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**AN INVESTIGATION INTO EXTERIOR  
ILLUMINATION OF BUILDINGS**

**A dissertation submitted to the department of Power Engineering in  
candidacy for the Masters Diploma in Technology, Electrical  
Engineering**

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"The nature of light is only describable by enumerating its properties and founding them on the simplest possible principles. As these principles transcend our ordinary experiences, they must be cast in a purely logical, that is to say, mathematical form. But that is never enough, for, though logic tells us what deductions must be right, it does not tell us what will be interesting, and so gives no guidance as to the direction the theory will take. In choosing this direction, much help is derived from analogies and models which are often loose and incomplete but without which no proper understanding of the subject can be acquired. We shall, therefore, describe, largely by means of analogies, the behaviour of light and this is the 'real' nature of light."

CG DARWIN 1929

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PLATE 1 : International Lighting Review 1980/3

PLATE 2 : International Lighting Review 1983/2

PLATE 3 : International Lighting Review 1988/4

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## 1.0 INTRODUCTION

The choice of undertaking a research project in illumination is the result of a particular interest in the subject dating back a number of years. Illumination forms part of most courses in Electrical Engineering and the student is normally introduced to it during the latter part of his studies. Sadly illumination has tended to be the cinderella in electrical engineering and consequently there is a great need for more engineers to become involved in what is both a fascinating science and art.

Exterior illumination was chosen, inter alia, for two principle reasons. Firstly, because not a great deal of information is readily available in South Africa and secondly, perhaps more importantly, that by so doing it may encourage others particularly architects to give serious consideration to illuminating their building thereby enhancing the attraction of cities and towns for not only the local citizens but more especially tourists. Such prestige lighting can only promote pride.

Just like buildings, water and greenery light is part of the city landscape. To light is to constantly seek attention.

Lighting, the architect of the night, creates and shapes our nocturnal impression of the town. It highlights its architectural heritage, leaving in shadow the ugly, daytime vista, and bringing to our attention a facade used because of over familiarity.

Lighting provides identity, social cohesion and safety. It also links the city centre to its suburbs and zones of activity.

Employed in such a way, light reveals to visitor and resident alike the strong features of the town, and binds them in a powerful, coherent image. The succession of places and ambiances and the traces of history become readable. The lighting creates a genuine book of the images of the city...we call this approach: the town planning of light. From "Urbanisme Lumière" leaflet on town planning of light issued by Philips Lighting in France (1991).

Such an approach involves much more than the mere planning of light colours for visual guidance. It requires a good definition of the objectives to be achieved by lighting beyond the traditional ones of traffic and personal safety.

Much more can be done with South African cities and towns but to achieve this, preliminary studies on various scales first have to be done in order to produce a coherent lighting scheme. The realisation of such an all embracing plan will occupy years and is clearly the work for a multidisciplinary team working closely with the lighting designer, and implies support, financial and otherwise of local citizens and the private sector.

This project, however, is confined to buildings specifically and comprises details of research and gathering of all the appropriate information and data for the study of exterior building illumination. The collation of the data in order to produce requirements for a preliminary design, outlining those parameters necessary for completion of the project and for reference.

It is hoped that such a study will be useful to architects and others in lighting in that it may engender a greater desire to enhance the beauty of some of our buildings by illuminating them.

A thorough knowledge of the principles of vision and light is essential to fully appreciate the art and science of illumination. The reader should therefore refer to appendix A before proceeding further.



PLATE 1

The Flavian Amphitheatre

Floodlighting by 18 x 1000W spots; 6 x 1000W and 2 x 300W halogen lamps and 350 low-pressure sodium lamps of 55W each.

## 2. RESEARCH

### 2.1 Introduction

The practice of floodlighting of buildings and monuments dates back to the early years of the century. In the United States this form of lighting was fairly extensively used for advertising purposes, the objective being to draw attention to certain industrial and commercial buildings thereby spotlighting the name of the firm. Floodlighting then spread to Europe where many of their ancient buildings and monuments have shown the ornamental and artistic value of this type of lighting. However the use of floodlighting for this purpose is not without various difficulties. The main difficulty here was that ancient monuments and buildings of architectural and artistic merit were designed to be seen in daylight, i.e. sunlight, which, depending on the time of day is never directed upwards.

Floodlighting is generally done from below and utilizes a number of sources situated in different positions, the light thus coming from various directions. Critics of this method argue that this negates the intentions of the original architect because lateral shadows were wrong and vertical shadows reversed.

Furthermore it was asserted that impression of depth was destroyed and the whole appearance of the structure ruined. In response to these criticisms it may be argued that by placing floodlights around the circumference of a building, will produce lighting, the direction of which can correspond well to a single lateral direction of all the rays required to obtain the desired shadows. Concerning loss of depth - this is almost always caused by inadequately designed lighting schemes and poor choice of the positioning of the type of floodlights used.

From the foregoing it is clear that the design of a good floodlighting installation calls for a close study of the lighting effects of the continuously changing interplay of light and shadow and their effects. This is often the best way of determining which features will be the most attractive when illuminated.

In addition to being used for aesthetic purposes, floodlighting can also be simply functional.

This is particularly true of industrial and commercial buildings where floodlighting is used for advertising and security reasons. It may be said that, in general, floodlighting satisfies three main purposes:

- \* As a relatively inexpensive means of advertising, many buildings carry their corporate identity which immediately attracts attention.
- \* For Prestige  
Floodlighting is an effective means of impressing visitors particularly if the architectural qualities of fine building can be enhanced.

- \* For security reasons  
Floodlighting acts as a significant deterrent to potential felons by giving a clear view of the surrounding.

Whatever the use to which floodlights are put, either aesthetic or purely functional, the standard of quality should be as high as possible. It is generally agreed that it is better not to proceed with an installation, than to be satisfied with a mediocre result.

In translating the above objectives into lighting criteria there are two major differences from the interior lighting situation. Firstly, since the visual size of the details to be seen are generally much larger, lower levels of lighting tend to suffice outside. Secondly, whereas most of these details lie on a horizontal plane indoors, the lighting of vertical surfaces tends to be more important outdoors.

## 2.2 Planning

Planning is the "thinking before the doing" and a floodlighting project is no different from any other project. To be successful a thorough study has to be made of the building (or monument) concerned. The lighting engineer must familiarise himself with all aspects relating to the design of a suitable installation. The most important feature to be studied first is the facade. This should be done under various conditions in daylight, preferably, with sunlight falling upon it at different angles in order to decide which are the most attractive features.

An on the spot survey should be undertaken. In addition, architectural drawings or a scale model can be useful. An analysis of daylight effects can be very informative as to how given effects arise.

Early architects designed their buildings to be aesthetically pleasing when viewed in daylight. They, therefore, designed a facade to be illuminated from above by the sun and sky. Today it is the task of the lighting engineer to illuminate the building after dusk by a floodlighting installation. In so doing he must take great care not to misinterpret the architects conception. Daylight may be regarded as a combination of both direct sunlight and the diffuse light of the sky. The sun, of course, may be regarded as point light source of small dimensions and considerable brightness. The sky, on the other hand, behaves like a very large diffuser of much lower brightness.

On a clear day with a cloudless sky and bright sunshine two natural sources of light can be said to be present at the same time. In consequence hard shadows falling under projections on the facade, caused by direct sunlight, are softened by the diffused light of the sky.

Fundamentally illumination by sunlight is the ideal form of floodlighting. Sunlight falling on a building causes shadows to form under projections on the facade on the side facing the viewer. This presents a pleasing interplay of

light and dark on the facade thus emphasizing the architectural features. In the ancient world particularly Greece and Italy where there is an abundance of sunlight, the bas relief of many of their structures of antiquity was sufficient to create interesting patterns of light and shadow. However in areas where the weather was frequently cloudy and dull greater relief was required in the facade and this was found in many of the magnificent Gothic cathedrals. This phenomenon reveals one of the first principles of floodlighting, which is that the direction of light and the direction of view should be at an angle to one another, preferably between  $45^{\circ}$  and  $135^{\circ}$ .

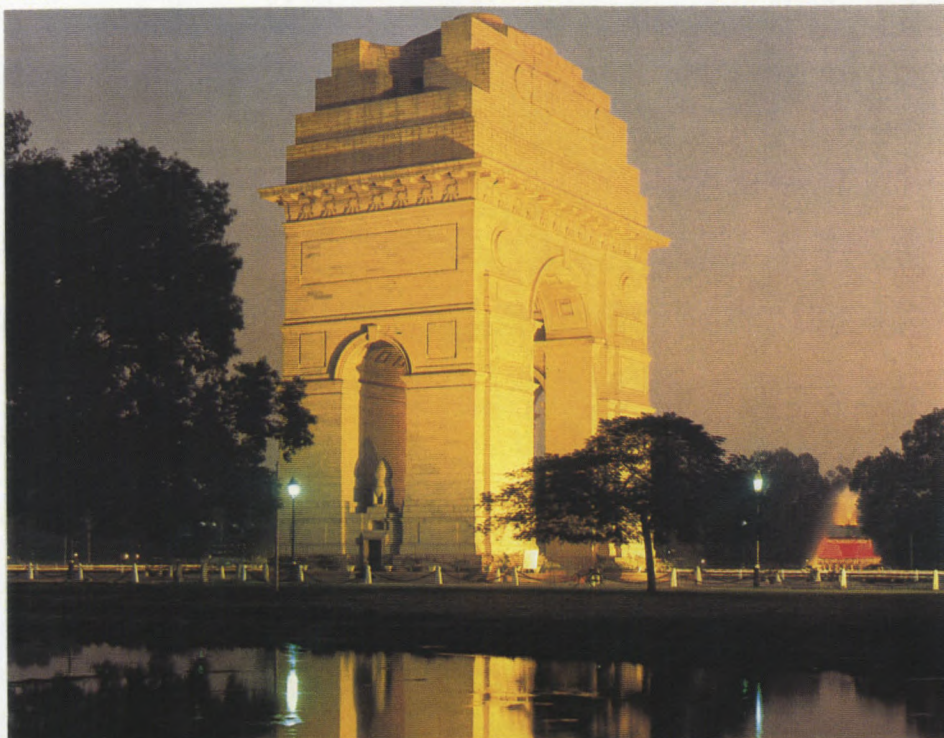


PLATE 2

**THE INDIA GATE**

Built of Dholpur stone, two types of floodlight have been used, one containing 2xSON 250W lamps and one with a single SON 400W lamp. The former are placed nearer the monument at ground level, while the 400W units are placed away from the monument on two special structures. The floodlights are so aimed as not to cause glare to motorists. Glare to pedestrians has been minimised through the use of special louvres attached to the floodlights.

### 2.3 The Contrast between facade and the background

Depending on the prevailing weather conditions, the contrast between a facade and the surrounding background changes continuously. If, for example, the sun rays in a cloudless sky fell directly on the facade, the greater reflection will cause the facade to seem brighter than the background. Direct sunlight on a building causes hard shadows. When the sky is clear but the facade receives no direct sunlight, the sky will seem brighter than the facade. The sky radiates light in all directions whereas the facade merely reflects the light. Since the light is diffused only soft shadows appear. If, however, the sky is overcast, diffuse light falls on the building. In this light few, if any shadows are seen. The facade then looks flat and uninteresting.

In addition to the study of daylight, the building's appearance changes over a given period of time. During the day the change in the sun's position cause shadows to move across the facade. Generally speaking, buildings appear at their best around sunrise and just before sunset.

This is because, at these times, there is contrast in colour between the sunlight, which contains much red light, and the diffused light from the sky, which contains a great deal of blue.

A good lighting designer will have a conception of what the building will look like when floodlit. He will then need to proceed from this mental image and translate the perceived natural lighting effect into an artificial lighting effect. A point to note is that at night the position of the light sources is completely different from the daytime situation.

### 2.4 Advantages of Floodlighting

Floodlighting is installed for many different reasons and serves a wide range of needs.

- i) **Security:** There is obviously a direct relationship between the hours of darkness and the incidence of crime, and the floodlighting of buildings and areas for security reduces crimes of violence and losses by theft.
- ii) **Advertising:** Companies like to draw attention to their buildings for publicity, e.g. banks offices, large departmental stores and even factories. The illuminated building and the signs used should form a harmonious whole.
- iii) **Prestige:** This aspect is very important. The attraction of floodlighting is here a function of the artistic effect and must take precedence. Great care must be taken at every stage of the design. The layout must be planned in great detail and all equipment chosen must be suitable for its purpose. Such installations must be first class in every respect.

## 2.5 Illumination Levels Required

These will, of course, vary quite considerably according to the purpose for which it was intended. The illumination must also vary according to the type of material used for the building or monument to be lit. For a given background, the darker the surface of the building the higher must be the illumination level.

Colour can also be used to provide an appropriate contrast between the background and the building.

Appendix F gives the value of the illumination required as a function of the background and the type of materials involved. It should be noted that in the centre of large towns or cities where the level of public lighting is very high and where there is a proliferation of advertising signs, the illumination to be used may be higher than that indicated in the table.

## 2.6 Equipment

### 2.6.1 Optical Characteristics

Floodlights in general fall into three groups. The general pattern of light distribution may be described as symmetrical, asymmetrical and double asymmetrical. They are classified according to their beam spread (see Table 1).

Table 1 Beam spread classification

Description	Beam Spread (at 50%I peak)
Narrow beam	< 20°
Medium beam	20° to 40°
Wide beam	> 40°

The beam spread of a floodlight is the angle over which the luminous intensity drops to a stated percentage (usually 50% or 100%) of its peak value.

For a floodlight having a rotationally symmetrical luminous intensity distribution (i.e. a distribution that remains unchanged no matter what plane through the beam axis is considered) one figure for beam spread may be quoted: e.g. 50° (i.e. 25° to both sides of the beam axis).

For an asymmetrical distribution as given by rectangular floodlights two figures will be given: e.g. 6°/24°, for the beam spreads in the two mutually perpendicular planes of symmetry (vertical and horizontal respectively). Sometimes the distribution in the vertical plane of such a floodlight is asymmetrical relative to the beam axis. Then two figures for the beam spread in this plane will be given, e.g. 5°-8°/24°.

i.e.  $5^{\circ}$  and  $8^{\circ}$  below the beam axis and in the horizontal plane  $12^{\circ}$  left and  $12^{\circ}$  right from the beam.

Most reflector profiles are based on the parabola which theoretically produces a parallel beam of light. In practice, however, this does not occur because no source is infinitely small and no reflector has a perfectly specular reflectance. A further point to note is the tolerance in the reflector profile and the position of the lamp mount. There are three further elements of light control which feature in some floodlights. Firstly auxiliary reflectors, uncounted in front of the lamp are used to direct otherwise uncontrolled forward flux from the lamp onto the main reflector to improve the beam factor and reduce spill light. Secondly external elements such as louvres, hoods and spill rings are used to reduce stray light; their presence tends to reduce the peak intensity and to modify the beam pattern. Thirdly alternative front glasses consisting of moulded lenses or stippled diffusers may be used to enable a variety of distribution patterns to be derived from one basic narrow beam floodlight.

### 2.6.2 Mechanical Characteristics

Two important factors influence the robustness or integrity of the luminaire housing; the materials used in its construction and the soundness of the construction itself.

In addition there are other mechanical design considerations of importance in floodlighting systems, i.e. those affecting their installation, their aiming and their maintenance which depend on the particular application.

Floodlights may be mounted on the ground and directed upwards or mounted on a wall or pole, or mounted singly or in groups on high masts or towers. Whatever the application, care should be taken in designing and selecting the accessories required.

Floodlights providing a long range projection aiming to an accuracy of  $\pm 0.5^{\circ}$  may be essential but a luminaire providing for a wide angle distribution aiming is not necessary. Once accurately positioned, the floodlight should have provision for securely locking in place. It is also important that once the installation is complete, relamping and cleaning should be possible without disturbing the orientation of the unit. Special aiming devices may be required where accuracy is necessary.

### 2.6.3 Control Gear

Control gear is mounted as close as is practical to its lamp or in a suitable locked, weatherproof, ventilated cubicle and which has no public access. Heat sensitive components such as switches and capacitors should be mounted as low as possible and provision made for ventilation.

## 2.7 Light Pollution

The problem of waste and stray light into the atmosphere and into private property is becoming an increasing problem throughout the developed world. Not only was this made clear at the SANCI Conference in Cape Town but other organisations are starting to investigate means by which this problem can be legally controlled. The CIE has two Technical Committees working on this, TC 4-21 on Interference by Light on Astronomical Observations, and TC 5-12 Guide on the Limitation of the Effects of Obtrusive Light from Lighting Installations. Dr D. Schreuder has given SANCI a very interesting paper on the Astronomical aspects which is a survey of the work that is going on in Division 4 of CIE. This paper highlights the background radiation, sky glow and the measurement thereof and recommended remedial measures. A copy of this paper can be made available to all interested people on application.

Under the Chairmanship of Dr A.J. Fisher of Australia, a draft of their guide to the control of waste light, has been drawn up which promises to be a very valuable document and is likely to be the basis of legal requirements in some major countries. The document covers the potential environmental impacts of stray light, the calculation of the technical parameters and the measurement of these parameters. One very important aspect is the need for controlled maintenance of lighting installations, as it is a known fact that unqualified people who replace lamps and clean luminaires are not always aware of the design techniques that went into the choice and aiming of the luminaires. As a result, they do not always check that they have reset the luminaires into the original designed positions.

Another interesting development in this matter is that the British Department of Transport has recently published a book entitled Road Lighting and the Environment. This book was issued with confidence that it will "encourage all those involved in the design and installation of road lighting and its equipment to think positively about limiting environmental intrusion". The book defines environmentally sensitive areas and covers aspects such as the day and night appearance of street lighting installations and "recommends a procedural framework to ensure that the environmental impact is taken into account at the earliest possible stage." Is this not perhaps something that our Government organisations could also look into and draw up local guidelines?

A recent publication on the subject of light trespass is a report circulated in Britain by the Institution of Environmental Health Officers which indicates that a large single cause of complaint is domestic security lighting. The Institution of Lighting Engineers in the U.K. has planned to release soon a revised and updated version of its Guidance Notes for the Reduction of Light Pollution.

*(SANCI NEWS No. 13, 1994)*

## 2.8 Criteria For the Lighting of Buildings

### 2.8.1 Illuminance And Uniformity

In determining the level of illuminance needed to give a structure the required degree of visual impact a number of important factors have to be taken into account. The brightness of the surroundings and background have already been mentioned. The nature of the building material employed now needs to be considered.

- i) The darker the material (whether by design or pollution) the higher the illuminance required to give a satisfactory impression of brightness.
- ii) For a normal installation, in which the light is directed upwards at a vertical surface, the amount of reflected light reaching an observer, and hence the brightness of the surface illuminated, will decrease with increase in the smoothness of the surface.
- iii) The illuminance needed will be influenced to some extent by the degree of match between the spectrum of the light source employed and the colour of the building material. Favourable results are obtained when the colour of the light is near to that of the surface being illuminated.

The illuminances recommended for building floodlighting are given in appendix F.

The illuminance values are those needed to create a luminance of 4,6 or 12 $\text{cdm}^{-2}$  on the facade where the surroundings are poorly lit, well lit and brightly lit respectively. The values are valid for tungsten filament lamps of 280°K and clean building surfaces. Correction coefficients are given for mercury, metal halide and sodium lamps for less than clean surfaces.

### 2.8.2 Atmospheric Losses

Environmental pollution is an important factor which affects external illumination installations. The loss incurred will vary according to the season, time of day and location. Because weather conditions are too variable, calculations should be based on the performance on a clear night.

### 2.8.3 Maintenance

In addition to allowances made for atmospheric loss, a maintenance factor should be included in design calculations to allow for loss of light due to dirt between cleaning intervals.

### 2.8.4 Glare

Choice of floodlight and care in aiming can go a long way towards reducing disturbing glare. Occasionally, when glare is critical, special louvres should be fitted to the floodlights.

