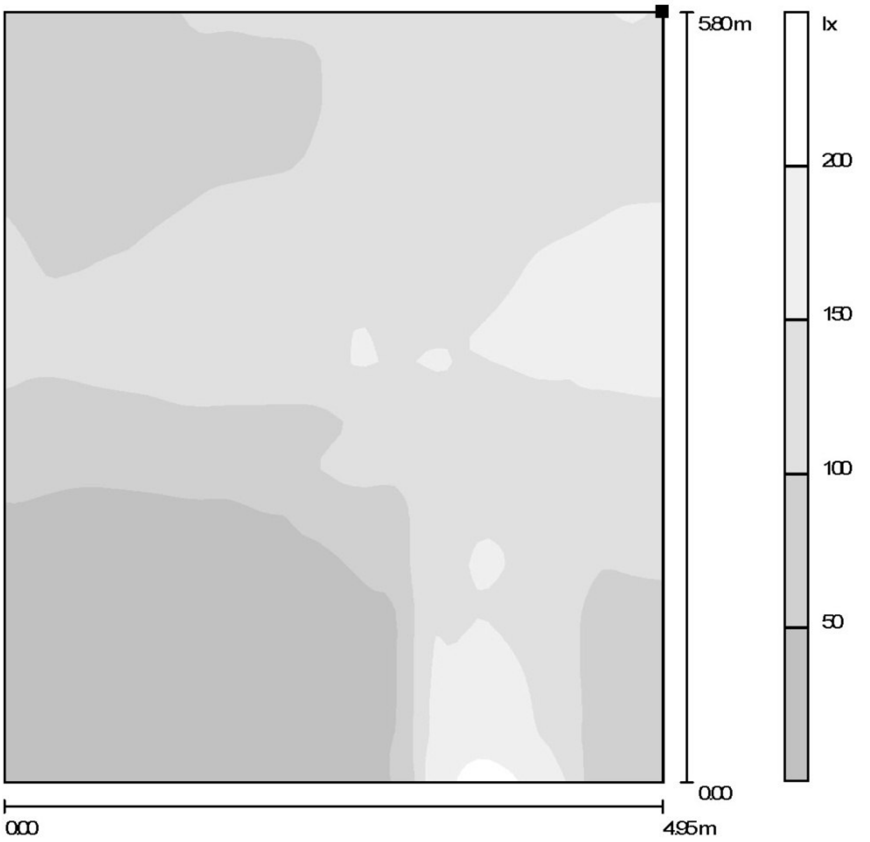
Values in Lux, Scale 1 : 46

Not all calculated values could be displayed.

Position of surface in room:
Marked point:
(29.450 m, 0.000 m, 5.800 m)

Grid: 128 x 128 Points

E_{av} [lx]	E_{min} [lx]	E_{max} [lx]	u0	E_{min} / E_{max}
168	17	371	0.10	0.05

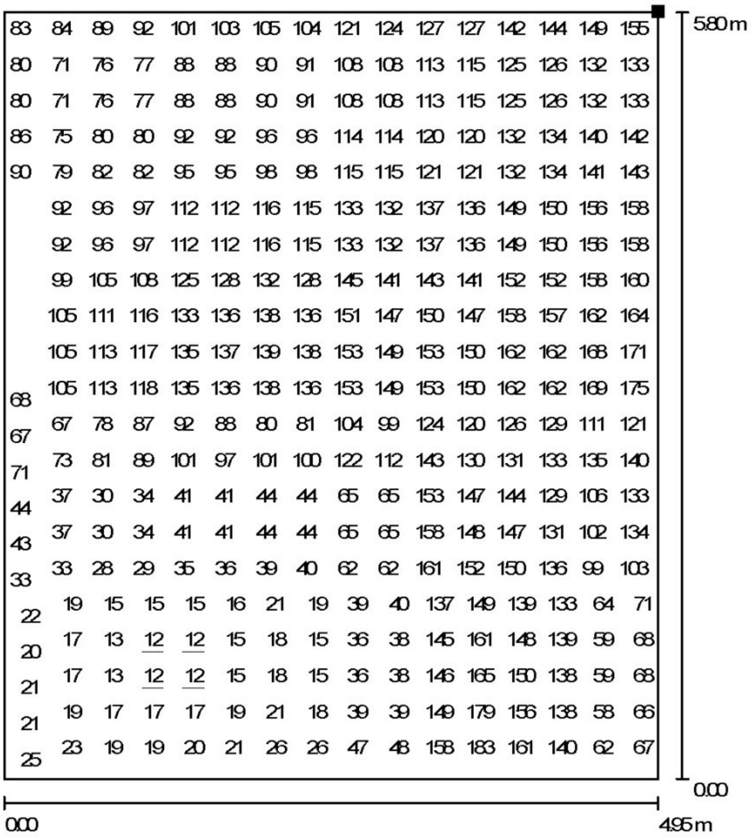


Scale 1 : 46

Position of surface in room:
Marked point:
(29.450 m, 5.570 m, 5.800 m)