## 2.9 The Lighting Of Buildings Proper

### 2.9.1 Buildings With Only Plane Surfaces

These tend to be modern buildings of little historical interest, which would be illuminated for publicity purposes and are intended to be seen from some distance, probably against an unlit background. Since the facade is flat the direction of incidence of light is not important. There are two alternatives:

- \* Floodlights may be placed at regular intervals with their axis at right angles to the facade to be illuminated; the uniformity, which depends on the light distribution of the luminaires, is easy to check.
- \* One single group of floodlights pointing in different directions. This results in cable saving, allows fewer floodlights of higher power to be used and sometimes allows these to be masked better from the eye of the observer.

The dimensions of the building's facade will determine what equipment will be used. Provided the building is of moderate height light sources may be placed reasonably close to the building. Differing type floodlights may be used, equally spaced at distances not exceeding twice the distance of the floodlight from the building. The distance of the floodlight from the building should be at least  $\frac{2}{3}$  the height of the building and mounted at least  $\frac{1}{3}$  the height of the building above the ground. (This has been determined to give the best results)

For tall buildings a higher concentrated beam of light must be used and the floodlight should be mounted further away from the facade if possible.

The use of coloured light sources such as sodium and mercury or incandescent and mercury may be used to relieve the monotomy of a flat surface.

### 2.9.2 Buildings With Relief

#### i) Relief on the facade

The appearance of shadows plays a very important role when appreciating the facade of a building. Ideally, vertical relief should be illuminated from the side and horizontal relief from below. This is rarely possible. Most buildings contain both types of relief so the axis of the floodlight should be neither in a vertical plane perpendicular to the facade nor in a horizontal one. The location of the floodlight can make a considerable difference to the effect obtained as to whether the floodlights point left or right or are in front of or behind the observer.

It is very important to ensure there is a certain angle between the direction in which the building is viewed and the direction of light in order to accentuate the relief. Fig. 1 shows the floodlight F suitably placed for observer B but not for observer A who sees practically no shadows.

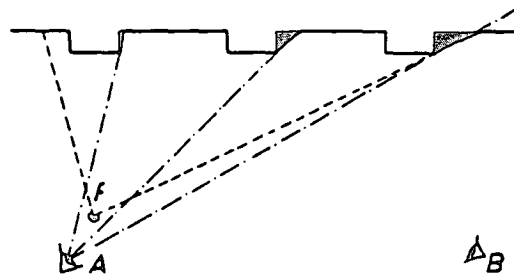


Fig. 1

Another technique to consider is to illuminate the interior of rooms, e.g. with lighting of drawn curtains. Sodium light may be used for special interior lighting to draw attention to the building.

To highlight horizontal relief it is best to place the floodlights between the observer and the facade, taking that cornices situated near the top of the building do not cast too long shadows. Fig. 2(a) shows no visible shadows on the top part of the facade and fig. 2(b) visible shadows may be seen on the top of the facade.

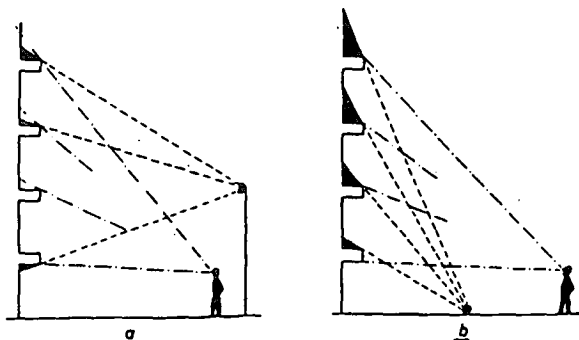


Fig. 2

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Many beautiful historic buildings have facades of rough masonry and it is here that compromise will have to be accepted between long shadows on one hand and bringing out the surface detail on the other, since the latter requires light at more or less glancing incidence. Shadows should be muted wherever possible in order to avoid sharp contrast between brightly lit areas and the presence of dark strips. This may be done by means of floodlights pointing at right angles to the beams of the main groups of lights, and with much wider beams giving less than a third of the illumination provided by the main beams (Fig.3).

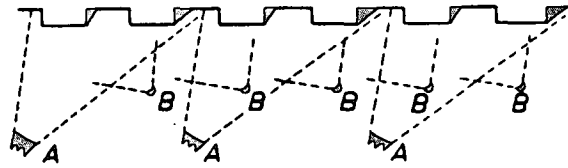


Fig. 3

ii) Relief Detached from the Facade

Details such as balconies, stairways, colonnades, etc. will cast shadows on the facade under general illumination. These details may be enhanced, for all directions of observations, by two special methods:

Firstly - the "silhouette effect". By lighting the main facade of a building at such a level that details in front of the facade are seen as dark silhouettes against a bright background.

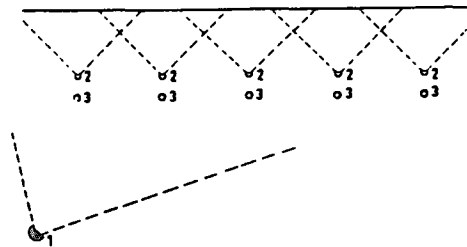


Fig. 4

Fig. 4 shows the principle of the silhouette 1) Floodlight illuminating the whole scene slightly, 2) Floodlights illuminating the background more strongly and 3) Relief detached from the facade.

Secondly - direct extra lighting of the facade itself. This may be achieved by using narrow beam floodlights placed at the top or bottom of each detail of the relief. (particularly columns). Fig. 5 shows the principle of bringing out relief by direct lighting.

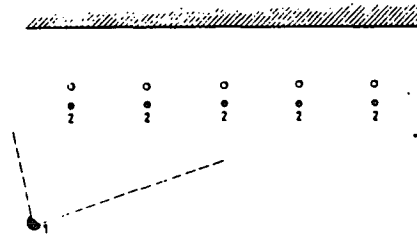


Fig. 5

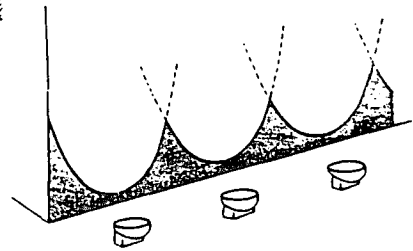


Fig. 6

- 1) Shows floodlight illuminating the whole facade directly.
- 2) Floodlights giving extra illumination for each column.

Fig. 6 shows a facade lit by floodlights placed close to the building and directed nearly vertically.

An excellent example of bringing out relief by direct lighting is the Acropolis in Athens. The beam must be very narrow and practically vertical so as not to light the facade as well. Care should be taken that the bright edges of the beam on the relief near the light source is avoided. This may be achieved by burying the floodlights. In this case an uneven illumination will be produced on the facade or relief. Care should be taken not to apply this method to very tall colonnades which might result in leaving too much of the structure in shade. Colour may also be used but only with care and good taste.

## 2.10 The Lighting of Towers

Towers present different problems as regards illumination, since in the case of a rectangular structure an observer sees more than one surface at the same time.

In illuminating a tower care should be taken that the two adjacent sides stand out from one another, so that an observer sees two distinct surfaces and not one continuous surface. Similarly a round tower should look round and not "flat".

i) **Round Towers**

Narrow beam floodlights mounted in close proximity to the tower are used. The light at the edges of the beam are tangential to the tower and therefore will tend to accentuate the relief. A suitable arrangement for positioning floodlights is shown in Fig. 7.

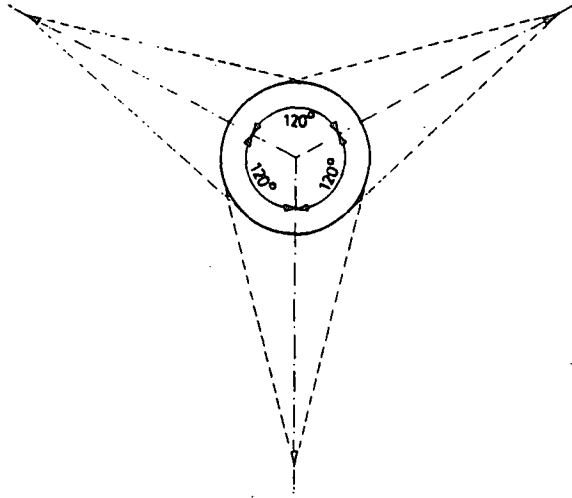


Fig. 7

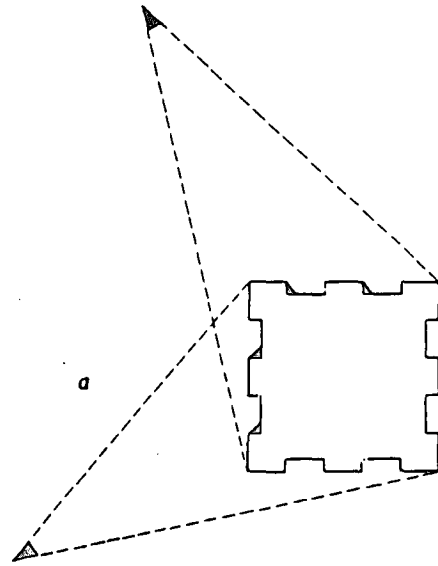


Fig. 8

ii) **Towers With Plane Surfaces**

Many historical towers have some relief on the faces. A floodlight directed towards each wall, at a slight angle (Fig. 8) in order to throw a certain amount of light on the neighbouring wall and to turn down shadow, will be quite effective. This technique should be avoided with structures with plane walls as it will make the walls look the same.

2.11 **Illuminating the Surroundings of A Building**

When planning the lighting of a park or garden the following questions should be answered:

- \* What are the most important objects to which attention must be drawn, and how can they be shown to the best advantage?
- \* What are the colours of the trees and flowers to be illuminated? (The effect of the time and season during which the installation is to operate must be taken into account.)

- \* Will the floodlighting give sufficient light for the public to find their way or will special lighting be required for footpaths?
- \* Is the installation only to be in operation for a short period or can it be regarded as permanent or semi-permanent? In the latter case is it worthwhile considering the use of energy - effective lamps and making the installation more vandal-resistant.

#### 2.11.1 Statues

A single floodlight may be all that is necessary if the statue is relatively small. Because of space limitations, a small reflector lamp would be ideal placed near the foot of the statue. The angle of aiming (found by experiment) must enhance the modelling of the sculpture without producing grotesque or disfiguring shadows.

#### 2.11.2 Trees and Shrubs

The illumination of foliage can give a spectacular effect and three different methods may be used:

- i) Illumination of foliage may be done from a distance, but would only normally be done for a background of trees. Economics would be a principal reason for adopting this method. Details of the foliage cannot be distinguished in this case.
- ii) Light sources may be placed at the base of a trunk more or less buried in the ground. This is practical only if visitors are not allowed too close to the trees or if the latter is surrounded by undergrowth serving as a natural screen. Beautiful effects can be achieved by using light of different colour. If fronted or vertical upward lighting is not desired, or is not practical trees in blossom or with bare branches can be dramatically silhouetted against a white or light coloured wall, fence or trellis. Another visually more interesting and subtle effect than lighting from the front can be obtained by using back lighting.
- iii) Light sources may be mounted on the lower branches of the tree directed upwards. This method is extensively used since the light sources are concealed from all angles. With trees adjacent to a path it is impossible to use any other system. The light diffused from the leaves provides illumination for walkways and gives a rather boreal effect. For aesthetic reasons, uniform floodlighting of a complete area is seldom satisfactory. It is generally better to concentrate the lighting on a few

trees and other points of visual interest, and to obtain a delicately composed scene.

### 2.11.3 Water - Fountains and Waterfalls

The tranquillity of an expanse of water such as a pond, lake, moat or moving water as in a fountain or cascade can be accentuated by applying tried and proven methods of lighting. Still water itself is not illuminated but is used as a mirror to reflect the illuminated surroundings. Care should be taken when positioning floodlights that these will not be seen in water to produce glare.

Moving water, as in an ornamented fountain or water curtains and cascades adds an extra dimension to the lighting. By reflecting, refracting and diffusing the light in a constantly changing way, an attractive sparkle and glitter is added.

Waterfalls may be front or back illuminated, but for single jets narrow beam spotlights arranged so they project their beams through or along the water stream are recommended.

### 2.11.4 Plants and Flowers

A popular solution is to illuminate the area concerned by a concealed floodlight fixed to a pole, branch or wall. A number of specially designed luminaires are available for this purpose. Decorative bollard-type luminaires having a widespread downward light distribution are also available. Good colour rendering is essential. In view of the low level of luminance required, normal incandescent lamps are generally used for this purpose. Pressed glass incandescent lamps are also very suitable for application because they are so robust and easy to install.

### 2.11.5 Terraces Patios and Balconies

The lighting of these areas may be done by screened spotlights or floodlights. An intimate atmosphere can be created by using pendant wall-bracket or post mounted luminaires constructed to withstand rain and sun.

## 2.12 CONCLUSION

Despite the fact that South Africa, in some advanced endeavours, has a foot in the first world, she is for most intents and purposes a developing country with a rapidly growing population. Funds are scarce and whatever money is available is being spread ever more thinly to try to satisfy the basic needs of this population. Therefore, it is understandable to some extent that in the public sector that whatever money that may be available would need to be used

with the greatest circumspection, and, perhaps, the illumination of some of our fine public buildings would rate very low on a list of priorities. However it is also true to say that exterior illumination has many positive effects apart from the obvious advantage of security, prestige lighting, where appropriate, can indirectly contribute to the coffers of any city. This is illustrated by the following examples. The Flavian Amphitheatre in the City of Rome and the India Gate in New Delhi are both fine examples of prestige illumination. (See Plate 1, page 1-2 and Plate 2, page 2-3 respectively). Plate 3 (see below) shows the beautiful 16th century Benedictine church of San Giorgio Maggiore in Venice.

The caves a Drach in Majorca are an example of floodlighting which has made a tourist attraction from a natural feature. Without lighting the wonders of these subterranean fairylands could not be seen. Some 200 000 visitors are conducted through the coves each year earning some R400 000 from entrance fees alone!

By upgrading our cities and towns and making them places that visitors want to come to can only benefit all. Tourism is fast becoming one of the highest foreign exchange earners for most countries and it should be incumbent on all, both the private and public sector do everything possible to exploit this.



PLATE 3

The Church of San Giorgio Maggiore - Venice

### 3.0 DESIGN PREPARATION

When carrying out a floodlighting project a number of points need to be considered.

#### 3.1 Direction Of View

There may be a number of directions from which a building may be viewed but often one can be decided upon as the main direction.

#### 3.2 Distance

The distance between an observer and the building is important, and the designer must decide whether all or none of the architectural detail on the facade will be seen. This will depend on the distance chosen.

#### 3.3 The surroundings and Background

The contrast between the building and its immediate surroundings is of fundamental importance. If the surroundings and background are dark a relatively small amount of light is needed to make the building lighter than its surroundings. If there are adjacent buildings in which interior lights are left on at night, the lighted windows will give an ever greater impression of brightness and therefore more light will be needed for externally illuminating the building to have an impact. If the background is bright, the same applies. In this case a maximum amount of light is needed to achieve the contrast between the building and its background. In addition to the above, the creation of a colour contrast instead of a brightness contrast can be found. The colours of the light already present in the background of the building (street lighting) must be taken into account.

Trees, shrubs and fences around a building can form a decorative part of the installation. One way of dealing with these obstacles is to place the sources of light behind them. Two advantages may be gained from this technique. Firstly the light sources are not seen by the viewer and secondly these obstacles are silhouetted against the light background of the facade. The impression of depth is therefore heightened.

Another feature that may also be taken advantage of is water in the vicinity such as a pond or moat. The illuminated building may be reflected in the water which serves as a "black mirror". The following points, however, should be borne in mind when setting up the light sources in this case:

- \* light rays must not strike the water's surface, which must be left totally dark;
- \* it is advisable to place the light sources as low down as possible. The rays are then either horizontal or sloping upwards;

- \* the water must be clean. Any matter such as weeds or slime floating on the surface will distort the reflection.

### 3.4 Position of Light Sources

Once the direction of view has been chosen, the positioning and aiming of the main floodlights may be decided upon. It is important to investigate all possible ways of setting up the light sources. The aim is to reveal the shape or form of the structure where buildings are concerned, this is done by creating a contrast in brightness, as seen from the main viewing position between two adjacent facades. This is best achieved by positioning and aiming the floodlights so as to give a difference in the angle of light incidence on the two facades concerned rather than by employing floodlights positioned square on to the facades that throw more light on one relative to the other. An advantage of the former technique is that in addition to creating the required brightness, the oblique angle of light incidence also helps bring out the surface texture of the building material employed. Secondary facades should, generally, be illuminated to about 50% of the value chosen for the main facade in order to bring out the three dimensional form of the building. The exception to this rule is where the form is revealed by a difference in the colour of the light rather than its level.

Where features, such as galleries or balconies are to be lighted, floodlights must be placed some distance away in order to avoid excessive shadow. If this is difficult to do because of the site location, it may be possible to use supplementary lighting provided by small light sources mounted on the projection or in a recess. The light of another colour is particularly suitable for this purpose.

A further point to consider carefully is the proximity of roads. Any floodlighting installed must not hinder traffic in any way. Fittings should be well shielded from the drivers of oncoming vehicles. Help may be required from local authorities or owners of adjacent buildings to ensure light sources are positioned in the most advantageous positions.

### 3.5 Form of the Structure

Having chosen the main direction of view, the choice of direction of the light will depend upon the shape of the building. This will enable the position of light sources to be more or less fixed. Despite the complexity of some facades, it is possible to reduce all ground plans of buildings to simple geometrical figures, rectangular, square or round. Some complex structures may contain a group of such figures where facades are set off with a special pattern of relief on the masonry. A pleasing interplay of light and shadow can be achieved by lighting from one side with concentrated beams of light.

As indicated previously, the direction of light and the direction of view must be at a certain angle to each other, so that the illuminated face of the building looks as attractive as possible.

The characteristics of the facade show to the best advantage when the incident light is at an angle smaller than  $90^{\circ}$ . No definite angle can be given. On the horizontal and vertical planes the angle, calculating from the vertical to the facade may vary between  $0^{\circ}$  and  $90^{\circ}$ . For a deep profile the angle should be between  $0^{\circ}$  and  $60^{\circ}$  and for a flat profile between  $60^{\circ}$  and  $85^{\circ}$ . To show the structural details of a facade to the best advantage, scattered light should be used incident at an angle of  $80^{\circ}$  to  $85^{\circ}$  to the vertical where round structures are concerned. The main concern is to accentuate its roundness rather than the texture or profile of the facade. This may be achieved by means of narrow beam or medium beam floodlights set up at two or three points around the tower (see fig. 7 and fig. 8, para 2.10 (i)). Because of its roundness the angle of incidence varies between  $0^{\circ}$  and  $90^{\circ}$  calculated from the middle outwards to the edges. This will affect both the direction and the brightness of the tower. This variation in brightness around its circumference will emphasize its roundness. Thus the rounded forms of towers are only visible if, in addition to highlights, shadow effects are also achieved. If batteries of floodlights are to be used, their positioning will depend principally upon the shape of the ground plan of the building. The type of fitting to be used, in particular the width of the beam is largely determined by the height. Wide beam floodlights are the most appropriate light sources for low buildings with one or two storeys.

In the case of buildings of eight or more storeys the best results are achieved by using narrow or medium beam floodlights. Uniform brightness is obtained by careful distribution of beams over the facade and the proper adjustments of the luminaire.

### 3.6 Facades

#### 3.6.1 Architecture of the Facade

- \* Flat facades, no architectonic details - no shadow effects required.
- \* Facades with vertical lines (columns, pillars, etc.) - narrow beam floodlights for creating shadow effects; wide beam floodlights for softening shadows.  
Light direction of narrow beam floodlights opposite direction of view.  
Light direction of wide beam floodlights same as direction of view.
- \* Facades with horizontal lines (cornices, etc.) - to prevent shadow bands above the horizontal lines large spacing between facade and light sources is required (fig. 1).

- \* Facades with protruding parts (balconies, canopies, parapets) - large distance between facade and light sources required. Small light sources have to be installed on or behind protruding parts for softening shadow band caused by light batteries floodlighting the facade (fig. 2).
- \* Facades with recessed parts (galleries, parapets, etc.) - Large distance between facade and light sources required. Interior of recessed parts should be lit separately. The use of another light colour for the interior stimulates depth working (fig. 3).

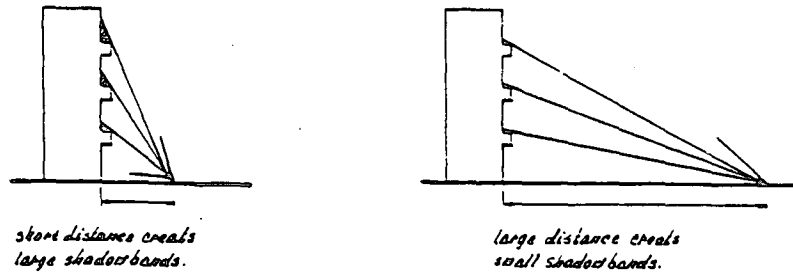


Fig. 1

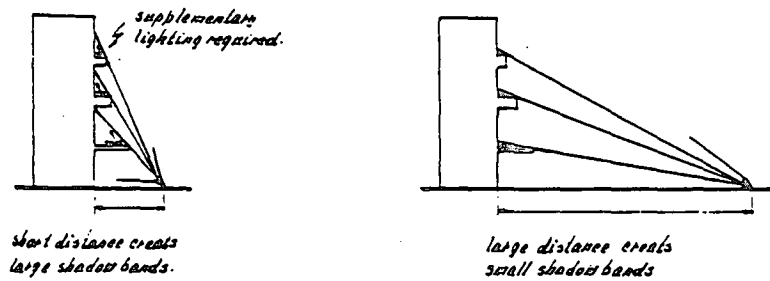


Fig. 2

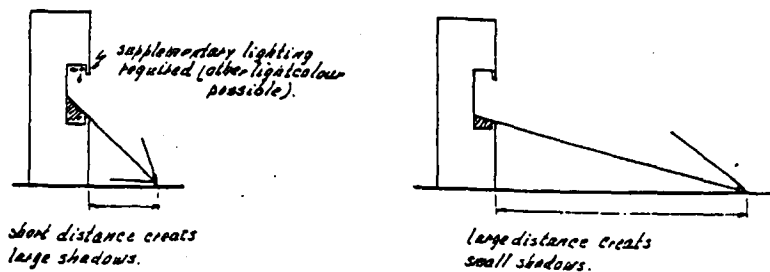


Fig. 3

### 3.6.2 Surface Texture and Colour of the Applied Building Materials

The total reflection from a facade depends on the following:

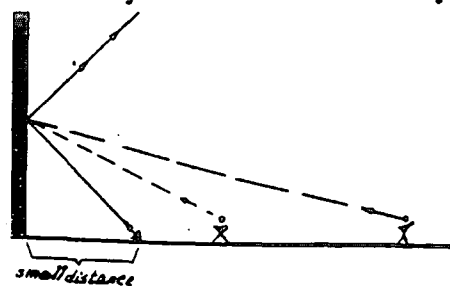
- \* the material of the facade;
- \* the angle of incidence of light;
- \* the position of the observer with regard to the reflecting material (specular reflection).

The colour of the material is also an important consideration and will be accentuated if light of the same colour is used.

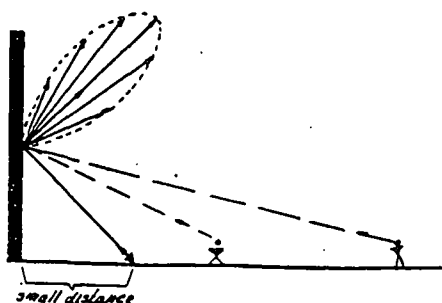
A distinction can be made between diffuse and specular reflection and of variations in between. These different types of reflection are due to the particular surface textures of building materials. These may be classified as follows:

- \* **Very smooth surface** - acts more or less like a mirror with most of the light reflected upwards away from the observer.
- \* **Smooth surface** - light is reflected somewhat diffusely with a small amount of light reaching the observer.
- \* **Dull surface** - reflected light is even more diffused with a larger part of the light received by the observer.
- \* **Very dull surface** - is extensively diffused with a great deal of the light directed to the viewer.

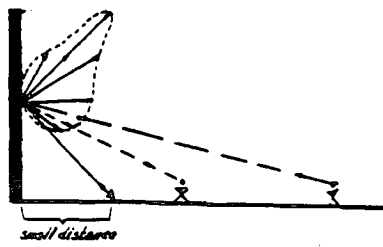
It is obvious that the different reflection properties of the surface material necessitates a different illumination of the facade in order to achieve the required brightness. Environmental factors such as pollution of the building is important; the reflection factor of a clean facade may be twice that of a dirty and grimy one.



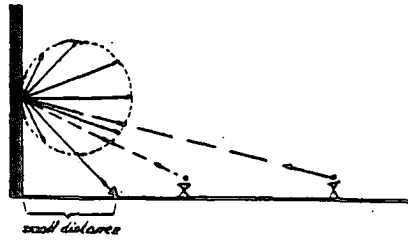
*Very smooth surface  
reflects light into direction of observer.*



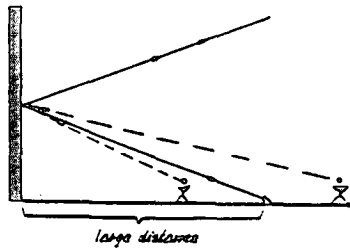
*Smooth surface  
reflects light into direction of observer.*



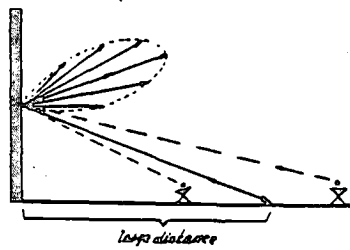
dull surface  
reflected light into direction of observer.



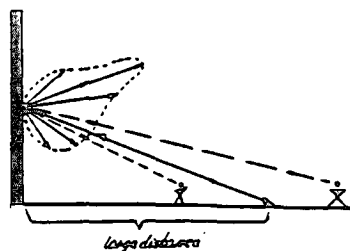
very dull surface  
reflected light into direction of observer.



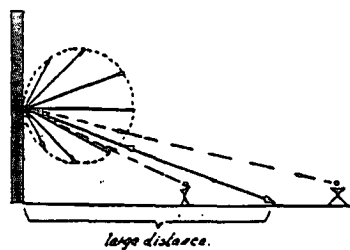
very smooth surface  
no reflected light into direction of observer.



smooth surface  
reflected light into direction of observer.



dull surface  
reflected light into direction of observer.



very dull surface  
reflected light into direction of observer.

- Reflections: i) Small distance between building and light source  
- less reflected light towards observer
- ii) Larger distance between building and light source  
- more reflected light towards observer

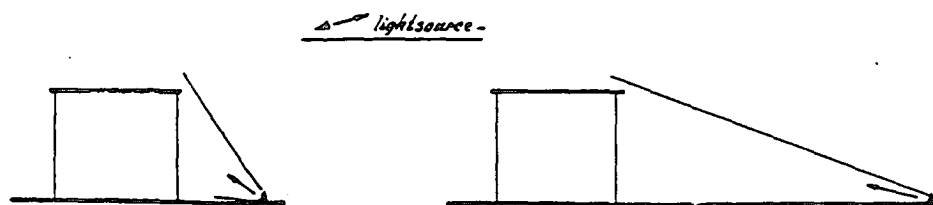
The table below indicates the reflection factors of a number of different building materials.

MATERIAL	STATE	REFLECTION FACTOR
White marble	fairly clean	0,6 - 0,65
Granite	fairly clean	0,10 - 0,15
Light concrete or stone	fairly clean	0,40 - 0,5
Dark concrete	fairly clean	0,25
or stone	very dirty	0,05 - 0,10
Imitation concrete point	clean	0,50
White brick	clean	0,80
Yellow brick	new	0,35
Red brick	dirty	0,05

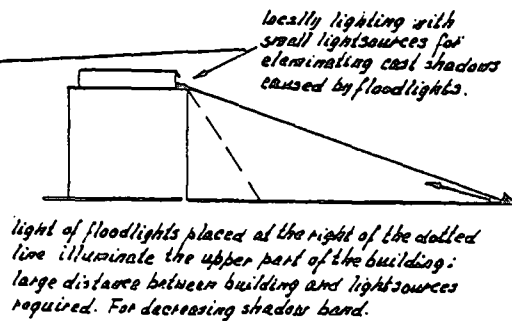
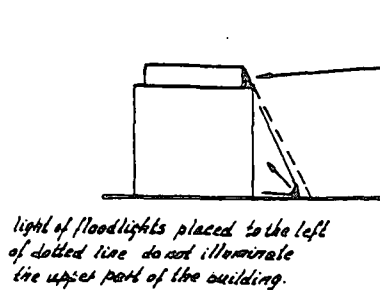
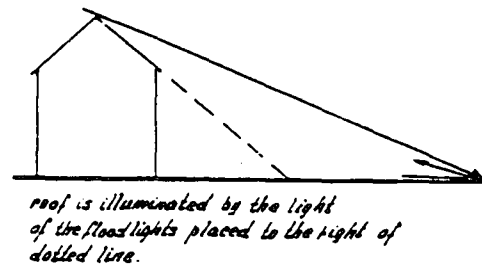
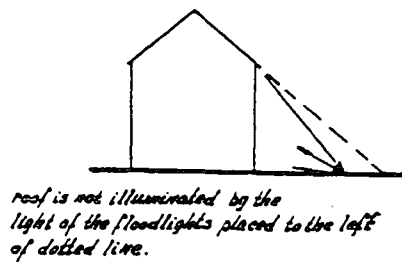
### 3.7 Roofs

The roof of a building should also be visible at night if the building is to be illuminated.

- \* Flat roof - invisible both in daylight and at night so lighting is restricted to the facade.
- \* Saddle or Gable roof - the distance between the building and the light sources has to be chosen in such a way that the roof is illuminated too. (see diagram below)



- flat roof is not visible - both in daytime and nighttime -



### 3.8 Costs

There are two major considerations to be taken into account when planning an exterior illumination installation. The first being whether the scheme is justified and secondly will the proposed scheme be a sound economic proposition? These questions, especially where they pertain to prestige lighting, are difficult to answer in times of economic constraints.

The economics of installations are difficult to judge in absolute terms, so comparisons are frequently used. This may be a simple annual cost method or the more complex discounted cash flow method. Whatever method is decided upon the costs of owning and operating an installation are needed. These may be divided, broadly into two areas, i) Capital costs which includes luminaires, associated control gear, installation and wiring and, ii) Operating costs which may be subdivided into: Fixed Annual Costs, Running Costs (electricity consumed, Replacement of Lamps, Labour, etc) and Maintenance Costs (cleaning luminaires and repair).

Perhaps the most realistic method of analysing costs is to itemize the anticipated expenditure on a year by year basis. This will allow, among other things, for inflation to be taken into account. The interest on borrowed capital is high and this capital, if available, may have been invested more profitably elsewhere.

Control of the illumination load profile by dimming or switching will help reduce electricity costs. Load shedding by ripple control may also be employed to reduce maximum demand. Prestige illumination installations must, in the final analysis, be seen to be giving value for money.

### 3.9 Survey Summary

The following check list may be useful when planning an external illumination installation.

3.9.1 **Direction of view** - establish the best position from which to view the building.

3.9.2 **Distance** - will depend upon which architectural details are to be accentuated.

#### 3.9.3 Surrounding and Background - Contrast

3.9.3.1 If background is dark a relatively small amount of light is required to make the building lighter than surroundings.

3.9.3.2 If adjacent buildings have interior lights left on this will give impression of brightness, therefore more light required to give impact to external illumination of building.

3.9.3.3 If background is bright - maximum amount of light needed to achieve contrast.

3.9.3.4 Take into account colour contrast - colours present in the background, e.g. street lights.

3.9.3.5 Trees, shrubs and fences are a decorative part of an installation. Consider placing light sources behind these obstacles. This will give impression of depth.

3.9.3.6 Water creates a "Black Mirror"  
\* No light should strike the surface of the water.  
\* Place light sources as low as possible.  
\* Water must be clean.

#### 3.9.4 Position of Light Sources

3.9.4.1 Investigate all possible ways of setting up light sources. This is best achieved by positioning and aiming floodlights so as to give a difference in the light incident on the two facades.

3.9.4.2 Illuminate secondary facades to about 50% of value chosen for main facade.

3.9.4.3 Galleries and balconies - place floodlights some distance away in order to avoid excessive shadow. Colour lamps very suitable for this purpose.

- 3.9.4.4 Proximity of roads - very important that floodlights do not hinder traffic. Fittings should be well shielded.
- 3.9.4.5 Consult local authorities concerning any bylaws or regulations.
- 3.9.5 **Form of Structure** - will depend upon shape of building. Reduce all ground plans of buildings to simple geometrical figures rectangular, square or round. **Note: Direction of light and direction of view must be at a certain angle to each other (between 45° and 135°).**
  - 3.9.5.1 Angles: To show facade to best advantage, incident light is at an angle smaller than 90°.
  - 3.9.5.2 On horizontal and vertical planes the angle calculated from the vertical to facade may vary between 0° and 90°.
  - 3.9.5.3 For deep profile angle should be between 0° and 60°.
  - 3.9.5.4 For flat profile angle should be between 60° and 85°.
  - 3.9.5.5 For round structures, scattered light should be used at an angle of between 80° and 85°.
  - 3.9.5.6 For multistorey buildings (eight or more floors) use narrow or medium beam floodlights.
- 3.9.6 **Facades**
  - 3.9.6.1 Flat facades - no shadow effect required.
  - 3.9.6.2 Facades with vertical lines - use narrow beam lamps for creating shadow and wide beam for softening shadows.
  - 3.9.6.3 Facades with horizontal lines - large spacing between facade and light sources to prevent shadow bands.
  - 3.9.6.4 Balconies, galleries and parapets
    - \* PROTRUDING - large distance between facade and light source required.
    - \* RECESSED - large distance between facade and light source required.
 Interior of recessed parts should be illuminated separately (Refer para 3.6 page 3-3)
- 3.9.7 **Reflection** will depend upon
  - 3.9.7.1 material - angle of incidence and position of observer with regard to reflecting material.

3.9.7.2 Surfaces - Very smooth; smooth; Dull; Very Dull  
(Refer 3.6.2).

3.9.7.3 Environmental Factors - pollution and its effect on  
reflection. (See table page 3-7, para 3.6.2)

3.9.7.4 Roofs - flat, saddle or gable. Should be visible if  
building is to be illuminated.

3.9.7.5 **Costs**

<b>Capital</b>	<b>Operating</b>
Luminaires	Fixed annual costs
Control Gear	Electricity Consumed
Installation	Replacement of lamps
Wiring	Labour
	Maintenance

Itemize anticipated expenditure on a year by year basis.

## 4.0 PRELIMINARY DESIGN CONSIDERATIONS

### 4.1 Diffusing Lamps for the Floodlighting of Buildings

Extensive use is now made of high luminous output sources. However, these sources often have a large light emitting area and a relatively low illuminance. They may be used for floodlighting purposes if the available equipment is sufficiently large, so that the source is small enough with respect to the dimensions of the mirror. With these sources the intensities of the axis of the beam will never be as high as those obtained with incandescent or small, high power discharge lamps. If, for example, a incandescent lamp of 500W is replaced by an ovoid fluorescent lamp of the same luminous flux (the luminance of the incandescent lamp being  $1000 \text{ cd/m}^2$  and that of the ovoid lamp  $15 \text{ cd/m}^2$  the ratio of the maximum intensities will be 1:67. Floodlights with lamps with fluorescent tubes cannot be used for long distance illumination because their beam will always be rather divergent. Moreover, because fluorescent lamps have an appreciable size, their tube will intercept some of the reflected rays and the output of a floodlight equipped with, for example, an ovoid fluorescent lamp will always be slightly worse than that of a similar floodlight equipped with an incandescent lamp.

The diffusing lamps that can be used for floodlighting or facades are tubular fluorescent lamps, mercury vapour lamps with or without fluorescent coating and sodium vapour lamps.

Tubular fluorescent lamps can, of course, only be used with cylindro-parabolic or cylindro-elliptical reflectors. The luminous intensity of the bare lamp can be multiplied by 5 or 6 by a good cylindro-parabolic reflector with, for example, an aperture of 250 mm. A maximum intensity of between 1200 and 1500 cd can be obtained from 40W TL lamps which can be used quite near vertical walls provided these walls are not too high. The Figure. 4.1 below shows the light distribution for a cylindro-parabolic reflector with an aperture of 260 mm and a depth of 125 mm in a plane perpendicular to the lamps axis.

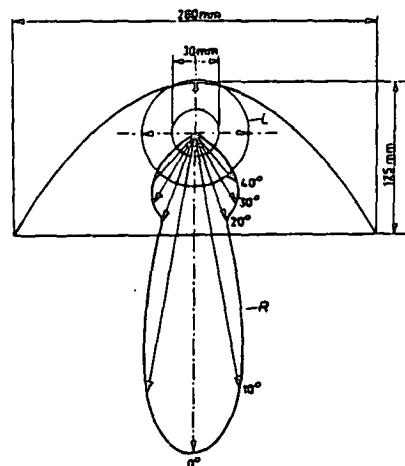


Fig 4.1

**Increasing the luminous intensity of a tubular fluorescent lamp with the aid of a cylindro-parabolic reflector.**

L: Distribution of luminous intensity of lamp above.

R: Distribution of luminous intensity of lamp and reflector.

Ovoid mercury lamps with a fluorescent bulb can frequently be used in floodlights designed for incandescent lamps. This does not reduce the efficiency to any great extent.

For example, an ovoid fluorescent lamp of 400W is substituted for an incandescent lamp of corresponding luminous flux in a parabolic floodlight with a diameter of 58cm, the output is reduced by about 22%. Considering the fact that the luminous efficiency of a 1000W (220V) incandescent lamp is in the order of 20 lm/W, then, from the power consumption point of view, it is a definite advantage to use mercury vapour lamps with a fluorescent bulb, provided the distances are not too great and the colour is alright. Moreover, its life is about four times that of incandescent lamps.

The same considerations hold for sodium-vapour lamps. A maximum luminous intensity of more than 15000cd can be obtained on the axis of the beam with a 50 x 100W lamp and a useful mirror aperture of 36cm x 43cm.

#### 4.2 The Light Output Ratio of a Floodlight

A knowledge of this quantity is very important to the designer. The efficiency naturally varies with the type of floodlight, its size, the source used, the form and the quality of the mirror. The light-output ratio can be easily determined for axially symmetrical equipment from the luminous intensity distribution curve. Things are a little more difficult with asymmetrical equipment. The most accurate data available is for parabolic reflectors which are the most widely used. The table below gives the light-output ratio of a number of current types of equipment of rotational symmetry.

Type of mirror	Power and type of the lamp	Approximate total aperture of beam (> 0.1 max. value)	Approximate light-output ratio
deep parabolic specular	250W and 500W floodlighting (incandescent)	18°-28°	0.45-0.55
shallow parabolic specular	100W and 500W standard, 500W floodlighting (incandescent)	22°-32° 9°-14°	0.25-0.30
deep diffusing parabolic	500W floodlighting 250W floodlighting (incandescent)	65° 35°	0.45-0.50 0.30-0.35

ditto with diffusing cover	250W floodlighting (incandescent)	44°	0.30-0.35
spherical and parabolic specular treated aluminium	1000W floodlighting (incandescent)	13°	0.53
	1000W standard (incandescent)	18°	0.61
ditto diffusing	1000W floodlighting (incandescent)	15°	0.55
	1000W standard (incandescent)	27°	0.65
ditto  specular	High-pressure mercury vapour lamp with fluorescent bulb (HPL) 400W	80°	0.55
diffusing parabolic enamelled plate	500W standard (incandescent)	140°	0.60

*With permission Philips Lighting B.V.*

#### 4.3 Choice of Floodlight

The siting of floodlights and the choice of floodlight type (i.e. beam width, beam shape, intensity) are mutually dependent. A building could either be lighted by a narrow beam floodlight placed close to it and aimed steeply upwards, or by a wide beam unit placed further away. In each case, the taller the building, the greater the intensity of the floodlight used.

The following is a general survey of the lamp types employed in floodlighting along with some typical applications.