Grid: 64 x 64 Points

E_{av} [lx]	E_{min} [lx]	E_{max} [lx]	u0	E_{min} / E_{max}
98	12	221	0.12	0.05



83	84	89	92	101	103	105	104	121	124	127	127	142	144	149	155
80	71	76	77	88	88	90	91	108	108	113	115	125	126	132	133
80	71	76	77	88	88	90	91	108	108	113	115	125	126	132	133
86	75	80	80	92	92	96	96	114	114	120	120	132	134	140	142
90	79	82	82	95	95	98	98	115	115	121	121	132	134	141	143
	92	96	97	112	112	116	115	133	132	137	136	149	150	156	158
	92	96	97	112	112	116	115	133	132	137	136	149	150	156	158
	99	105	108	125	128	132	128	145	141	143	141	152	152	158	160
	105	111	116	133	136	138	136	151	147	150	147	158	157	162	164
	105	113	117	135	137	139	138	153	149	153	150	162	162	168	171
68	105	113	118	135	136	138	136	153	149	153	150	162	162	169	175
67	67	78	87	92	88	80	81	104	99	124	120	126	129	111	121
71	73	81	89	101	97	101	100	122	112	143	130	131	133	135	140
44	37	30	34	41	41	44	44	65	65	153	147	144	129	106	133
43	37	30	34	41	41	44	44	65	65	158	148	147	131	102	134
33	33	28	29	35	36	39	40	62	62	161	152	150	136	99	103
22	19	15	15	15	16	21	19	39	40	137	149	139	133	64	71
20	17	13	12	12	15	18	15	36	38	145	161	148	139	59	68
21	17	13	12	12	15	18	15	36	38	146	165	150	138	59	68
21	19	17	17	17	19	21	18	39	39	149	179	156	138	58	66
25	23	19	19	20	21	26	26	47	48	158	183	161	140	62	67

Values in Lux, Scale 1 : 46

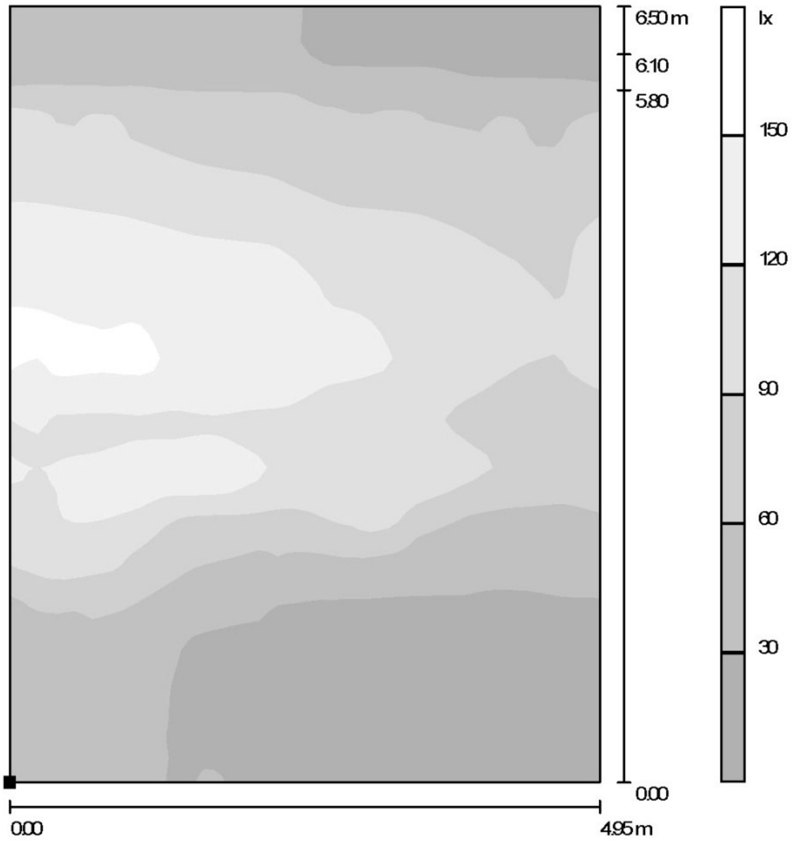
Not all calculated values could be displayed.

Position of surface in room:
Marked point:
(29.450 m, 5.570 m, 5.800 m)

Grid: 64 x 64 Points

E_{av} [lx]	E_{min} [lx]	E_{max} [lx]	u0	E_{min} / E_{max}
98	12	221	0.12	0.05

Wall / Greyscale (E)



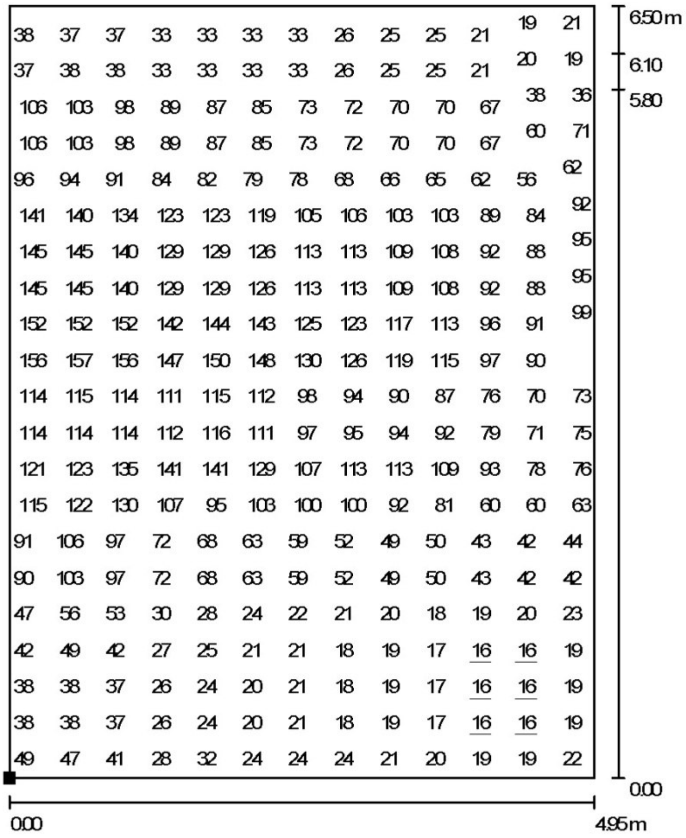
Scale 1 : 51

Position of surface in room:
Marked point:
(29.450 m, 10.000 m, 0.000 m)