- \* **Incandescent:** Incandescent lamps with their own built-in reflector are best suited for simple installations of a temporary nature or where annual operating times are limited. Most commonly used is the PAR lamp, which is ideal for accent lighting or illuminating a small area.
- \* **Tungsten Halogen:** These are more efficient than standard incandescent lamps. They are also more compact. This allows them to be used in small luminaires with tightly-defined optical systems. There are also halogen versions of the PAR lamp. Where dimming or optimal colour is required, incandescent and tungsten halogen lamps are very suitable. They may also be used with colour filters to produce colour effects or accents.

- \* **Fluorescent:** These are ideal for illuminating linear elements such as parapets, low walls or small surfaces. Compact units are now used for floodlighting purposes in wide-beam housings.
- \* **High-pressure mercury:** These lamps are used for both accent and floodlighting purposes where a "cool" light is needed to accentuate greenish or bluish subjects.
- \* **Metal halide:** These are more efficient than high-pressure mercury lamps, and provide better colour rendering. There are versions with "cool", "medium" and "warm" colour appearances.
- \* **High-pressure sodium:** Suitable for applications where a "warm" colour appearance is desirable.
- \* **Low-pressure sodium:** These lamps are only used where the objects being illuminated respond to monochromatic yellow light, for example, golden domes or yellow stone.

#### 4.4 Design Data Requirements

The principal data required to facilitate the design of a floodlighting installation may be listed as follows:

- \* Scale drawings showing plan, elevations and principal cross-sections of the structure to be illuminated.
- \* Drawing showing in plan view, details of the immediate surroundings of the structure (e.g. location of other buildings, roads, paths, trees, etc.) and indicating the main direction of view and the property boundary lines.
- \* Description of cladding material used including texture and lightness. (obtain samples, if possible, from architects or contractors)
- \* Information regarding the brightness of the surroundings against which the floodlighted structure will be seen.
- \* Colour photographs of the completed structure or of the architect's model or the model itself.
- \* Information pertaining to the maximum permitted installed load.
- \* Information pertaining to the building itself - its present use - its historical background (if any) and its local significance.
- \* A copy of all relevant bye-laws governing lighted structures.

## 4.5 Calculations

### 4.5.1 Direct Calculations

Complex floodlighting installations are designed with the aid of a computer. Smaller projects, however, can be quite satisfactorily designed by applying direct calculation in the form of the Lumen and Luminous Intensity methods.

Luminous intensity method which should be used when dealing with high towers steeples, etc. determines the luminous intensity distribution required from the floodlight. The lumen method is more suitable for large facades, indicates the number of floodlights needed to illuminate a facade to a specified level. The luminous intensity method is then applied to determine the intensity distribution required for a desired lighting uniformity.

#### The Luminous Intensity Method

In order to produce the desired surface illuminance, the luminous intensity in candelas, that must be radiated in a given direction, must first be determined.

$$\begin{aligned}\text{Luminous Intensity } I_{\gamma} &= E_p d^2 / \cos^3 \gamma \\ &= E_p d^2 / \cos^3 \alpha \cdot \cos \beta\end{aligned}$$

Where  $E_p$  = Surface illuminance on the facade at point P in lux.  
 $d$  = distance in metres from floodlight to facade.  
 $\gamma$  = angle at which the light beam is incident on the facade

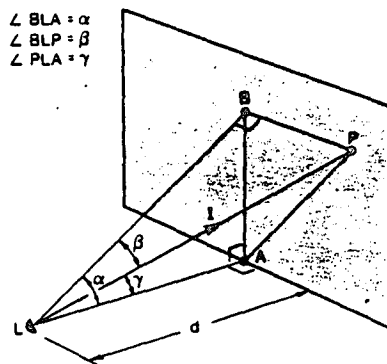


Fig. 1

Fig. 1 indicates the luminous intensity required by a floodlight to illuminate a point P on a plane. By knowing the value of  $I_\gamma$ , the luminous intensity diagram or tables may be used to determine a suitable light source.

In  $\Delta LAP$ ,  $\cos \gamma = LA/LP$

In  $\Delta LAB$ ,  $LA = LB \cos \alpha$ , and in  $\Delta LBP$ ,  $LP = LB/\cos \beta$ .

So  $\cos \gamma = LA/LP = \cos \alpha \cos \beta$

By substituting this for  $\cos \gamma$  in the equation for  $I_\gamma$  gives:

$$I_\gamma = E_p d^2 / \cos^3 \alpha \cos^3 \beta$$

### Lumen Method

This method is used to determine the luminous flux directed onto the facade.

The total flux  $\phi_{total}$  can be determined thus:

$$\phi_{total} = AE/\eta M$$

- where A = area of surface illuminated in  $m^2$   
 E = desired illuminance, in lux  
 $\eta$  = utilisation factor  
 M = maintenance factor

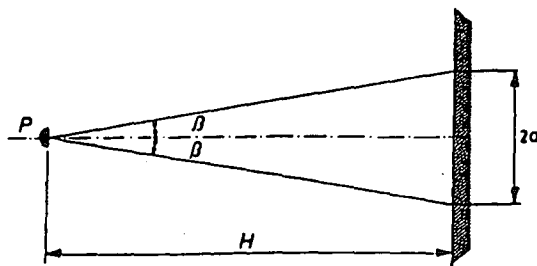
It can be seen that the inclusion of a utilisation factor in this formula indicates that not all the lamp lumens contribute to the illuminance level on the facade. There is some loss within the floodlight and some leaving the floodlight are not incident upon the surface being lighted.

The maintenance factor takes into account the loss that occurs after the floodlight has been in operation for some time. This loss is due to the decrease in luminous flux due to the ageing of the lamp and the accumulation of dirt on both it and the floodlight.

In practice, an average utilisation factor of between 0,20 and 0,40 may be satisfactory, while a maintenance factor can range from 0,6 to 0,9.

#### 4.5.2 Average Illumination of the Beam

- i) The beam is normal to the surface to be illuminated. The method is not frequently used. In this case the size of the circular spot of light which the beam forms must be known before the average illumination can be calculated.



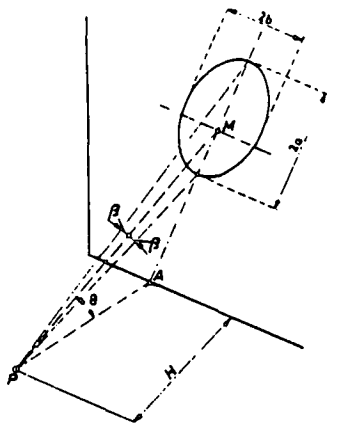
The figure above shows a beam of rotational symmetry of aperture  $2\beta$  normal to the illuminated surface. If  $H$  denotes the distance of the floodlight from the facade and  $\beta$  the semi-angle of the aperture of the beam, the radius  $a$  of the spot of light is given by:

$$a = H \tan \beta$$

and the area  $S$  covered is:

$$S = \pi H^2 \tan^2 \beta$$

ii) The beam is at an angle to the surface to be lit.



The figure above shows a beam of rotational symmetry of aperture  $2\beta$  at an angle  $\theta$  to the surface to be illuminated.

Here, the intersection of the conical beam with the plane of the facade is an ellipse. The dimensions of this ellipse will need to be calculated.

Let  $a$  and  $b$  be half the long and short axes of the ellipse.

With the same notation as above it may be shown that:

$$a = \frac{1}{2}H \cdot \frac{\sin^2 \beta}{\cos^2 \beta - \sin^2 \theta}$$

and

$$b = a \cdot \sqrt{1 - \frac{\sin^2 \theta}{\cos^2 \beta}}$$

Where  $\theta$  is the angle the axis of the beam makes with the normal to the facade to be illuminated.

The area  $S = \pi ab$  enclosed by the ellipse may be determined and hence the average illumination  $E$  due to the flux  $\phi_b$  in the beam:

$$E = \phi_b / S$$

#### 4.5.3 Isolux Curves

It is sometimes useful to know the uniformity of illumination given by a beam of light on a facade. This may be determined as follows. Each axially symmetrical part of the beam, of aperture  $2\beta$ , gives an ellipse on the illuminated facade. Each of these ellipses defines directions with respect to the axis of the beam, along the edge of a given cone corresponding to the same value of the illuminous intensity. The illumination along the perimeter of an ellipse is given by:

$$E_H = \frac{I \cos^3 a}{H^2}$$

Consider a value of  $E$ , say  $E_0$

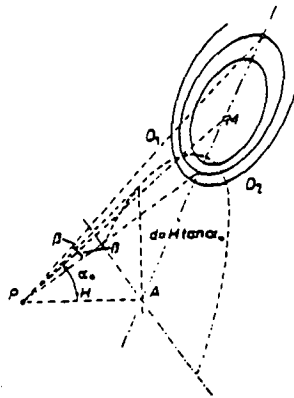
then:

$$\frac{E_0 H^2}{I_0} = \cos^3 a_0$$

Where the left hand side of the equation is known for a given ellipse. The value  $a_0$  of  $a$  for the ellipse can thus be determined:

$$a_0 = \arccos \left\{ \frac{E_0 H^2}{I_0} \right\}^{\frac{1}{3}}$$

The distance  $d$  may now be deduced, defined by the relation  $d = H \tan a_0$ .



#### Method of Determination of Isolux Curves

- \* Draw a number of ellipses for increasing values of  $\beta$  and consider a certain value of  $E_0$ .

- \* Draw a number on the surface to be illuminated, with the projection of the floodlight on this surface as centre and radius  $d = \tan a_0$ . (See fig. above) The intersection of this circle with the ellipse gives two points  $D_1$  and  $D_2$  of the isolux for  $E_0$ .

The superposition of the isolux curves for different floodlight allows for the average resultant illumination, the uniformity factor and, if required, the utility to be calculated.

#### 4.5.4 Determination of the Number of Floodlights

A number of factors need to be known. These include the light output ratio  $\eta$  of the floodlights, which must allow for a certain depreciation factor  $f$  to take into account the decrease in the luminous output of the lamps during their life, the accumulation of dust and dirt and the decrease in the reflectance of the mirrors. Generally, this factor may be taken as 0,70 to 0,75. A factor  $g < 1$  must also be included to take into account loss of flux at the edges of the surface.

If  $\phi_0$  is the flux of one lamp, the number of lamps  $n$  is given by

$$n = \frac{E \cdot S}{\eta \cdot f \cdot g \cdot \phi_0}$$

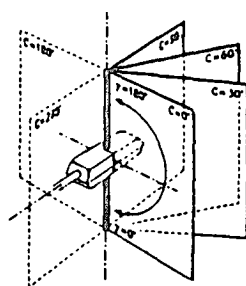
## 4.5.5 Computer Aided Design

### Calculux Program\*

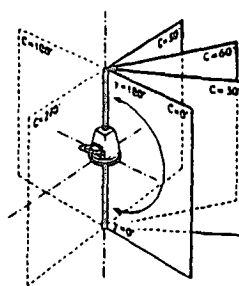
The light distribution characteristics of each luminaire are established by measurements and the results are recorded under a Measuring Code. For this reason a luminaire's General Data always includes the Measuring Code. In the CALCULUX Program the luminous intensity characteristics of the luminaires use the C-Gamma ( $C-\gamma$ ) System (See Figure below). The number of C-planes and Gamma-angles used to define the luminous intensity distribution of a luminaire depends on the evenness of the distribution. For instance, one C-plane will be sufficient to describe the distribution pattern of a rotationally symmetrical luminaire. For other types of luminaires with symmetrical distribution patterns, it will be sufficient to describe a number of C-planes over one-half or even one-quarter of the total distribution.

In most cases,  $10^\circ$  steps in the C-planes and  $5^\circ$  steps in Gamma ( $\gamma$ ) angles will be sufficient. However,  $5^\circ$  steps in Gamma ( $\gamma$ ) angles will not be sufficient for a narrow-beam floodlight. Experience will help you to select the appropriate increments for different types of luminaires.

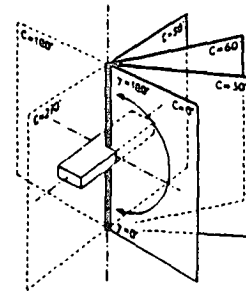
For most fluorescent luminaires which have symmetrical light distributions in all the four quadrants, it is sufficient to store values for  $C=0, 30, 60$  and  $90^\circ$  planes and with Gamma ( $\gamma$ ) angle increments of  $5^\circ$ .



Road Lighting



Floodlighting



Indoorlighting

The C-Gamma ( $C-\gamma$ ) Co-ordinate System

\* Phillips Lighting BV

#### 4.5.5.1 Measuring Systems

There are 3 measuring systems, namely:

A  $\alpha$   
B  $\beta$   
C  $\gamma$

The SABS measures floodlights in the A $\alpha$  system in the A gonio. C $\gamma$  is used for fluorescents and sheet lanterns. The B $\beta$  system is seldom used as it requires very expensive and complex goniometers.

In order to do these diagrams the luminaire is installed in the goniometer in front of a photocell installed some distance away, (min 5 x the size the luminaire) from the luminaire.

If this distance is set at say 12m and the diameter of the photocell is 4cm (0,04m) then for the area of the measuring cell we have  $\pm 12,5\text{cm}^2 = 0,00125\text{m}^2$ . The square of the measuring distance is 144m and the solid angle ( $\omega$ ) for which the measurement is made is:

$$\begin{aligned}\omega &= \frac{0,00125}{144} \\ &= 86 \times 10^{-7} \text{ sr}\end{aligned}$$

If the sphere has

$$\frac{4\pi \text{ sr area}}{R^2}$$

the entire sphere around the luminaire covers

$$\frac{4\pi \times 10^7}{86}$$

of these directions, of which only a small representative part is measured.

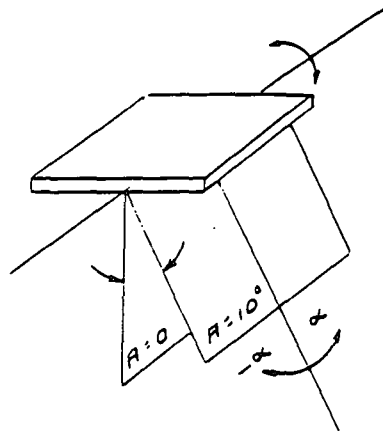
The photocell may be connected to a galvanometer. Each division may be a certain factor proportional to illuminance. If the factor is 1, then we read lux off the display.

$$ER^2 = I$$

$$\therefore E = \frac{I}{R^2} \text{ The inverse square law.}$$

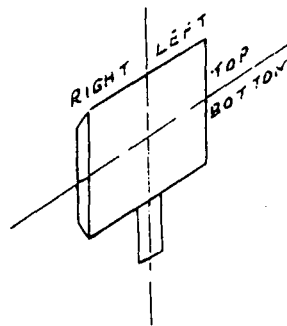
#### 4.5.5.2 The Three Systems

The photocell always moves on a defined plane. Thus in A $\alpha$  A are the planes and  $\alpha$  are the angles.



When the luminaire is horizontal the plane perpendicular to the glass is  $A = 0$ , the luminaire is now rotated to the left so that the plane perpendicular to the glass is  $10^\circ$  deviated from the original position, i.e. there are  $10^\circ$  between the two planes. The photocell now scans the luminaire, travelling on a plane. Intensities are recorded at various angles in various planes. The

planar representation of these intensity values as well as  $A$  and  $\alpha$  angles is shown in the table (Appendix F). The horizontal angles left and right are the planes whilst the vertical angles top and bottom are the  $\alpha$  angles, because at the SABS the floodlight is installed upright in the goniometer, type A



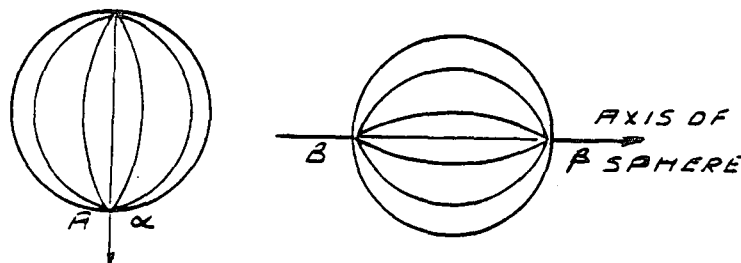
All intensity data is represented by seeing the luminaire from the back.

Comparing the planar representation of  $A\alpha$  to  $B\beta$  will not distinguish the difference unless so specified. (normally gonio type A and we then know it is  $A\alpha$  system). The difference is that:

Left - Right = planes in  $A\alpha$   
 = angles in  $B\beta$

Top - Bottom = angles in  $A\alpha$   
 = planes in  $B\beta$

if representation is made with the (polar) onion diagram

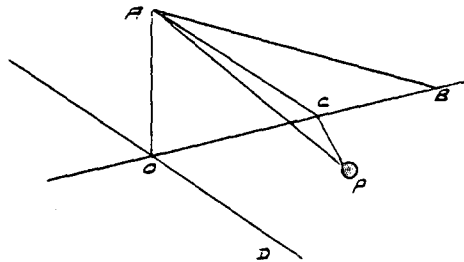


But with the onion diagram representation arc will not distinguish between  $A\alpha$  and  $C\gamma$ .

### 4.5.5.3

### Transformations

$B\beta$  is never measured in the laboratory because the minute we touch the fitting for another plane we change the arc position of the discharge in the lamp relative to the reflector. On the other hand if the photocell is to move along the angles and still have to make for the planes, this will mean such a complex mechanical arrangement for photocell (normally fixed) and mirror that the system is not reliable anymore. But the  $B\beta$  system is the preferred system for point-by-point calculations because it is the shortest cut to results.



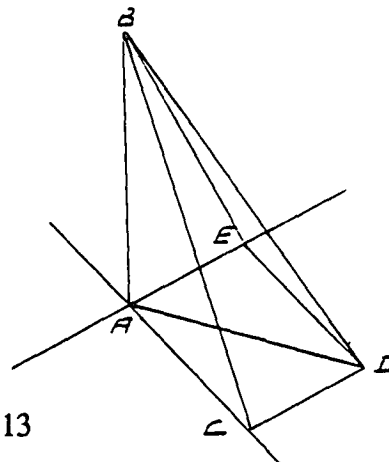
$\therefore$  BAC negative B angle of plane CAP. CAB is  $\beta$  angle of P.

Refer to the tabular representation and look for the intensity at  $-B, -\beta$  which ever angular value calculated. Because labs normally work with  $A\alpha$  for floods and  $C\gamma$  for street lanterns (CIE recommends  $C\gamma$  for all) and fluorescents there will be a need to find what angles and planes of one system will be planes and angles on the other (i.e. calculating planes and angles in  $B\beta$  and having to read intensities supplied in  $A\alpha$ ). It is then necessary to make use of transformation formulae.

### 4.5.5.4

### Interpolation

Unfortunately the planes and angles of the points to calculate, not always correspond to the planes and angles of the measuring system. There is thus a need to interpolate.



- ABC = A
- CBD =  $\alpha$
- CAD = C
- ABD =  $\gamma$
- ABE = B
- EBD =  $\beta$

C to A

$$AD = AB \tan \gamma ; AC = AB \tan \gamma \cos C ; CD = AB \tan \gamma \sin C$$

$$\tan A = \frac{AC}{AB}$$

$$\tan A = \tan \gamma \cos C$$

$$BD = \frac{AB}{\cos \gamma}$$

$$\sin \alpha = \frac{CD}{BD} = AB \tan \gamma \sin C \frac{\cos \gamma}{AB}$$

$$\sin \alpha = \sin \gamma \sin C$$

B to A

$$AE = AB \tan B$$

$$ED = BE \tan \beta = \frac{AB}{\cos B} \tan \beta = AC$$

$$\tan A = \frac{AC}{AB}$$

$$\tan A = \frac{\tan \beta}{\cos B}$$

$$BD = \frac{BE}{\cos \beta} ; BE = \frac{AB}{\cos B}$$

$$\begin{aligned} \sin \alpha &= \frac{CD}{BD} = \frac{AE}{BD} = AB \tan B \cdot \frac{\cos \beta}{BE} \\ &= AB \tan B \cos \beta \cos B \frac{1}{AB} \end{aligned}$$

$$\sin \alpha = \sin B \cos \beta$$

C to B

$$CD = AB \tan \gamma \sin C$$

$$\tan B = \frac{AE}{AB} = \frac{CD}{AB}$$

$$\tan B = \tan \gamma \sin C$$

$$\sin \beta = \frac{ED}{BD} = \frac{AC}{BD} = \frac{AB \tan \gamma \cos C}{\frac{AB}{\cos \gamma}}$$

$$\sin \beta = \sin \gamma \cos C$$

A to C

$$AC = AB \tan A ; CD = \frac{AB}{\cos A} \tan \alpha$$

$$\tan C = \frac{CD}{AC} = \frac{AB}{\cos A} \tan \alpha \cdot \frac{1}{AB \tan A}$$

$$\tan C = \frac{\tan \alpha}{\sin A}$$

$$BD = \frac{AB}{\cos A} \tan \alpha \cdot \frac{1}{\sin \alpha}$$

$$\cos \gamma = \frac{AB}{BD}$$

$$\cos \gamma = \cos A \cos \alpha$$

A to B

$$\tan B = \frac{AE}{AB} = \frac{CD}{AB}$$

$$\tan B = \frac{\tan \alpha}{\cos A}$$

$$\sin \beta = \frac{ED}{BD} = \frac{AC}{BD} = \frac{AB \tan A}{\frac{AB}{\cos A \cos \alpha}}$$

$$\sin \beta = \sin A \cos \alpha$$

B to C

$$\tan C = \frac{CD}{AC} = \frac{AE}{ED} = \frac{AB \tan B}{\frac{AB}{\cos B} \tan \beta}$$

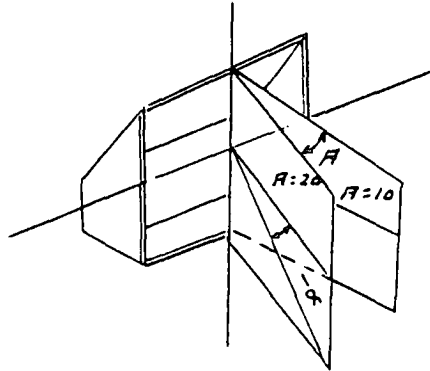
$$\tan C = \frac{\sin B}{\tan \beta}$$

$$\sin \gamma = \frac{AD}{BD} = \frac{AD}{\frac{BE}{\cos \beta}} = \frac{AD \cos \beta}{\frac{AB}{\cos B}} = \frac{AB \tan \gamma \cos \beta \cos B}{AB}$$

$$\frac{\sin \gamma}{\tan \gamma} = \cos \beta \cos B$$

$$\cos \gamma = \cos \beta \cos B$$

SABS Measures  $A \alpha$  for floodlights



The table (appendix F) shows the planar representation of the  $A \alpha$  system. Calculux only takes  $C \gamma$  system, so transformation must be done from one system to the other.

The planar table for  $C \gamma$  system should look like this:

		C → plane				
$\alpha$	0	10°	20°	30°	40°	etc up to 360°
	10°					
	20°					
	30°					
	40°					
	etc					
	up					
	to					
	180°					

The intention is to convert  $A\alpha$  into  $C\gamma$   
Intensity is required at:

$$C = 210^\circ$$

$$\gamma = 50^\circ$$

$$\therefore 210^\circ = \frac{210^\circ \pi}{180^\circ}$$

$$= 3,67 \text{ rad}$$

$$50^\circ = 0,87 \text{ rad}$$

Conversion C to A

$$\begin{aligned} \tan A &= \tan \gamma \cos C \\ &= \tan 0,87 \cos 3,67 \end{aligned}$$

$$\begin{aligned} \tan A &= -1,03 \\ &= -0,8 \text{ rad} \end{aligned}$$

$$A = -45,9^\circ$$

$$\begin{aligned} \sin \gamma &= \sin \gamma \sin C \\ &= \sin 0,87 \sin 3,67 \\ &= -0,38 \end{aligned}$$

$$\alpha = -22,5^\circ$$

Refer to table appendix F for a matrix in  $A\alpha$  intensities.

Negative A plane is left

Negative  $\alpha$  angle is bottom

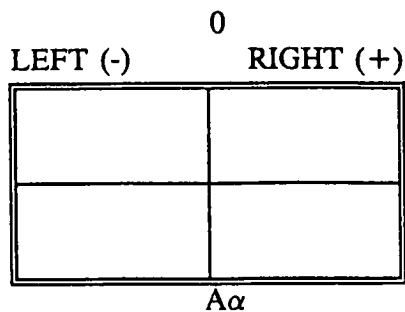
$$\therefore C = 210^\circ \rightarrow A = -45,9^\circ$$

$$\gamma = 50^\circ \rightarrow \alpha = -22,5^\circ$$

Read two planes and two angles to each side of A and  $\alpha$

				-49,5				
	-65	-55		-45	-35	← A		
-5	8	58	I <sub>1</sub>	164	374			
-15	6	51	I <sub>2</sub>	130	297			
-22,5								
	-25	5	53	I <sub>3</sub>	108	184		
	-35	5	19	I <sub>4</sub>	86	125		
	↓							
	$\alpha$							

The \* is the intensity to look for, viz 105,1 cd.



Left - negative A planes  
 Right - positive A planes  
 Top - positive  $\alpha$  angles  
 Bottom - negative  $\alpha$  angles

1. Always read two planes to each side of the corresponding A plane.
2. Always read two angles to each side of the corresponding  $\alpha$  angle.
3. Find the average value of the two planes and angles to each side of the A and  $\alpha$ , i.e.

$$\frac{(-55) + (-45)}{2} = -50 < -49,5$$

$$\frac{(-15) + (-25)}{2} = -20 > -22,5$$

4. The planes to be used are: -55, -45 and -35  
and the form angles are: -5, -15 and -25

$$I_1 = 374 + \left\{ \frac{[-49,5 - (-45)](58 - 374)}{[-55 - (-35)]} + \frac{[-55 - (-49,5)](164 - 374)}{[-45 - (-35)]} \right\} \times \left\{ \frac{[-49,5 - (-35)]}{[-55 - (-45)]} \right\}$$

$$= 150,1 \text{ cd}$$

$$I_2 = 297 + [0,0452(51 - 297) + 0,91(130 - 297)](1,019) = 119,2 \text{ cd}$$

$$I_3 = 184 + [0,0452(53 - 184) + 0,91(108 - 184)](1,09) = 102,2 \text{ cd}$$

$$I_4 = 125 + [0,0452(19 - 125) + 0,91(86 - 125)](1,09) = 81,1$$

$\alpha$	-5	-15	-22,5	-25	-35
	150,1	119,2		102,2	81,1

$$I = 150,1 + \left\{ \frac{[-22,5 - (-15)]}{[-25 - (-5)]} (102,2 - 150,1) + \frac{[-25 - (-22,5)](119,2 - 150,1)}{[-15 - (-5)]} \right\} \times \left\{ \frac{[-22,5 - (-5)]}{[-25 - (-15)]} \right\}$$

$$= 105,1 \text{ cd}$$

angles	1	2	3	4	planes
5	9	10	11	12	
6	13	14	15	16	intensities
7	17	18	19	20	
8	21	22	23	24	

Construct a  $C\gamma$  matrix from the  $A\alpha$  matrix (Table appendix F)

	C					
$\gamma$	$0^\circ$	$5^\circ$	$10^\circ$	$15^\circ$	$20^\circ$	etc.
$0^\circ$						
$5^\circ$						
$10^\circ$						
$15^\circ$						
etc.						

for each combination of  $C\gamma$  we calculate from  $A\alpha$

#### 4.5.5.5

#### Example

$$C = 25^\circ$$

$$\gamma = 36^\circ$$

$$A = 33^\circ$$

$$\alpha = 14,3^\circ$$

				$33,4^\circ$		
				↓		
	A	$15^\circ$	$25^\circ$		$35^\circ$	$45^\circ$
$\alpha$						
$25^\circ$		279	244		197	134 cd
$15^\circ$		444	378		293	172 cd
$14,3^\circ \rightarrow$				I		
$5^\circ$		571	491		384	222 cd
$-5^\circ$		545	477		376	213 cd

$$I = 318,3 \text{ cd}$$

Note that  $A\alpha$  matrix as per table appendix F has no  $A = 0, \alpha = 0$ . It has to be added to the matrix and read from the curves supplied separately.

#### 4.5.5.6

#### Calculators

The following program is designed for use with the H.P. 41 calculator and is useful for both the  $A\alpha$  to  $C\gamma$  conversion and transformation processes.

Program for carrying out the conversion and transformation process using an H.P. 41 calculator

01	LBL ATOC	58	XEQ 03	115	CF 02	172	XEQ 08	229	RCL 33
02	J6	59	PLANE 2 = ?	116	RCL 01	173	-	230	*
03	PSIZE	60	XEQ 03	117	XEQ 05	174	RCL 31	231	XEQ 10
04	CF 06	61	PLANE 3 = ?	118	-	175	*	232	+
05	CF 07	62	XEQ 03	119	XEQ 07	176	FS? 01	233	XEQ 02
06	CF 08	63	PLANE 4 = ?	120	XEQ 06	177	RCL 17	234	RCL 02
07	CF 09	64	XEQ 03	121	-	178	FC? 01	235	XEQ 16
08	CF 10	65	ANGLE 1 = ?	122	:	179	RCL 16	236	-
09	RAD	66	XEQ 03	123	STO J1	180	XEQ 08	237	XEQ 11
10	FIX 1	67	ANGLE 2 = ?	124	FS? 01	181	-	238	XEQ 14
11	CLRG	68	XEQ 03	125	RCL 12	182	RCL 32	239	-
12	CLA	69	ANGLE 3 = ?	126	FC? 01	183	*	240	:
13	CF 28	70	XEQ 03	127	RCL 13	184	+	241	FS? 02
14	SF 29	71	ANGLE 4 = ?	128	FS? 01	185	RCL 33	242	RCL 28
15	LBL 12	72	XEQ 03	129	RCL 14	186	*	243	FC? 02
16	0	73	4,00001	130	FC? 01	187	XEQ 08	244	RCL 29
17	X<>F	74	STO 30	131	RCL 11	188	+	245	XEQ 17
18	1	75	STO 29	132	-	189	XEQ 02	246	-
19	STO 00	76	2	133	*	190	FS? 01	247	*
20	PLANE C = ?	77	STO 27	134	XEQ 07	191	RCL 20	248	XEQ 11
21	PROMPT	78	7	135	RCL 01	192	FC? 01	249	RCL 02
22	STO 34	79	STO 28	136	-	193	RCL 21	250	-
23	SF 00	80	LBL 04	137	XEQ 05	194	XEQ 09	251	XEQ 16
24	XEQ 01	81	1	138	XEQ 06	195	-	252	XEQ 14
25	STO 10	82	STO + 27	139	-	196	RCL 31	253	-
26	GAMMA ANG=?	83	I AT	140	:	197	*	254	:
27	PROMPT	84	ARCL IND 28	141	STO 32	198	FS? 01	255	FS? 02
28	STO 35	85	/	142	FS? 01	199	RCL 21	256	RCL 29
29	XEQ 01	86	ARCL IND 27	143	RCL 13	200	FC? 01	257	FC? 02
30	STO 11	87	XEQ 03	144	FC? 01	201	RCL 20	258	RCL 28
31	CF 00	88	DSE 29	145	RCL 12	202	XEQ 09	259	XEQ 17
32	RCL 11	89	GTO 04	146	FS? 01	203	-	260	-
33	TAN	90	4,00001	147	RCL 14	204	RCL 32	261	*
34	RCL 10	91	STO 29	148	FC? 01	205	*	262	+
35	COS	92	1	149	RCL 11	206	+	263	RCL 02
36	*	93	STO + 28	150	-	207	RCL 33	264	XEQ 14
37	ATAN	94	2	151	*	208	*	265	-
38	XEQ 01	95	STO 27	152	+	209	XEQ 09	266	XEQ 11
39	XEQ 02	96	DSE 30	153	RCL 01	210	+	267	XEQ 16
40	PLANE A =	97	GTO 04	154	XEQ 06	211	XEQ 02	268	-
41	ARCL .X	98	SF 01	155	-	212	FS? 01	269	:
42	AVIEW	99	SF 02	156	XEQ 07	213	RCL 24	270	*
43	STOP	100	RCL 04	157	XEQ 05	214	FC? 01	271	XEQ 17
44	RCL 10	101	RCL 05	158	-	215	RCL 25	272	+
45	SIN	102	+	159	:	216	XEQ 10	273	I AT
46	RCL 11	103	2	160	STO 33	217	-	274	ARCL 34
47	SIN	104	:	161	*	218	RCL 31	275	/
48	*	105	RCL 01	162	FS? 01	219	*	276	ARCL 35
49	ASIN	106	X<Y?	163	RCL 14	220	FS? 01	277	AVIEW
50	XEQ 01	107	CF 01	164	FC? 01	221	RCL 25	278	PSE
51	XEQ 02	108	RCL 08	165	RCL 11	222	FC? 01	279	I =
52	CLA	109	RCL 09	166	+	223	RCL 24	280	ARCL .X
53	ALPHA =	110	+	167	XEQ 02	224	XEQ 10	281	CD
54	ARCL .X	111	2	168	FS? 01	225	-	282	AVIEW
55	AVIEW	112	:	169	RCL 16	226	RCL 32	283	STOP
56	STOP	113	RCL 02	170	FC? 01	227	*	284	Y
57	PLANE 1 = ?	114	X<Y?	171	RCL 17	228	+	285	ASTO .Y

286	AON	346	FC? 01
287	FINISHED=?	347	RCL 15
288	PROMPT	348	RTN
289	ASTO .X	349	LBL 09
290	AOFF	350	FS? 01
291	X=Y?	351	RCL 22
292	GTO 12	352	FC? 01
293	0	353	RCL 19
294	X<>F	354	RTN
295	DEG	355	LBL 10
296	FIX 2	356	FS? 01
297	LBL 13	357	RCL 26
298	GOOD BEY	358	FC? 01
299	AVIEW	359	RCL 23
300	STOP	360	RTN
301	PISS OFF	361	LBL 11
302	AVIEW	362	FS? 02
303	PSE	363	RCL 08
304	GTO 13	364	FC? 02
305	LBL 01	365	RCL 09
306	PI	366	RTN
307	FS? 00	367	LBL 14
308	*	368	FS? 02
309	FC? 00	369	RCL 10
310	:	370	FC? 02
311	180	371	RCL 07
312	FS? 00	372	RTN
313	:	373	LBL 15
314	FC? 00	374	FS? 02
315	*	375	RCL 30
316	RTN	376	FC? 02
317	LBL 03	377	RCL 27
318	PROMPT	378	RTN
319	LBL 02	379	LBL 16
320	STO IND 00	380	FS? 02
321	1	381	RCL 09
322	STO + 00	382	FC? 02
323	RDN	383	RCL 08
324	RTN	384	RTN
325	LBL 05	385	LBL 17
326	FS? 01	386	FS? 02
327	RCL 05	387	RCL 30
328	FC? 01	388	FC? 02
329	RCL 04	389	RCL 27
330	RTN	390	END
331	LBL 05		
332	FS? 01		
333	RCL 06		
334	FC? 01		
335	RCL 03		
336	RTN		
337	LBL 07		
338	FS? 01		
339	RCL 04		
340	FC? 01		
341	RCL 05		
342	RTN		
343	LBL 08		
344	FS? 01		
345	RCL 18		

GTO.. ( PACK )

N.B. \* = multiplication  
: = division  
- = subtraction  
step 83.... I AT space  
step 85.... add forward slash  
step 273... I AT space  
step 275... add forward slash  
step 279... I space  
step 281... add CD  
step 291... if X different to Y  
step 301... by 'obstinatum' RS pressing after GOOD BEY  
step 306... 3,141593  
step 323... R

#### 4.5.6 Typical Calculation Models

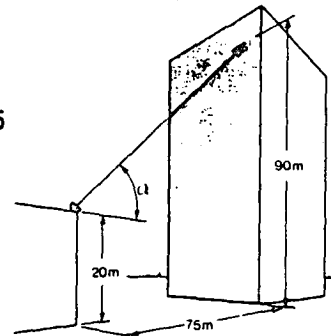
- (i) A 90m high tower block has to be floodlit. A floodlight can be mounted on the roof of a nearby building that is 20m high and situated at a distance of 75m from the tower. What floodlight is required to provide a surface illuminance on the tower of 60 lux?

$$\alpha = \tan^{-1} \frac{90 - 20}{75} = 43^\circ$$

Using the equation for luminous intensity page 4-5

$$\beta = 0 \text{ hence } \cos^3 \beta = 1$$

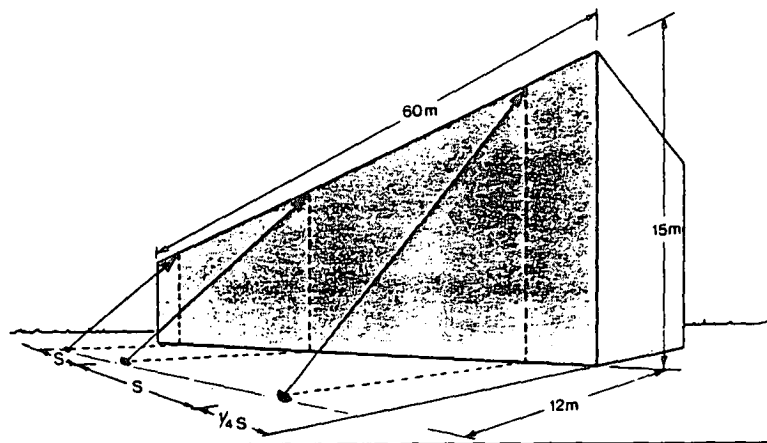
$$I_{43^\circ} = \frac{60 \times 75^2}{0,731^3} = 864\,000 \text{ cd}$$



The floodlight chosen should therefore have a luminous intensity in its beam centre of around 864 000cd. If this is not possible a number of units will have to be combined to give the desired result.

Repeating the calculation for different values of elevation (angle  $\alpha$ ) within the beam will provide an indication of the illuminance distribution in the vertical direction.

- (ii) The facade of an office building has to be illuminated relatively uniformly. The height of the facade is 15m and the length 60m. The floodlights can be placed at a distance of 12m from the facade. Given that the utilisation and maintenance factors are 0,3 and 0,75 respectively. What type of floodlight is required to produce an average illuminance on the facade of 120 lux?



$$\phi_{\text{total}} = \frac{(15 \times 60) \times 120}{0,3 \times 0,75} = 480\,000 \text{ lm}$$

The luminous intensity method can now be used to choose a light distribution that gives the desired illuminance uniformity in the vertical direction (different  $\alpha$  values). The same equation is also used to determine the floodlight spacing  $S$  needed to give the desired uniformity in the horizontal direction (different  $\beta$  values).

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## 6.0 GLOSSARY OF TERMS

AVERAGE ILLUMINANCE:	Illuminance averaged over a specified surface.
BEAM AXIS:	The direction in the centre of a solid angle which is bounded by directions having luminous intensities of 90% of the maximum intensity of a luminaire.
BEAM EFFICIENCY:	The ratio of the flux emitted within the solid angle defined by the beam spread, to the bare lamp flux.
BEAM LUMENS:	The quantity of light contained in that part of the beam at which $I = \frac{1}{2}I_{MAX}$ (Europe) or $I = 1/10I_{MAX}$ (USA).
BEAM SPREAD:	The angle (in the plane through the beam axis) over which the luminous intensity drops to a state of percentage of its peak intensity.
DESIGN ILLUMINANCE:	The calculated level, based on the output of the lamps 2000h. Because of depreciation, the actual level of illuminance will pass through this level periodically and then be restored to a level higher than the design illuminance by virtue of lamps being replaced and luminaires being cleaned periodically.
EFFICACY:	The efficacy of a lamp is the number of lumens emitted by the lamp per watt of input power, and is expressed as lumens per watt (lm/w).
FLOODLIGHT:	Projector designed for floodlighting, usually capable of being pointed in any direction and of weatherproof construction.
GLARE:	This is the condition where there is excessive brightness contrast in the subjects field of view. The degree of glare is subjective and can be assessed or calculated, but not measured. Glare sensation is not directly related to light output of the glare source, nor to its intrinsic brightness.
ILLUMINANCE (E):	At a point on a surface, it is the quotient of the luminous flux incident on an element of the surface containing the point and the area of the element (Unit: lux, lx).