Grid: 64 x 64 Points

E_{av} [lx]	E_{min} [lx]	E_{max} [lx]	u0	E_{min} / E_{max}
74	16	158	0.21	0.10

Wall / Value Chart (E)



38	37	37	33	33	33	33	26	25	25	21	19	21
37	38	38	33	33	33	33	26	25	25	21	20	19
106	103	98	89	87	85	73	72	70	70	67	38	36
106	103	98	89	87	85	73	72	70	70	67	60	71
96	94	91	84	82	79	78	68	66	65	62	56	62
141	140	134	123	123	119	105	106	103	103	89	84	92
145	145	140	129	129	126	113	113	109	108	92	88	95
145	145	140	129	129	126	113	113	109	108	92	88	95
152	152	152	142	144	143	125	123	117	113	96	91	99
156	157	156	147	150	148	130	126	119	115	97	90	
114	115	114	111	115	112	98	94	90	87	76	70	73
114	114	114	112	116	111	97	95	94	92	79	71	75
121	123	135	141	141	129	107	113	113	109	93	78	76
115	122	130	107	95	103	100	100	92	81	60	60	63
91	106	97	72	68	63	59	52	49	50	43	42	44
90	103	97	72	68	63	59	52	49	50	43	42	42
47	56	53	30	28	24	22	21	20	18	19	20	23
42	49	42	27	25	21	21	18	19	17	16	16	19
38	38	37	26	24	20	21	18	19	17	16	16	19
38	38	37	26	24	20	21	18	19	17	16	16	19
49	47	41	28	32	24	24	24	21	20	19	19	22

Values in Lux, Scale 1 : 51

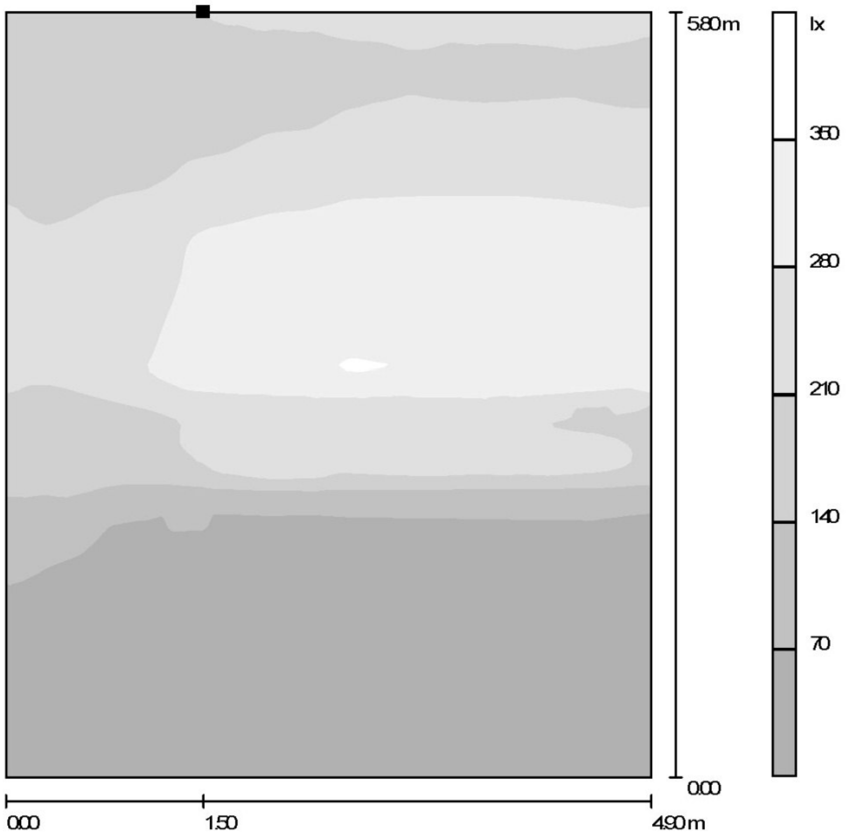
Not all calculated values could be displayed.

Position of surface in room:
Marked point:
(29.450 m, 10.000 m, 0.000 m)

Grid: 64 x 64 Points

E_{av} [lx]	E_{min} [lx]	E_{max} [lx]	u0	E_{min} / E_{max}
74	16	158	0.21	0.10

Wall / Greyscale (E)