**ISOLUX CURVE (diagram):**

Is a plot of a succession of point by point calculations, usually prepared as a standard document for future use.

**LUMINAIRE:**

Apparatus that distributes, filters or transforms the light given by a lamp or lamps and which includes all the items necessary for fixing and protecting these lamps and for connecting them to a supply circuit.

7. **APPENDICES**

APPENDIX A	Fundamentals of Light & Vision
APPENDIX B	Photometric Concepts
APPENDIX C	Basic Photometric Equations
APPENDIX D	Light Distribution
APPENDIX E	Systems of Colours Specification
APPENDIX F	Miscellaneous Design Specifications
APPENDIX G	Progress Reports
APPENDIX H	Guide for Exterior Security Lighting SANCI

APPENDIX A

## APPENDIX A

### LIGHT AND VISION

#### 1. THE NATURE OF LIGHT

##### 1.1 Some Physical Properties

Light is a form of electromagnetic energy which, when impinging on the eye, produces the sensation of sight.

This electromagnetic energy may be thought of as a wave of electric and magnetic fields, and is identical in form to radio-waves, microwaves, X-rays, etc. The particular form is characterised by its frequency  $f$  (Hz or cycles per second). An alternative way is to specify its free-space wavelength  $\lambda$ . It can easily be shown that if  $c$  = free space velocity of propagation of a wave,

$$\text{then } c = \lambda f \text{ and } \lambda = c/f$$

The wavelength  $\lambda$  is usually given in nm (nanometres).

For electromagnetic waves, the free-space velocity of propagation is very nearly  $3 \times 10^8$  m/sec and the velocity in air is only slightly less.

It can be readily seen from Fig. 1 that visible light constitutes a very small part of the electromagnetic spectrum. However, each wavelength within this band is perceived by the eye as a different colour.

Some sources of visible light radiate energy continuously at all wavelengths in this band, e.g. the sun, and incandescent lamps. If roughly equal amounts are emitted in all portions of the band, the light is perceived as white.

Other sources of light radiate energy only at discrete wavelengths, e.g. mercury and sodium-vapour lamps.

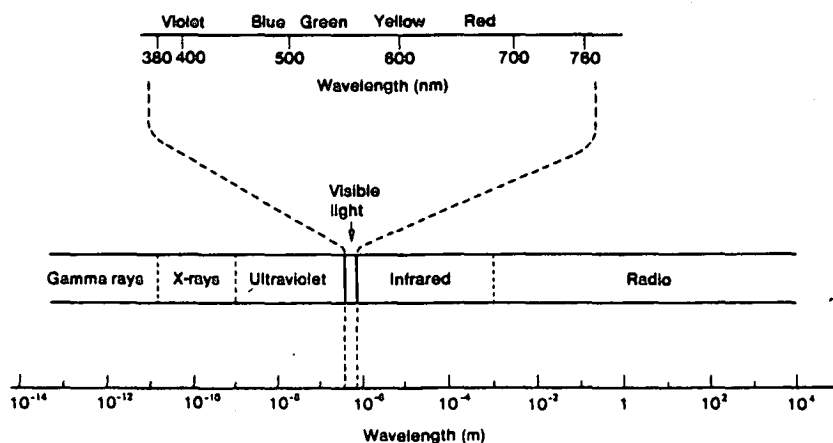


Fig. 1: THE ELECTROMAGNETIC SPECTRUM

## 1.2 Light and Radiation

It is intuitively obvious that the electromagnetic radiation producing the sensation of sight is a form of energy, and as such can be measured in work units, e.g. watts, etc.

This is quite true, but the measurement of light in watts is unsatisfactory, and for a simple reason - it is the subjective sensation of sight that we wish to measure, and the eye is not equally sensitive to all wavelengths.

It can be proposed therefore, that each watt of electromagnetic radiation be multiplied by an effective "seeing factor" or "luminosity factor" to obtain its useful effect as light.

However, this unit, the light-watt is large and in preference another unit (the lumen) is used which is effectively 1/680 of a light-watt, although defined in another way.

## 1.3 Vision

### Introduction

Vision is not instantaneous - it is the end product of a number of stages of coding and analysis which together give meaning to the changing pattern of ambient luminance and chromaticity. The lighting engineer must use his knowledge of these processes to control the luminous environment more effectively.

The eyes are complex sense organs that have evolved from primitive light sensitive spots on the surface of invertebrates. Within its protective casing the eye has a layer of receptors, a lens system for focusing light on these receptors, and a system of nerves for conducting impulses from the receptors to the brain.

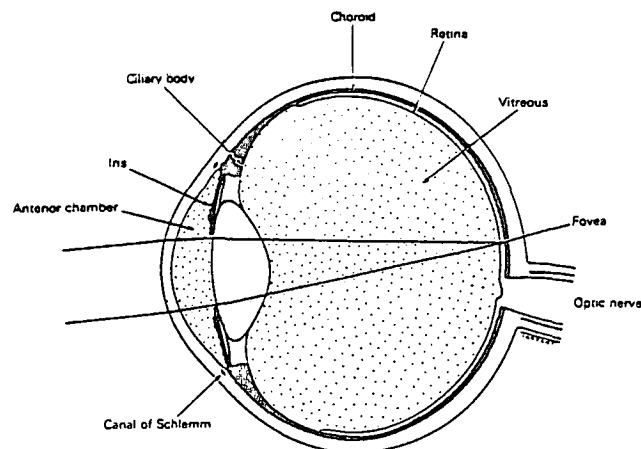


Fig 2: Section diagram of the human eye

## 1.4 The eye as a Optical System

The principal structures of the eye are shown in fig 2. The outer protective layer of the eyeball, the sclera, is modified anteriorly to form the cornea through which the light rays enter the eye. Lining the posterior two thirds of the choroid is the retina, the neural tissue containing the receptor cells.

The crystalline lens is a transparent structure held in place by a circular lens ligament (zonule). In front of the lens is the pigmented and opaque iris, the coloured portion of the eye. The iris contains circular muscle fibres that constrict and radial fibres that dilate the pupil.

The Retina extends anteriorly almost to the ciliary body. It is organised in 10 layers and contains the rods and cones which are the visual receptors. Since the receptor layer of the retina is apposed to the choroid light rays must pass through the ganglion cell and bipolar cell layers to reach the rods and cones. The pigmented layer of choroid next to the retina absorbs light rays preventing the reflection of rays back through the retina. Such reflection would produce blurring of visual images.

The fovea is highly developed in humans and is the point where visual acuity is greatest. When attention is attracted or fixed on an object the eyes are normally moved so that light rays coming from the object fall on the fovea.

The Rods are extremely sensitive to light and are the receptors for night vision (Scotopic vision). The scotopic visual apparatus is not capable of resolving the details of boundaries and objects or determining their colour. The cones have a much higher threshold, but the cone system has a much greater acuity and is the system responsible for vision in bright light (photopic vision) and for colour vision.

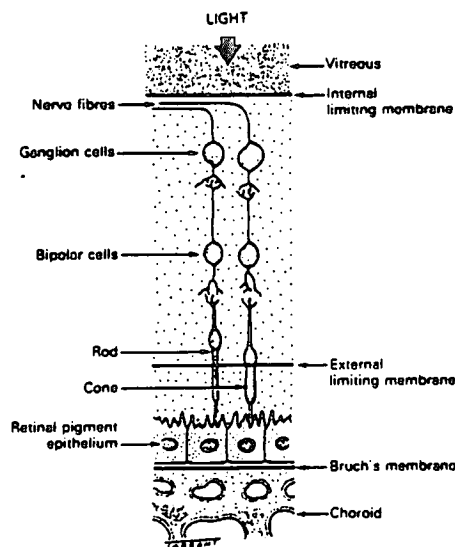


Fig 2: THE RETINA

## 1.5 Principles of Optics

Light rays are refracted when they pass through one medium into another of different density, except when they strike perpendicular to the interface. Parallel light rays striking a biconvex lens are refracted to a point (principal focus) behind the lens. The principal focus is on a line passing through the centres of curvature of the lens, the principal axis.

For practical purposes light rays from an object that strike a lens more than 6m away are considered to be parallel. The rays from an object closer than 6m are diverging and are therefore brought to a focus farther back on the principal axis than the principal focus. Biconcave lenses cause light rays to diverge.

The greater the curvature of a lens, the greater its refractive power. The refractive power of a lens is conveniently measured in diopters, the number of diopters being the reciprocal of the principal focal distance in meters. For example, a lens with a principal focal distance of 0.25m has a refractive power of  $1/0.25$ , or 4 diopters. The human eye has a refractive power of approximately 66.7 diopters at rest.

## 1.6 Accommodation

When the ciliary muscle is relaxed, parallel light rays striking theoptically normal (emmetropic) eye are brought to a focus on the retina. As long as this relaxation is maintained, rays from objects closer than 6m from the observer are brought to a focus behind the retina, and consequently the objects appear blurred. The problem of bringing diverging rays from close objects to a focus on the retina can be solved by increasing the distance between the lens and the retina or by increasing the curvature or refractive power of the lens.

The process by which the curvature of the lens is increased is called accommodation. At rest, the lens is held under tension by the lens ligaments. Because the lens substance is malleable and the lens capsule has considerable elasticity, the lens is pulled into a flattened shape. When the gaze is directed at a near object, the ciliary muscle contracts. This decreases the distance between the edges of the ciliary body and relaxes the lens ligaments, so that the lens springs into a more convex shape. In young individuals, the change in shape may add as many as 12 diopters to the refractive power of the eye. The relaxation of the lens ligaments produced by contraction of the ciliary muscle is due partly to the sphincter like action of the circular muscle fibres in the ciliary body and partly to the contraction of longitudinal muscle fibres that attach anteriorly, near the corneoscleral junction. When these fibres contract, they pull the whole ciliary body forward and inward. This motion brings the edges of the ciliary body closer together.

The change in lens curvature during accommodation affects principally the anterior surface of the lens. This can be demonstrated by a simple experiment first described many years ago. If an observer holds an object in front of the

eyes of an individual who is looking into the distance, 3 reflections of the object are visible in the subject's eye. A clear, small upright image is reflected from the cornea; a larger, fainter upright image is reflected from the anterior surface of the lens; and a small inverted image is reflected from the posterior surface of the lens. If the subject then focuses on an object nearby, the large, faint upright image becomes smaller and moves toward the other upright image, whereas the other 2 images change very little. The change in size of the image is due to the increase in curvature of the reflecting surface, the anterior surface of the lens. The fact that the small upright image does not change and the inverted image changes very little shows that the corneal curvature is unchanged and that the curvature of the posterior lens surface is changed very little by accommodation.

### 1.7 Near Point

Accommodation is an active process, requiring muscular effort, and can therefore be tiring. Indeed, the ciliary muscle is one of the most used muscles in the body. The degree to which the lens curvature can be increased is, of course, limited, and light rays from an object very near the individual cannot be brought to a focus on the retina even with the greatest of effort. The nearest point to the eye at which an object can be brought into clear focus by accommodation is called the near point of vision. The near point recedes throughout life, slowly at first and then rapidly with advancing age.

### 1.8 Spectral Sensitivity of the Eye

The sensitivity of the human eye is not uniform over the visible spectrum, but varies with light wavelength. Photopic vision relates to bright viewing conditions and scotopic vision refers to viewing for the dark adapted eye.

Lighting technology is almost entirely concerned with relatively high brightness and therefore photopic vision demands greater attention.

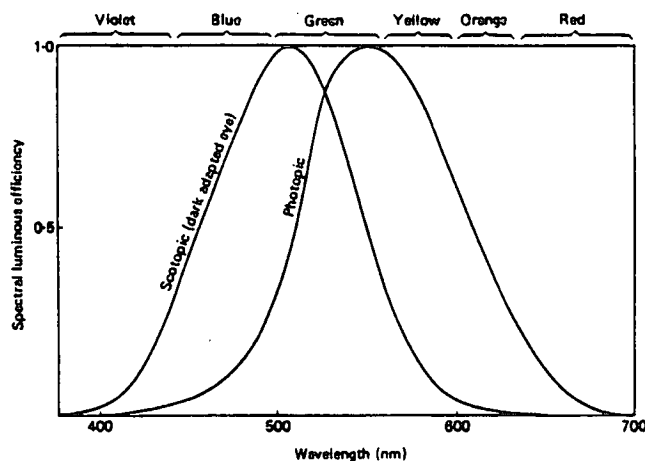


Fig. 3: Relative spectral sensitivity of the human eye; the spectral luminous efficiency for the CIE standard

## 1.9 Photopic Vision

Where luminance is generally above about  $10^{-2}\text{cd m}^{-2}$  vision is entirely mediated by the cone receptors and the visual response is maximum in the yellow-green region of the spectrum at a wavelength of 555nm. This response indicated by the right hand curve in the fig. 3 was agreed internationally in 1924 after experimental work requiring subjects to match the brightness of monochromatic stimuli of different wavelengths. With a maximum ordinate of 1.0 this curve is known as  $V(\lambda)$ , the spectral luminous efficiency of photopic vision. It is of fundamental importance in photometric units, colour and the measurement of light. The normal eye is fully responsive to colour in photopic vision and an indication is given at the top of fig. 3 of the various colours likely to be ascribed to light of different wavelengths. The eye is unable to analyse the wavelength components in mixed radiation in the way the ear can detect the different frequency components in a musical sound.

## 1.10 Scotopic Vision

This comes into operation when the luminance of the surroundings is below  $10^{-2}\text{cdm}^{-2}$  and the eye has had time to become dark adapted. (This takes about 30 mins). The spectral luminous efficiency curve under these conditions is denoted by  $V'(\lambda)$ , the left curve in fig. 3 with a peak of 507nm which represents a shift towards the blue end of the spectrum.

A peculiar characteristic of scotopic vision is that an object is seen more readily out of the corner of the eye than when it is made the centre of visual observation. This is because at very low luminance levels vision is mediated primarily at the rod receptors which are absent in the foveal region of the retina. Unlike the cone receptors, the rods are insensitive to colour differences, consequently the scotopic view of things is monochromatic.

## 1.11 Mesopic Vision

As the brightness of a scene is increased with luminances from about  $10^{-2}\text{cdm}^{-2}$  upwards, three effects can be observed in addition to a general increase in luminosity. Firstly foveal detection becomes as easy a peripheral detection and then easier. Secondly a sense of colour can be appreciated, feebly at first and then stronger. Thirdly the relative luminosity of objects of different colour changes, in particular the luminosity of reds increases more strongly than that of blues. The last effect is known as the Purkinje phenomenon and like the other two effects is due to the changing contributions of the rod and cone receptors to vision as the luminance changes in the mesopic range.

## 1.12 Visual Performance

The ability of the eye to see small contrasts of brightness or small objects is termed its visual acuity or sharpness of vision. Acuity can be measured in units of the reciprocal of the angle subtended at the eye by the smallest detail

the subject can pick out. This is the principle of the familiar sight-testing chart (Snellen chart) used by opticians, in which lines of letters of diminishing size are presented, and the subject must try to read down the chart. The limit of acuity is revealed when the subject cannot distinguish similar letters, e.g. a 'C' from an 'O', where the gap in the 'C' is just beyond his acuity.

The Snellen chart works because the conditions of the visual test are standardised. The usual test illuminance is 300 lux, but if by mistake the illuminance provided is less, the subject under test would apparently have less acuity; if the illuminance was higher than that for which the card was designed, the subject would appear to have greater acuity. It will be seen that the effect is due to the reduction in contrast between the letters and their (nominally white) background as the illuminance is reduced, i.e. the contrast ratio has been reduced. The effect holds good for anything we look at, so we can state the general case that there will be an improvement in our visual acuity as we increase the illuminance up to certain practical limitations. Note also that our sensitivity to contrast ratio reduces in the presence of glare. Most of the standards and recommendations for the illumination of tasks have been developed from consideration of test results relating to the acuity needed for the efficient performance of specific visual test tasks. Obviously, tasks having low contrast ratio content, or tasks having a great deal of fine detail, will require higher illuminance than simpler tasks. We see that the provision of suitable illuminance actually contributes positively to the efficient performance of work as well as safety.

The Snellen chart effect is reversible, e.g. by varying the contrast between the reflectance of the background and the letters, as well as considering the size of the letters, we can use a special chart of this kind as a crude sort of light meter. The results are good enough to detect severe under lighting.

With continued activity, we tire. This applies also to vision, and visual fatigue has a more rapid onset if the illuminance provided is insufficient, or if there is a significant degree of glare. A task which must be performed for only a short time may be performed with reasonable efficiency in poor light, but as the duration extends, the visual performance will decline, and the onset of fatigue will be more rapid.

### 1.13 Vision And Perception

We can distinguish between the process of vision (in which objects are seen and visual information about them passed to the brain), and perception (a cerebral process in which visual information is processed and compared with remembered material). Optical illusions confuse us because we see something which we find difficult to perceive. Perception is very much a learning process; a primitive man could see a page of this project but would not perceive the information it contains; A Town-Dweller would see the ripples in a pool but would not perceive the motion of a fish which caused them. If an image is blurred or indistinct, perception takes longer. Similarly, if the illuminance and contrast ratios in a visual scene are insufficient, perception

takes longer. In many industrial situations this can lead to dangers not being perceived quick enough for corrective or evasive action to be taken; in security lighting installations such delayed perception may be perilous for the guard and result in lowered security.

The lengthening of perception - time as is described in the first paragraph is also observed in an unusual way if the image presented to the subject is at first blurred and then becomes clear. For example, if when observing a scene on a closed-circuit television (CCTV) monitor, the subject is presented with a slightly out-of-focus picture which he then has to correct, perception-time is considerably longer than the time taken to perceive the same scene if presented in sharp focus initially. This is one reason why fixed-focus lens CCTV cameras having wide-angle lenses of great dept-of-focus are preferred for security surveillance, rather than camera's having adjustable zoom lenses - even if the image presented is smaller, perception is better, and faster.

#### 1.14 Colour Vision

##### Characteristics of Colour

Colours have 3 attributes: hue, intensity, and saturation (degree of freedom from dilution with white). For any colour there is a complementary colour that, when properly mixed with it, produces a sensation of white. Black is the sensation produced by the absence of light, but it is probably a positive sensation, because the blind eye does not "see black", it "sees nothing." Such phenomena as successive and simultaneous contrasts, optical tricks that produce a sensation of colour in the absence of colour, negative and positive after-images, and various psychologic aspects of colour vision are also pertinent. Detailed discussion of these phenomena can be found in textbooks of physiologic optics.

Another observation of basic importance is the demonstration that the sensation of white, any spectral colour, and even the extraspectral colour, purple, can be produced by mixing various proportions of red light (wavelength 723-647nm), green light (575-492nm), and blue light (492)-450nm). Red, green, and blue are therefore called the primary colours.

A third important point is that, as shown by Land, the colour perceived depends in part on the colour of other objects in the visual field. Thus, for example, a red object is seen as red if the field is illuminated with green or blue light but as pale pick or white if the field is illuminated with red light.

#### 1.15 Retinal Mechanisms

The Young-Helmholtz theory of colour vision in humans postulates the existence of 3 kinds of cones, each containing a different photopigment and maximally sensitive to one of the 3 primary colour, with the sensation of any given colour being determined by the relative frequency of the impulses from each of these cone systems.

The cones are clustered densely around the fovea, but are less closely spaced

towards the edges of the retina. Therefore, seeing colour is associated with deliberate (foveal) vision, while the edges of the retina, which are most sensitive to movement, are relatively insensitive to colour. This may be demonstrated in a simple experiment. Extend one arm sideways, while looking straight forward, and it will be found that while the hand is held steady it cannot be seen, but, if the fingers be moved, they can be seen. Next, repeat the experiment holding in one's hand a card having two different colours on its faces, say blue on one side and red on the other, and it will be found that while looking straight ahead one can see the card turn over in one's hand, but cannot determine whether the red or the blue side is presented to the eyes.