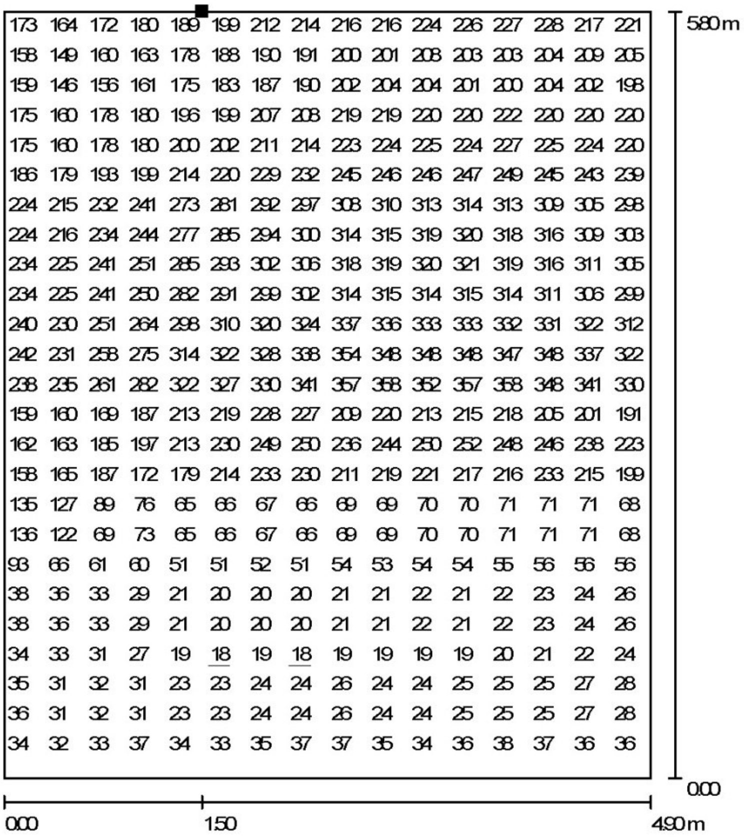
Scale 1 : 46

Position of surface in room:
Marked point:
(29.450 m, 13.400 m, 5.800 m)

Grid: 128 x 128 Points

E_{av} [lx]	E_{min} [lx]	E_{max} [lx]	u0	E_{min} / E_{max}
167	18	360	0.11	0.05

Wall / Value Chart (E)

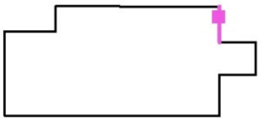


173	164	172	180	189	199	212	214	216	216	224	226	227	228	217	221
158	149	160	163	178	188	190	191	200	201	208	203	203	204	209	205
159	146	156	161	175	183	187	190	202	204	204	201	200	204	202	198
175	160	178	180	196	199	207	208	219	219	220	220	222	220	220	220
175	160	178	180	200	202	211	214	223	224	225	224	227	225	224	220
186	179	193	199	214	220	229	232	245	246	246	247	249	245	243	239
224	215	232	241	273	281	292	297	308	310	313	314	313	309	305	298
224	216	234	244	277	285	294	300	314	315	319	320	318	316	309	303
234	225	241	251	285	293	302	306	318	319	320	321	319	316	311	305
234	225	241	250	282	291	299	302	314	315	314	315	314	311	306	299
240	230	251	264	298	310	320	324	337	336	333	333	332	331	322	312
242	231	258	275	314	322	328	338	354	348	348	348	347	348	337	322
238	235	261	282	322	327	330	341	357	358	352	357	358	348	341	330
159	160	169	187	213	219	228	227	209	220	213	215	218	205	201	191
162	163	185	197	213	230	249	250	236	244	250	252	248	246	238	223
158	165	187	172	179	214	233	230	211	219	221	217	216	233	215	199
135	127	89	76	65	66	67	66	69	69	70	70	71	71	71	68
136	122	69	73	65	66	67	66	69	69	70	70	71	71	71	68
93	66	61	60	51	51	52	51	54	53	54	54	55	56	56	56
38	36	33	29	21	20	20	20	21	21	22	21	22	23	24	26
38	36	33	29	21	20	20	20	21	21	22	21	22	23	24	26
34	33	31	27	19	18	19	18	19	19	19	19	20	21	22	24
35	31	32	31	23	23	24	24	26	24	24	25	25	25	27	28
36	31	32	31	23	23	24	24	26	24	24	25	25	25	27	28
34	32	33	37	34	33	35	37	37	35	34	36	38	37	36	36

Values in Lux, Scale 1 : 46

Not all calculated values could be displayed.

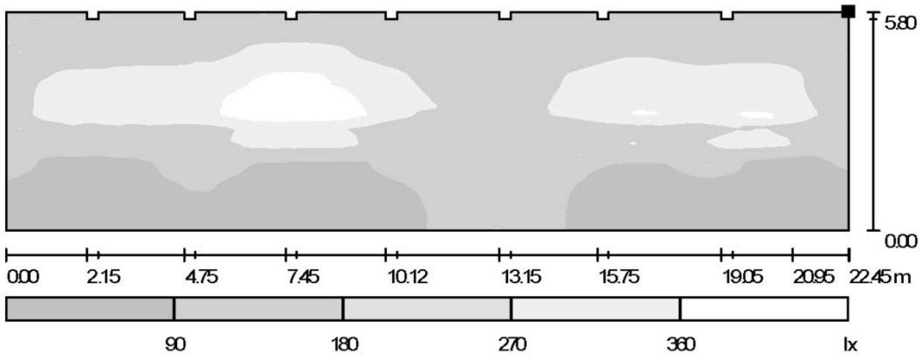
Position of surface in room:
Marked point:
(29.450 m, 13.400 m, 5.800 m)



Grid: 128 x 128 Points

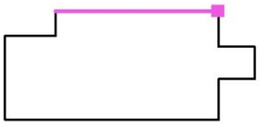
E_{av} [lx]	E_{min} [lx]	E_{max} [lx]	u0	E_{min} / E_{max}
167	18	360	0.11	0.05

Wall / Greyscale (E)



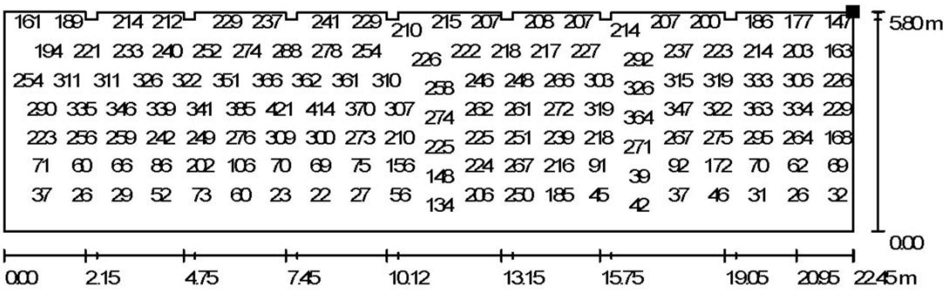
Scale 1 : 161

Position of surface in room:
Marked point:
(29.450 m, 14.900 m, 5.800 m)



Grid: 128 x 128 Points

E_{av} [lx]	E_{min} [lx]	E_{max} [lx]	u0	E_{min} / E_{max}
199	19	428	0.10	0.05



Values in Lux, Scale 1 : 161

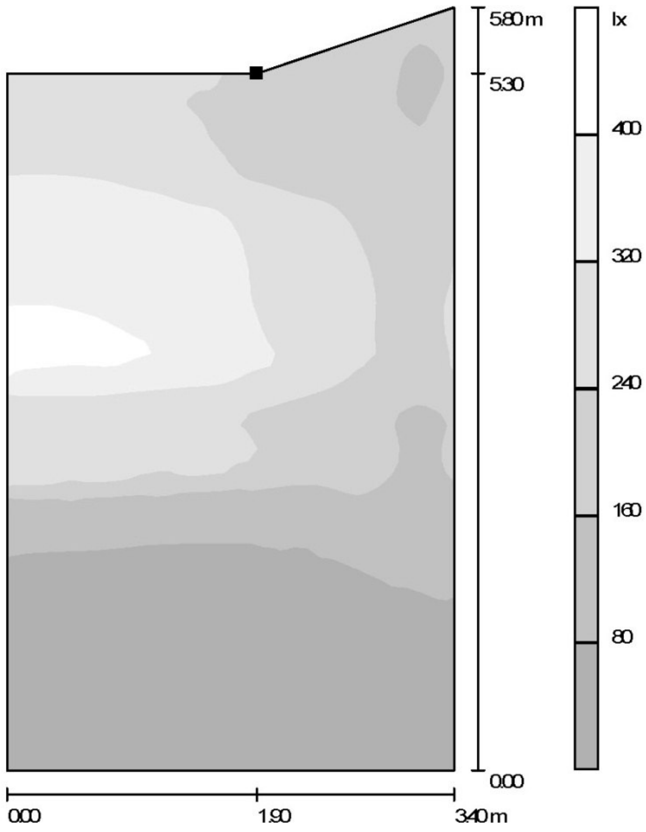
Not all calculated values could be displayed.

Position of surface in room:
Marked point:
(29.450 m, 14.900 m, 5.800 m)

Grid: 128 x 128 Points

E_{av} [lx]	E_{min} [lx]	E_{max} [lx]	u0	E_{min} / E_{max}
199	19	428	0.10	0.05

Wall / Greyscale (E)

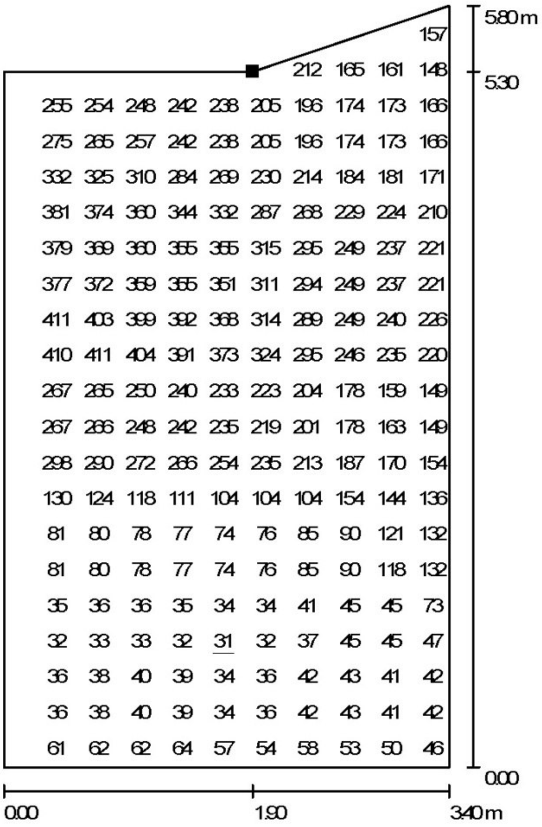


Scale 1 : 46

Position of surface in room:
Marked point:
(7.000 m, 13.400 m, 5.300 m)

Grid: 64 x 64 Points

E_{av} [lx]	E_{min} [lx]	E_{max} [lx]	u0	E_{min} / E_{max}
187	31	421	0.17	0.07



									157
						212	165	161	148
255	254	248	242	238	205	196	174	173	166
275	265	257	242	238	205	196	174	173	166
332	325	310	284	269	230	214	184	181	171
381	374	360	344	332	287	268	229	224	210
379	369	360	355	355	315	295	249	237	221
377	372	359	355	351	311	294	249	237	221
411	403	399	392	368	314	289	249	240	226
410	411	404	391	373	324	295	246	235	220
267	265	250	240	233	223	204	178	159	149
267	266	248	242	235	219	201	178	163	149
298	290	272	266	254	235	213	187	170	154
130	124	118	111	104	104	104	154	144	136
81	80	78	77	74	76	85	90	121	132
81	80	78	77	74	76	85	90	118	132
35	36	36	35	34	34	41	45	45	73
32	33	33	32	31	32	37	45	45	47
36	38	40	39	34	36	42	43	41	42
36	38	40	39	34	36	42	43	41	42
61	62	62	64	57	54	58	53	50	46