Objects which appear to us to have a particular colour, have the property of absorbing certain wavelengths of light and reflecting others. An object perceived as red, reflects light from the long-wavelength (red) part of the visible spectrum, while absorbing substantially all other wavelength. It therefore follows that an object can only be seen as being a particular colour if the wavelengths it is capable of reflecting are present in the light falling on it. Therefore, a red object seen in light which contains a substantial amount of spectral energy in all parts of the visible spectrum, i.e. "white light" (e.g. sunlight, or the light from lamps of good colour-rendering) will be seen as a red object. But that same red object, seen in the light of a source which does not contain a substantial amount of spectral energy in all parts of the visible spectrum, i.e. coloured light (e.g. light from low-pressure sodium-vapour lamps, this being nearly monochromatic) will not appear to be any particular colour, or will be perceived as a shade of yellow/black.

When a subject experiences vision under any colour of illuminant, a process of colour adaptation takes place, the degree of adaptation vary with the time exposure to it. Some amount of adaptation can take upwards of an hour, though most of the adaptation takes place within 10 minutes. This can be demonstrated by a subject donning a pair of spectacles with coloured lenses. For example, if one wears pink glasses, on first putting them on everything seems tinged with pink. But, after about 10 minutes, the sensation of pinkness appears to fade away, and colours seem once more to be normal. However, if after the adaptation is well advanced, one removes the glasses, one has the illusion that everything is tinged with green, i.e. we are seeing the complementary colour to red/pink. But, again, the process of adaptation takes place, and after a while the sensation of greenness wears off. The same experience may occur when entering an area lighted by a non-white illuminant, e.g. by high-pressure sodium vapour lamps. On entry to the area, the scene seems to have a yellow/golden appearance; but, after a period of adaptation, the scene comes to appear to be perfectly normal, and the sensation of yellowness/goldenness fades away. Therefore, provided the light from the illuminant gives sufficient spectral energy in the various parts of the spectrum needed for the recognition of colour, some departure from a white light-source is not a disadvantage.

## 1.16 Glare

Glare is the condition where there is excessive brightness contrast in the subjects field of view. The degree of glare is subjective, and can be assessed, or calculated (by reference to previous subjective assessments of glare experience) but not measured. Glare sensation is not directly related to the light output (lumens) of the glare source, nor to its intrinsic brightness.

Glare may produce either disability or discomfort. Disability glare is the effect we suffer when, for example, we are suddenly confronted with undimmed headlights of an oncoming vehicle on an unlighted road. Note that 12 hours later, in bright sunshine, a repetition of that situation would produce no disability glare, because the headlights would be seen against a background of far higher luminance. We say that the luminance of the headlights has not changed, but that their luminosity as perceived by the subject has changed, and very considerably. Glare which produces discomfort without actually disabling vision is tiring, and leads to fatigue. The degree of annoyance is a direct function of the luminance of the glare source to the general luminance of the interior, the size of the glare source and its position in relation to the eye of the observer.

When subjected to glare, the eye is unable to adjust itself to the luminance conditions. The iris is contracted, and the retina is attempting to adapt to the brightness presented to it - so time is an important factor in glare sensation.

Above it was noted that glare sensation is time linked, i.e. it depends upon the subject's state of adaptation. If the subject has spent a period in very low illuminance and is suddenly presented with a modest source of light, for example, a candle-flame, this can appear to be intensely bright, even painfully so. Yet a candle flame in sunshine appears to be barely luminous. From these observations we may deduce that we can reduce glare to an acceptable level:

- \* ensure that the contrast of brightness between any two parts of the visual field are not in an excessively high ratio, and,
- \* not requiring the subject to observe anything of substantially different luminance to that which he is adapted, without allowing adequate time for further adaptation.

In some situations we may interpose a zone of intermediate luminance to aid the transition (transition illumination).

It will suffice to note that the main factors which can contribute to the assessment of glare in relative or absolute terms are:

- \* the intrinsic brightness of the glare source (candelas per square metre).
- \* the projected area of the glare source presented to the eye, and, taking account of the distance, the angles subtended by this area to the eye,

- \* a positional factor to take account of the fact that a glare source will be more troublesome to vision if it lies close to the direction of view,
- \* the contrast ratio between the glare source and its background,
- \* the time needed by the subject to adapt to a different field luminance.

In the case of interior lighting installations, computation enables a non-quantitative number (i.e. a figure of merit) to be compiled to express the degree of glare, but this does not take into account the effect of time and the adaptation of the subject.

When a subject is experiencing glare, he is less able to distinguish small differences of brightness, i.e. his contrast sensitivity is reduced. Therefore, reduction of glare may improve the subjects visual performance, just as would an improvement of illuminance. It therefore becomes an objective in the design of exterior lighting to limit glare to a tolerable level, this enabling the desired visual effects to be achieved without wastefully high illuminances. This can reduce capital cost, running cost and energy consumption. However, the economic return for the extra cost of glare limitation cannot be of great magnitude, and therefore glare limitation should simply be treated as one factor to be considered in performing a lighting design.

Reverting to the topic of how the brightness of something appears to vary according to our state of adaptation, the true brightness (luminance) can be measured in candelas per square metre or apostilbs, but the apparent brightness (luminosity) cannot be measured. Similarly, glare itself has not yet been successfully measured by any practical instrument.

APPENDIX B

## APPENDIX B

A. PHOTOMETRIC CONCEPTS: See Glossary of Terms

### B PHOTOMETRIC UNITS AND THEIR DEFINITIONS

The formal definitions of the Candela and the Lumen are inter-related and are somewhat complicated in their currently-accepted form. In essence, however, they can be expressed in the following way:

1. The **lumen** is now effectively defined as 1/680 of a watt of radiant energy at 555nm, and  $(680 V)^{-1}$  at other wavelengths within the visible range.
2. The definition of the **candela** is then a geometric one making use of the fact that Intensity is the concentration of Flux per unit Solid angle, or  $I = \phi \omega$  (or, to be more precise mathematically,  $I = d\phi/d\omega$ ).

Thus, if a light source has an intensity of  $I$  cd in a given direction, then unit solid angle in that direction will contain 1 lm of luminous flux.

Note that the candela has formerly been defined in terms of the light output of (a) a standard wax candle and, later (b) a molten platinum standard; but these definitions have been phased out.

3. The **Lux** is an illuminance of 1 lm/m<sup>2</sup>.
4. The **Nit** is the luminance of a surface of a 1 cd/m<sup>2</sup> of projected area.
5. The **Lumen-Second** represents the luminous energy radiated by a source whose output is 1 lm, during a time interval of 1 sec.

### SUMMARY OF UNITS AND EQUIVALENTS

N.B. Although officially replaced now by the SI quantities, the units based on earlier measurement systems are still to be found in the literature, and they are listed here for reference.

QTY	BASIC SI	EQUIVALENT ACCEPTED	EQUIVALENT "OLD" UNITS
I	1 cd	-	= 1 Candle
$\phi$	1 lm	-	-
E	1 lx	(= 1 lm./m <sup>2</sup> )	= (10,76) <sup>-1</sup> lm./ft <sup>2</sup> = (10,76) <sup>-1</sup> ft-Candle (ft-C)
L	1 nt	. . . (= 1 cd./m <sup>2</sup> ) = $\pi$ apostilb (asb)	= (10,76) <sup>-1</sup> cd/ft <sup>2</sup> = ( $\pi/10,76$ ) ft-Lambert (ft-L) = 0,292 ft-L = (1550) <sup>-1</sup> cd/in <sup>2</sup> = 10 <sup>-4</sup> stilb (sb) = 10 <sup>-4</sup> cd/cm <sup>2</sup> = $\pi \times 10^4$ Lambert (L)

### C. RELATIONSHIP BETWEEN PHOTOMETRIC QUANTITIES

A uniform point source of 1 cd (luminous intensity = 1 cd in any direction) is shown at the centre of a spherical surface in space, of radius 1 metre (see Fig.1). This surface is assumed to possess zero reflectance.

The illuminance (due to the point source) at any point on the surface of the sphere will be 1 lux (= 1 lumen per square metre).

The solid angle subtended by the area ABCD is 1 steradian.

The flux density is therefore 1 lumen per steradian, which corresponds to a luminous intensity of 1 candela as originally assumed.

The sphere has a total surface area of  $4\pi$  (=12,57) square metres, and there is a luminous flux of 1 lumen on each square metre; hence, the source produces a total light output of  $4\pi$  lumens.

#### D. POLAR DIAGRAMS

A polar diagram is a definition of the directional properties of a light source.

The polar diagram of a light source or fitting may be defined as the locus - in some specified plane - of the extremities of the intensity vectors emanating from that source. (One occasionally encounters Luminance polar curves, as in Figs. 5, 6, 8 and 9 of this note.)

In any one diagram, or family diagrams, the lengths of the intensity vectors are drawn to a uniform scale.

See for example, Fig. 2. Also see Figs. 10 to 17 for specific examples of intensity polar curves.

Because sources will, in general, radiate in all directions, it is (strictly speaking) necessary to represent the directional properties of a source by means of a 3-dimensional "polar body".

However, because of the difficulties involved in drawing or constructing such a body, it is usually acceptable to represent it by means of 3 polar diagrams drawn in 3 mutually-perpendicular planes.

If a source possesses rotational symmetry (of its output), a single polar curve will provide all the required information.

#### E. REFLECTION, TRANSMISSION AND ABSORPTION

Assume that a certain flux  $F$  is incident upon a given surface (see cross-sectional illustration, Fig. 3). In general, three effects occur, splitting the original flux into 3 new components:

- |                  |   |                             |
|------------------|---|-----------------------------|
| (i) Transmission | - | transmitted Flux: $r\phi$   |
| (ii) Reflection  | - | reflected Flux: $\rho\phi$  |
| (iii) Absorption | - | absorbed Flux: $\alpha\phi$ |

The absorbed flux represents absorbed energy, and so it goes into heating the material.

It is clear from the above that  $\phi = \rho\phi + \alpha\phi + r\phi$ , i.e.  $\rho + \alpha + r = 1$  for any given surface.

N.B. Alternative notation:  $\rho$  sometimes written  $r$   
 $\alpha$  sometimes written  $a$ , and  
 $r$  sometimes written  $t$

(These will be interchangeable from time to time)

**Terminology:**      r,ρ - **reflectance**, reflection factor  
                         t,   - **transmittance**, transmission factor  
                         a,α - **absorption**, absorption factor

Each may be expressed as a percentage, or as a fraction (less than 1).

An opaque material is one for which there is no transmitted light (i.e.  $t = 0$ ) and hence

$$r + a = 1 \text{ for this case.}$$

Reflection and transmission of flux give rise to the effect of light appearing to emanate from the material in question - so that it becomes a "virtual source" of illumination.

## TYPES OF REFLECTION

One can basically categorize reflection into three varieties:

- (a)    **Specular:**      e.g. highly polished metal surfaces, etc. The light is reflected in accordance with the laws of geometric optics (see Fig. 4).
- (b)    **Diffuse:**        e.g. matt surfaces such as painted walls, coarse white paper, etc. In reality, most surfaces are mixed reflectors, but these examples are generally quite close to being perfect diffusers. The chief property of a diffusing surface is that it appears equally bright when viewed from different directions (i.e. its luminance does not depend on the direction from which the surface is observed). The direction of the incident light is also immaterial (see Fig. 5).
- (c)    **Mixed:**            e.g. gloss paints, plastic surfaces, etc. Light is reflected in all directions - but preferentially in the direction of specular reflection (see Fig. 6).

## TYPES OF TRANSMISSION

- (a)    **Regular:**        The incident flux passes through the medium without scattering (see Fig. 7). The transmitted light rays emerge essentially unchanged in character and the medium is said to be transparent (e.g. glass window panes, etc). There may, however, be a colour change.
- (b)    **Diffuse:**        The incident flux passing through the medium is scattered and the medium is said to be translucent (e.g. frosted glass, opal glass, etc.). As before, the diffusion may either be perfect (Fig. 8) or mixed (Fig. 9).

## DESIRABLE SURFACE PROPERTIES

From the point of view of good lighting conditions, it is important to specify surface finishes with reasonably high reflectances.

## PHOTOMETRIC PROPERTIES OF MATERIALS

Some typical reflection, absorption and transmission factors for various materials under white light:

MATERIAL	REFLECTANCE	ABSORPTANCE	TRANSMITTANCE
Fresh Plaster (dry)	0,8	0,2	-
Old plaster (dry)	0,6-0,7	0,4-0,3	-
Polished aluminium	0,7	0,3	-
Dull aluminium	0,6	0,4	-
Polished chromium	0,6	0,4	-
Fresh concrete	0,4-0,5	0,6-0,5	-
Window glass, 3mm thick	0,08	0,02	0,9
Frosted glass, 3mm thick	0,12	0,08	0,8
Figured glass, 3mm thick	0,1	0,05	0,85
Painted surfaces:			
White	0,7-0,8	0,3-0,2	-
Yellow	0,3-0,7	0,7-0,3	-
Beige	0,25-0,65	0,75-0,35	-
Brown	0,1-0,5	0,9-0,5	-
Red	0,1-0,35	0,9-0,65	-
Green	0,1-0,6	0,9-0,4	-
Blue	0,05-0,5	0,95-0,5	-
Grey	0,2-0,6	0,8-0,4	-
black	0,04-0,08	0,96-0,92	-

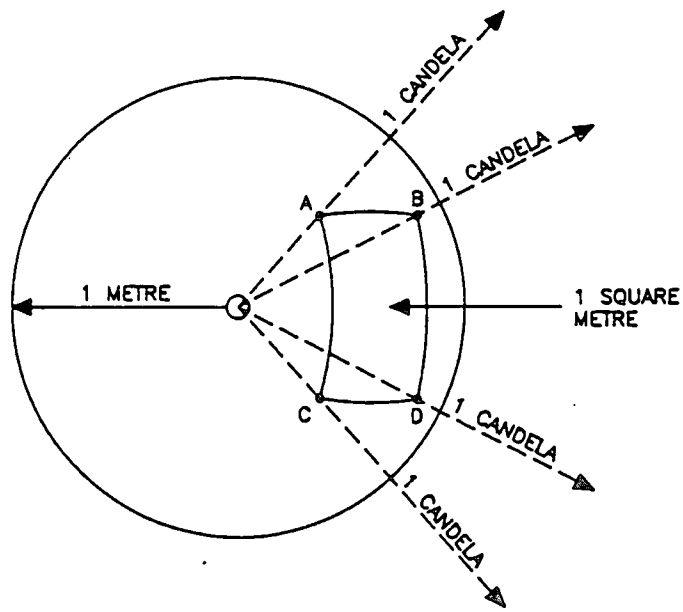


FIGURE 1

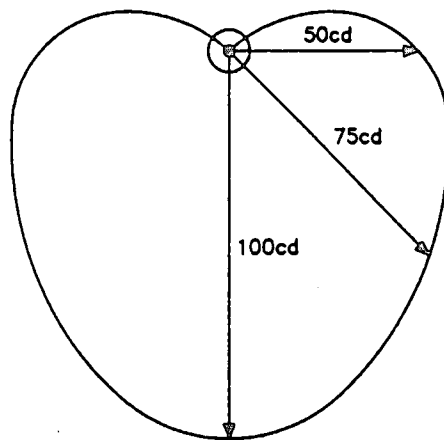


FIGURE 2

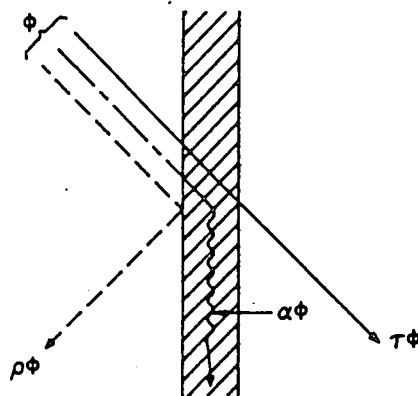


FIGURE 3

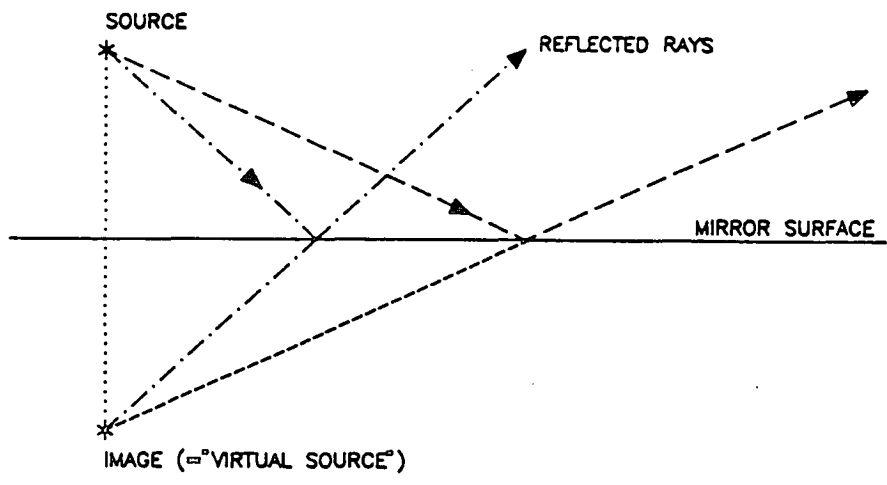


FIGURE 4

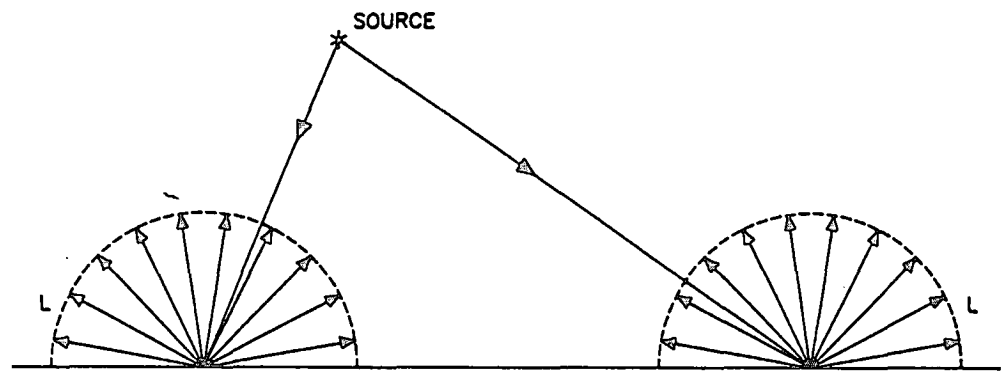


FIGURE 5

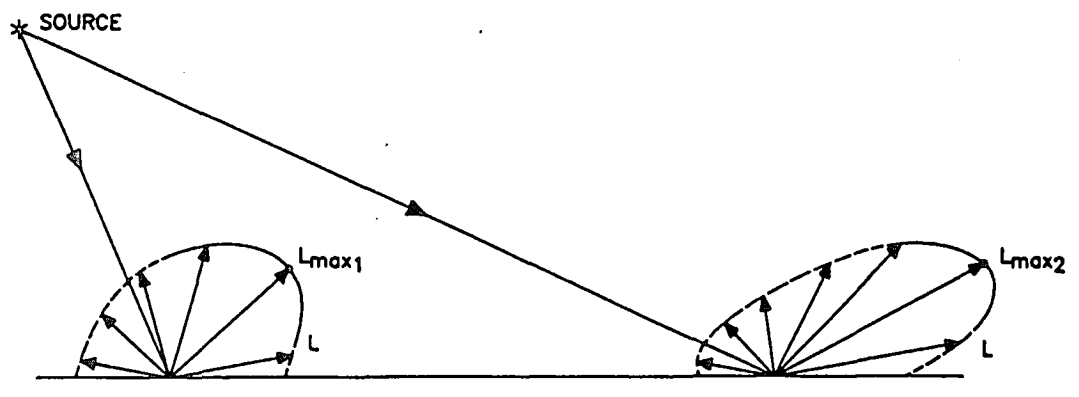


FIGURE 6

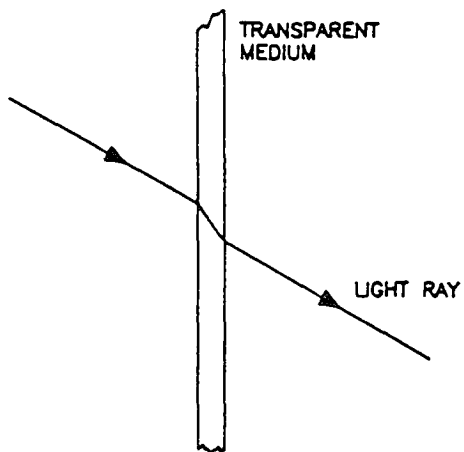


FIGURE 7

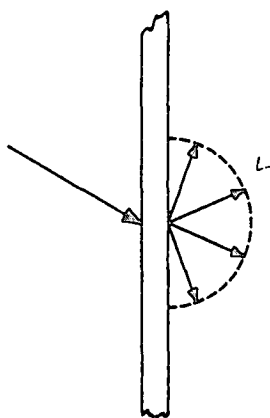


FIGURE 8

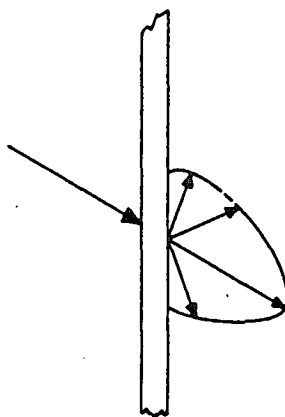


FIGURE 9

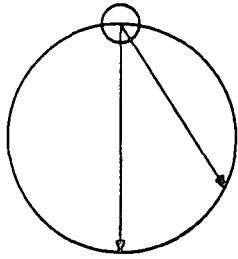


FIGURE 10 Origin is at the top for a downwards facing surface.