Values in Lux, Scale 1 : 46

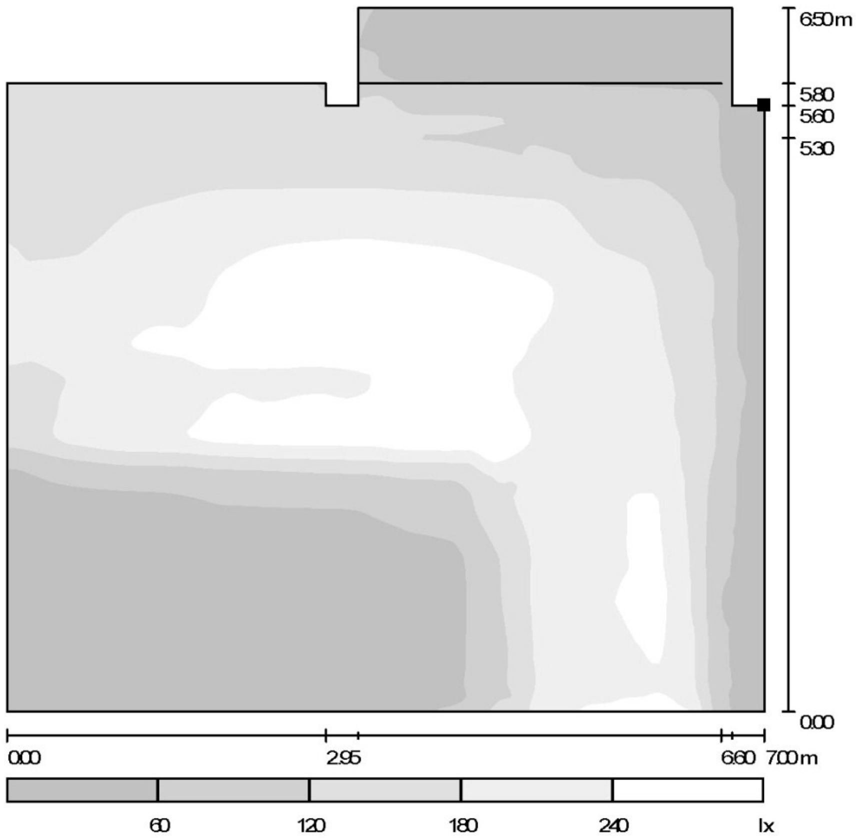
Not all calculated values could be displayed.

Position of surface in room:
Marked point:
(7.000 m, 13.400 m, 5.300 m)

Grid: 64 x 64 Points

E_{av} [lx]	E_{min} [lx]	E_{max} [lx]	u0	E_{min} / E_{max}
187	31	421	0.17	0.07

Wall / Greyscale (E)



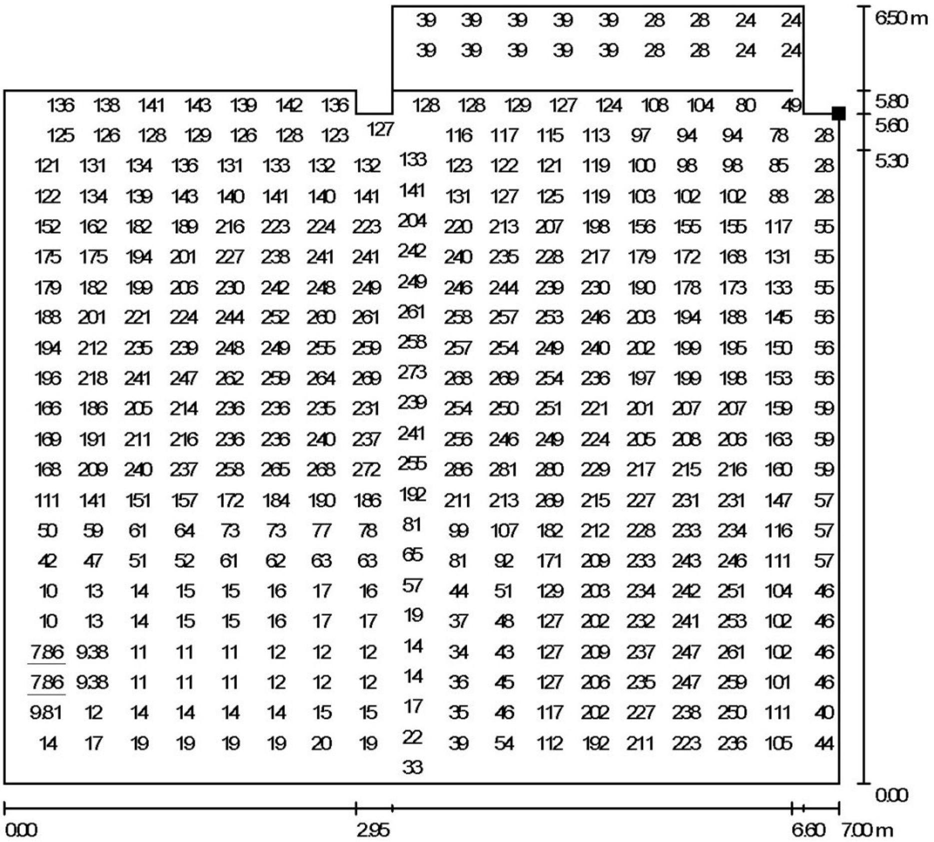
Scale 1 : 56

Position of surface in room:
Marked point:
(7.000 m, 11.500 m, 5.600 m)

Grid: 128 x 128 Points

E_{av} [lx]	E_{min} [lx]	E_{max} [lx]	u0	E_{min} / E_{max}
138	7.86	291	0.06	0.03

Wall / Value Chart (E)



									39	39	39	39	39	28	28	24	24
									39	39	39	39	39	28	28	24	24
136	138	141	143	139	142	136			128	128	129	127	124	108	104	80	49
125	126	128	129	126	128	123	127		116	117	115	113	97	94	94	78	28
121	131	134	136	131	133	132	132	133	123	122	121	119	100	98	98	85	28
122	134	139	143	140	141	140	141	141	131	127	125	119	103	102	102	88	28
152	162	182	189	216	223	224	223	204	220	213	207	198	156	155	155	117	55
175	175	194	201	227	238	241	241	242	240	235	228	217	179	172	168	131	55
179	182	199	206	230	242	248	249	249	246	244	239	230	190	178	173	133	55
188	201	221	224	244	252	260	261	261	258	257	253	246	203	194	188	145	56
194	212	235	239	248	249	255	259	258	257	254	249	240	202	199	195	150	56
196	218	241	247	262	259	264	269	273	268	269	254	236	197	199	198	153	56
166	186	205	214	236	236	235	231	239	254	250	251	221	201	207	207	159	59
169	191	211	216	236	236	240	237	241	256	246	249	224	205	208	206	163	59
168	209	240	237	258	265	268	272	255	286	281	280	229	217	215	216	160	59
111	141	151	157	172	184	190	186	192	211	213	269	215	227	231	231	147	57
50	59	61	64	73	73	77	78	81	99	107	182	212	228	233	234	116	57
42	47	51	52	61	62	63	63	65	81	92	171	209	233	243	246	111	57
10	13	14	15	15	16	17	16	57	44	51	129	203	234	242	251	104	46
10	13	14	15	15	16	17	17	19	37	48	127	202	232	241	253	102	46
7.86	9.38	11	11	11	12	12	12	14	34	43	127	209	237	247	261	102	46
7.86	9.38	11	11	11	12	12	12	14	36	45	127	206	235	247	259	101	46
9.81	12	14	14	14	14	15	15	17	35	46	117	202	227	238	250	111	40
14	17	19	19	19	19	20	19	22	39	54	112	192	211	223	236	105	44
								33									

Values in Lux, Scale 1 : 51

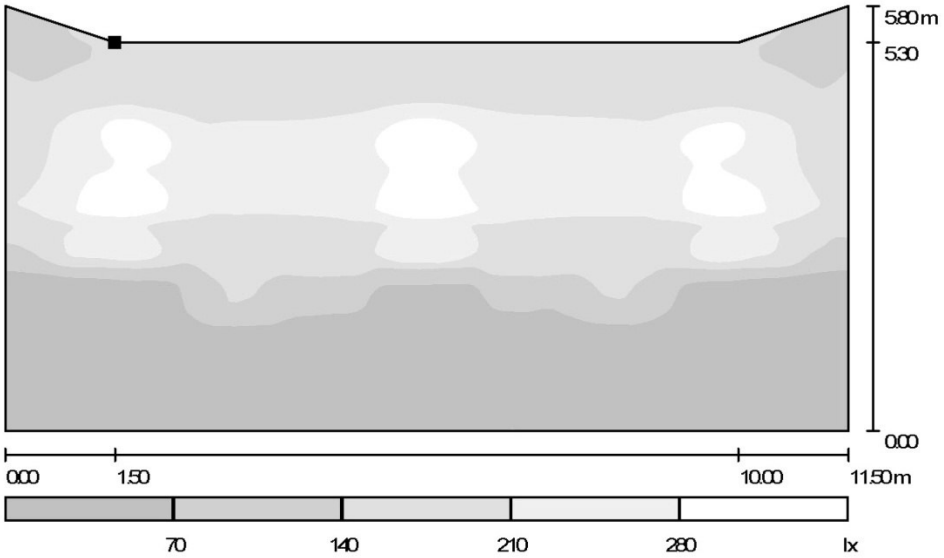
Not all calculated values could be displayed.

Position of surface in room:
Marked point:
(7.000 m, 11.500 m, 5.600 m)

Grid: 128 x 128 Points

E_{av} [lx]	E_{min} [lx]	E_{max} [lx]	u0	E_{min} / E_{max}
138	7.86	291	0.06	0.03

Wall / Greyscale (E)

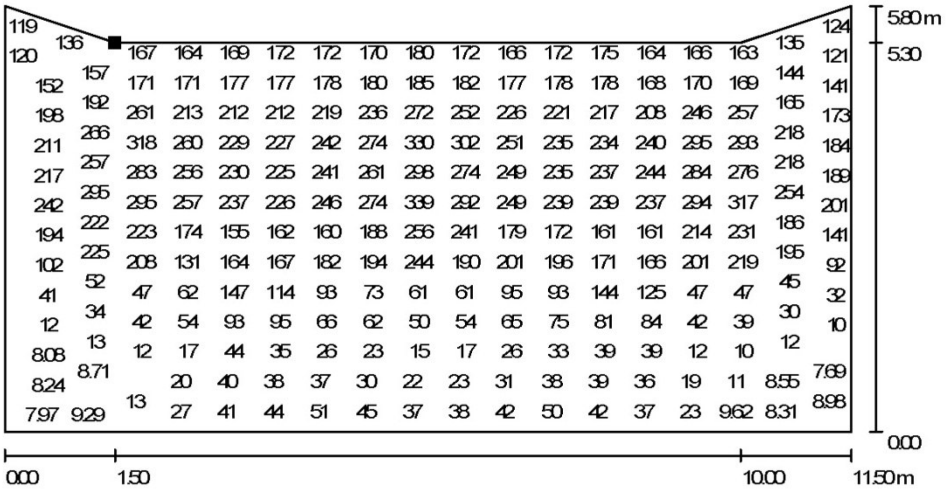


Scale 1 : 83

Position of surface in room:
Marked point:
(0.000 m, 1.500 m, 5.300 m)

Grid: 128 x 128 Points

E_{av} [lx]	E_{min} [lx]	E_{max} [lx]	u0	E_{min} / E_{max}
141	5.71	343	0.04	0.02



Values in Lux, Scale 1 : 83

Not all calculated values could be displayed.

Position of surface in room:
Marked point:
(0.000 m, 1.500 m, 5.300 m)

Grid: 128 x 128 Points

E_{av} [lx]	E_{min} [lx]	E_{max} [lx]	u0	E_{min} / E_{max}
141	5.71	343	0.04	0.02

APPENDIX C

SURVEY

1. Personal Information:

1 .1. Sex: female ☐
male ☐

1.2. Age .... years old

1.3. Job ....

1.4. Do you wear glasses or lenses yes ☐
no ☐

if yes: longsighted ☐
shortsighted ☐
astigmatic ☐

Please do not fill below this line

1.6. The temperature in space : C

1.7. The temperature outside : C

1.8. Time : ....

2. Lighting and Task:

Please answer the questions below, only after you have visited all parts of the gallery.
For the questions with a scale, make a circle in the appropriate row on your answer sheet with a number close to your opinion.

extremely	slightly	neutral	slightly	extremely
1	2	3	4	5

2.1. Perception of the images in the print-outs under this lighting arrangement is

strong 1 2 3 4 5 weak

2.2. The ability to concentrate and interact with the exhibition under this lighting arrangement is

strong 1 2 3 4 5 weak

2.3. The informative texts are readable under this lighting arrangement

yes ☐ no ☐

2.4. Have you seen any reflected images on the vertical planes of exhibition? If yes, please specify the exact location on the map.

yes ☐ no ☐

3. Aesthetic and Environmental Judgments:

Please make a circle in the appropriate row with a number close to your opinion.

extremely	slightly	neutral	slightly	extremely
1	2	3	4	5

3.1. Perception of the form of the gallery under this lighting arrangement is

strong 1 2 3 4 5 weak

3.2.Perception of the structural elements under this lighting arrangement is

strong 1 2 3 4 5 weak

3.3. Perception of details [materials of architectural components and furnishing and their characteristics such as texture and color] of the gallery under this lighting arrangement is

strong 1 2 3 4 5 weak

3.4. The general illumination in the gallery is

too dark 1 2 3 4 5 too bright

3.5. The illumination on the ceiling is

too dark 1 2 3 4 5 too bright

3.6. The illumination on the walls are

too dark 1 2 3 4 5 too bright

3.7. The general illumination in the gallery is

uniform 1 2 3 4 5 not uniform

3.8. The gallery under this lighting arrangement appears as

inviting 1 2 3 4 5 repulsive

3.9. The gallery under this ligting arrangement appears as

cozy 1 2 3 4 5 cold

3.10. The gallery under this lighting arrangement appears as

interesting 1 2 3 4 5 dull

3.11. I like the gallery under this lighting arrangement

yes 1 2 3 4 5 no

4. Feelings:

Take about two minutes to really get into the mood of the situation created by the interior lighting; then rate your feelings in the situation with the adjective pairs below. Some of the pairs might seem unusual, but you'll probably feel more one way than the other. So, for each pair, make a circle in the appropriate row with a number close to the adjective which you believe to describe your feelings better. The more appropriate that adjective seems, the more closer the circle you fill in.

extremely	slightly	neutral	slightly	extremely
1	2	3	4	5

I feel ………… under this lighting arrangement

Happy	1	2	3	4	5	Unhappy
Annoyed	1	2	3	4	5	Pleased
Relaxed	1	2	3	4	5	Tense
Autonomous	1	2	3	4	5	Guided
Hopeful	1	2	3	4	5	Despairing
Aroused	1	2	3	4	5	Unaroused
Dominant	1	2	3	4	5	Submissive
Sleepy	1	2	3	4	5	Wide-awake
Talkative	1	2	3	4	5	Shy
Excited	1	2	3	4	5	Calm
Controlling	1	2	3	4	5	Controlled
Satisfied	1	2	3	4	5	Unsatisfied
Stable	1	2	3	4	5	Depressed
Important	1	2	3	4	5	Unimportant

5. Perceptual Preferences:

5.1. Do you think this lighting arrangement creates any hierarchical order (lit, semi-lit, and dark) in the gallery? Do you think that there is variance in the degree that a part of the space (structural elements, ceiling, walls, etc.) or part of the exhibition is perceived better than another? Please specify.

Lit : ....

Semi-lit : ....

Dark : ....

5.3. Please stand on the points displayed with SP on the map and decide which direction to take without concerning the exhibit just the lighting itself. Which direction is it?

For SP1:

d1 d2 does not matter

For SP2

d1 d2 d3 does not matter

VITA

Hilmi Gökhan Kutlu, son of Münevver and Orhan, little brother of Okan, was born on 30th April 1973 in İstanbul. He attended Özel Türk High School in İzmir, and was graduated in 1991. He was admitted to Dokuz Eylül University in September 1991 and received his bachelor degree in 1996. He was accepted to the Master of Science Program in Architecture in September 1996 and received his M.Sc. Degree in June 2000.

He is currently holding a research/teaching assistant position at İzmir Institute of Technology since October 1997. He has assisted basic design studio and building technology and science courses.

His research interests are architectural lighting, basic design, and modern architecture. He is a member of Chamber of Architects since July 1996, and Docomomo-tr National Committee since November 2005.

His current e-mail address is hgokhankutlu@gmail.com.