A PLANE DIFFUSING SURFACE HAS A CIRCULAR POLAR CURVE.

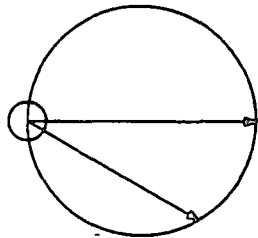


FIGURE 11 Origin is at the left for a vertical surface facing right.

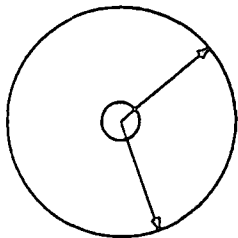


FIGURE 12 A DIFFUSING SPHERE OF UNIFORM LUMINANCE HAS A CIRCULAR POLAR CURVE WITH THE ORIGIN AT THE CENTRE.

This also applies to a point source.

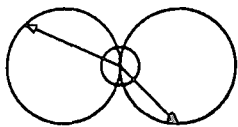


FIGURE 13

A DIFFUSING CYLINDER OF UNIFORM LUMINANCE HAS A TOROIDAL POLAR BODY WHICH YIELDS CIRCULAR POLAR CURVES WITH DIFFERENT ORIGIN POSITIONS DEPENDENT ON THE SECTION.

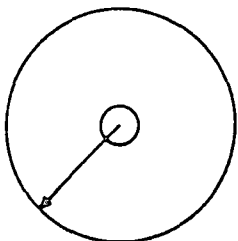
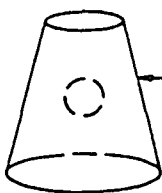


FIGURE 14



Opaque Sides

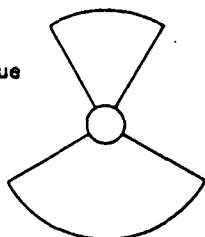
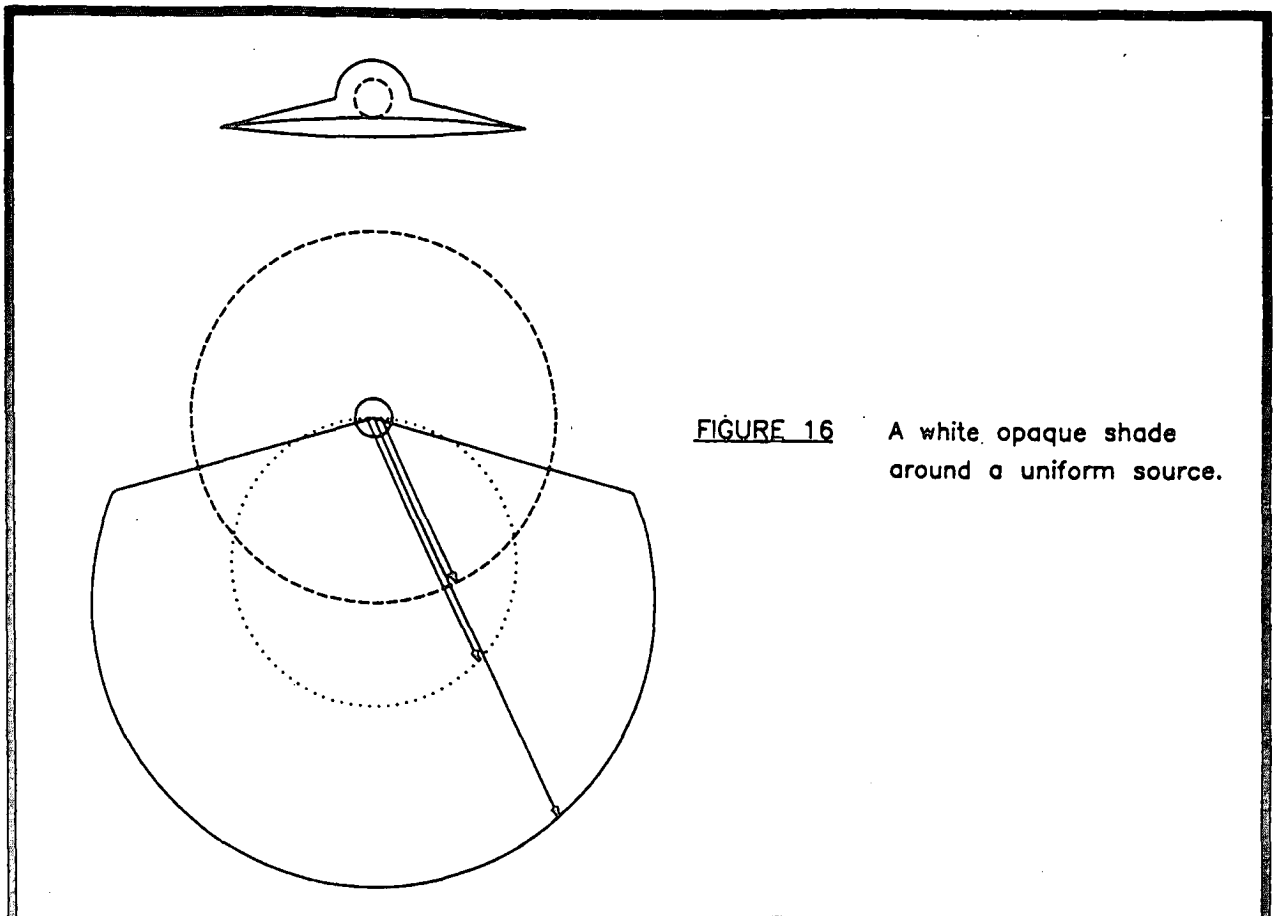
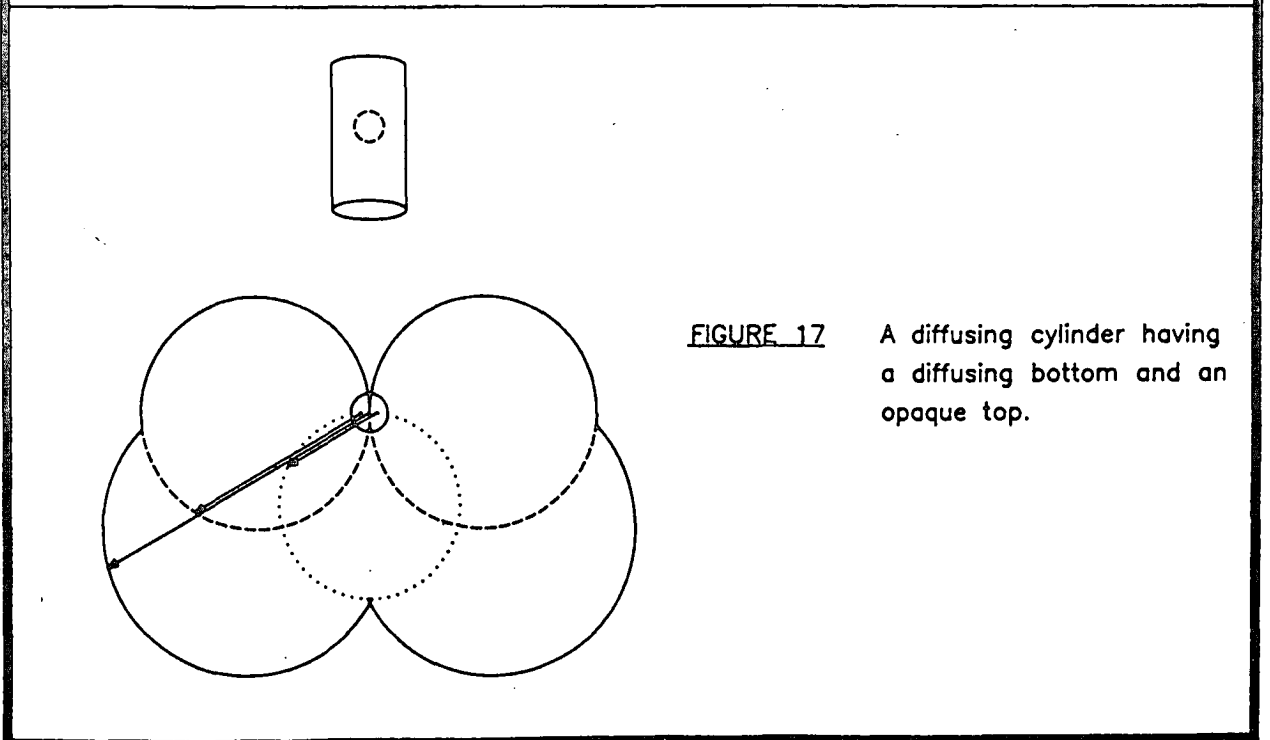


FIGURE 15 Cut-off angles are clearly reflected in the Polar Curves.



POLAR CURVES CAN EASILY BE SUPERIMPOSED IF IT IS CLEARLY UNDERSTOOD THAT INTENSITY VECTORS ARE ADDED.



SYNTHESIS OF POLAR CURVES BY SUPERPOSITION.

## APPENDIX C

### BASIC PHOTOMETRIC EQUATIONS AND APPLIED OPTICS

#### 1. ILLUMINATION PRODUCED BY A POINT SOURCE

##### 1.1 **Illuminance** (Symbol: E; Unit: lux)

This is the incident flux per unit area falling on a plane surface. The illuminance at any particular point is given by:  $E = d\phi/dA$ , where  $d\phi$  is the luminous flux incident on the element of area  $dA$  surrounding the point in question. The unit of illuminance is the lux which is identical to the  $\text{lm}/\text{m}^2$  (lumen per square metre).

The terms "illumination" and "illumination level" have been widely used in the past, but "illuminance" is now the preferred quantitative term. "Illumination" is now used in its general sense of "the provision of light".

##### 1.2 **The Point Source Concept**

A point source is a light source having zero physical dimensions. Thus a true point source cannot exist in practice; however, it is possible for a real source to approximate a point source very closely, provided that the source is remote from the surface being illuminated by it.

A useful practical guide is that, if  $d$  is the maximum dimension of a source, then the distance  $r$  from the source to the illuminated surface must be about 5 times  $d$  ( $r = 5d$ ) for the approximation to point-source conditions to be accurate within about 1% (e.g. a 1,2m fluorescent luminaire can be regarded as a point source, within 1% error, provided that the surface it illuminates is at least 6m away).

##### 1.3 **The Intensity of a Point Source** (Symbol: I; Unit: Candela)

This is the luminous flux emitted per unit solid angle in a specified direction with respect to the light source. The luminous intensity in any particular direction is given by:  $I = d\phi/d\omega$ , where  $d\phi$  is the luminous flux contained within the element of solid angle  $d\omega$  in the specified direction. The unit of intensity is the candela (abbreviated cd) which is identical to the  $\text{lm}/\text{sr}$  (lumen per steradian).

Luminous intensity therefore represents the concentration of luminous flux per steradian, emitted in a particular direction. With most area sources, the intensity varies with the direction.

A steradian can be represented as a 3-dimensional segment of space in a shape such as a cone or a pyramid terminating at a single point (apex) and so proportioned that the area  $A$  of its base is equal to the square of its height  $r$

( $A = r^2$ ). The point source is located at the apex.

If a point source is an isotropic radiator (i.e. having uniform intensity in all directions) then its intensity in any direction will be given by  $I = \phi/4\pi$ , where  $\phi$  is its total lumen output (and  $4\pi$  is the total solid angle surrounding it).

#### 1.4 The Inverse-square Law

This is the relationship between the intensity of a point source and the illuminance it produces on some remote surface. From the definitions of illuminance and intensity, we have:

$$E = d\phi/dA$$

and  $d\phi = I.d\omega$

thus  $E = I.d\omega/dA$

but  $dA = r^2.d\omega$ , by the definition of Solid Angle

therefore  $E = I.d\omega/r^2.d\omega$

i.e.  $E = I/r^2$

where E will be in lux if I is in candelas and r is in metres.

Implicit in this result is the assumption that the rays of light are falling perpendicularly onto the illuminated surface. At other angles of incidence, the illuminance will decrease with the cosine of the angle.

#### 1.5 The Cosine Law

Suppose that luminous flux  $d\phi$  lumens is falling perpendicularly on some given surface of area  $dA$ , to yield an illuminance of  $E_1$  lux, and

$$E_1 = d\phi/dA$$

If this surface were now to be tilted relative to the rays of light, to make the angle of incidence  $\Theta$ , then the flux  $d\phi$  would be spread over a greater area than before, given by  $dA/\cos\Theta$ . The illuminance under these circumstances will be  $E_2$  lux, and

$$E_2 = d\phi.\cos\Theta / dA = E_1.\cos\Theta$$

This law exists independently of the inverse-square law, but is often combined with it to give the result:

$$E = I \cos\Theta / r^2$$

## 2. PROPERTIES OF THE IDEAL DIFFUSER

### 2.1 The Ideal Diffuser

This is a surface that has the property that its luminance is independent of direction. It is also known as a **Uniform Diffuser** since the luminance is uniform in all directions.

The diffuser may be a primary source of light or it may be a light modifier, i.e. a reflecting or transmitting surface. The general principles remain the same in all cases, but special attention will be paid in this section to the uniformly diffusing reflector.

The luminance of an ideal diffuser as viewed from a direction at angle  $\Theta$  from the normal will be:

$$L = I_{\Theta} / [S \cdot \cos\Theta]; \text{ where } S = \text{its surface area}$$

The luminance  $L$  must be constant, irrespective of angle  $\Theta$ , therefore:

$$I_{\Theta} = L \cdot S \cdot \cos \Theta = I_0 \cos \Theta; \text{ where } I_0 = L \cdot S = \text{maximum intensity}$$

### 2.2 Lambert's Law

This law provides a relationship between the luminance of an ideal diffuse reflector and the illuminance incident on it.

Consider a diffusing surface of area  $S$  square metres and luminance  $L$  cd/m<sup>2</sup>. The maximum luminous intensity will be  $I_0 = L \cdot S$  cd, and the intensity in direction  $\Theta$  will be  $I_{\Theta} = I_0 \cos \Theta$  candelas.

Consider now the flux emitted by this diffusing source into an elemental ring centre above the surface.

$$\begin{aligned} d\phi &= I_{\Theta} \cdot d\omega, \text{ where } d\omega = dA / r^2 \\ &= 2\pi r \sin\Theta \cdot r \cdot d\Theta / r^2 \\ &= 2\pi \sin \Theta \cdot d\Theta \text{ steradians} \end{aligned}$$

$d\omega$  being the solid angle subtended at the source by the ring,  $dA$  the area of the elemental ring, and  $r$  the distance from the source to the ring.

$$\text{Thus, } d\phi = L \cdot S \cdot \cos \Theta \cdot 2\pi \sin \Theta \cdot d\Theta \text{ lumens}$$

Hence, the total flux emitted from the area S is given by integration:

$$\phi = \int_0^{\pi/2} 2\pi \cdot L \cdot S \cdot \sin\theta \cdot \cos\theta \cdot d\theta$$

$$= 2\pi \cdot L \cdot S \left\{ -\cos 2\theta/4 \right\}_0^{\pi/2} = \pi \cdot L \cdot S \text{ lumens}$$

The result  $\phi = \pi \cdot L \cdot S$  is Lambert's Law.

Now, an illuminance of E lux on a perfect diffusing surface whose reflection factor is r will give a reflected flux of:

$$\phi_r = r \cdot E \cdot S \text{ lumens}$$

Equating this to the total emitted flux of Lambert's Law, one obtains the luminance as  $L = r \cdot E / \pi \text{ cd/m}^2$

### 2.3 Luminance and Luminous Exitance

The luminous exitance of a uniformly diffuse surface is the luminous flux emitted per unit area of the surface. The symbol M is used for this quantity and it is measured in units of apostilbs ( $= \text{lm} / \text{m}^2$ ).

Referring to the previous example where E lux is incident on a perfect diffuser of reflectance r, its exitance will be:

$$M = r \cdot E \text{ apostilbs}$$

Comparison with the above expression for Luminance shows that, for a perfect diffuser,  $M = \pi \cdot L$ . Thus, the relationship between the units is:

$$1 \text{ nit} = \pi \text{ apostilbs (Note: nit} = \text{cd/m}^2\text{.)}$$

## 3. EXTENDED SOURCE GEOMETRIES

### 3.1 Introduction

It is relatively rare that one encounters an isolated point source in practical lighting situations. Many lighting installations are made up of arrays of point sources, linear sources or diffuse sources of various geometries.

To illustrate that the inverse-square law is not universally applicable, therefore, two other idealised source geometries will be considered. These are the infinite line source and the infinite plane source.

### 3.2 The Uniform Linear Source and the Inverse-Distance Law

Consider an infinitely-extended line source. Note that this need not necessarily be made up of linear segments (such as tubular lamps) but that it could comprise a series of point sources at regular spacings.

Applying the usual concepts of flux lines (viz. that they leave the source at right-angles and can never cross over one another), it is apparent that the light energy spreads out in two dimensions only.

Suppose that the output of the line source is  $N$  lumens per metre of length, and that this light output is uniformly distributed around the line source. Then, at a distance  $r$  metres from the source, this number of lumens becomes spread over the curved surface of a cylinder 1 metre high and with a radius of  $r$  metres, i.e. an area of  $2\pi \cdot r$  square metres.

Therefore, the illuminance on the inner surface of this imaginary cylinder will be:

$$E = d\pi/dA = N/[2\pi \cdot r] \text{ lux}$$

Thus, it is clear that the illuminance produced by an infinite line source varies inversely with the first power of the distance.

The above expression gives the illuminance when the light is falling at normal incidence on the illuminated surface. If the angle of incidence were  $\Theta$ , then the cosine law would apply:

$$\text{viz. } E = N \cdot \cos\Theta / 2\pi \cdot r \text{ lux.}$$

Many real sources are sufficiently close approximations to the infinite line source to make this a useful practical concept in lighting engineering, and the measures "angle flux" and "sector flux" are often employed in this context.

### 3.3 The Uniform Plane Source and the Distance-Independent Law

Arguments similar to those for the point and line sources can be developed to show that, for an infinite plane source, the illuminance it produces is unaffected by distance. The informal illuminance in lux will be numerically equal to the exitance of the source in apostilbs. (If off the normal, the illuminance decreases in accordance with the equation below\*).

An infinite plane source is unlikely to be encountered in practice; however, a very large plane source, such as a luminous ceiling, may be regarded as a good approximation for many practical purposes.

$$* \quad E = M \frac{1 + \cos \Theta}{2}$$

APPENDIX D

## APPENDIX D

### LIGHT DISTRIBUTION AND PHOTOMETRIC DIAGRAMS

#### 1. GENERAL

Quantitative lighting design is greatly dependent on the light distribution of luminaires. This is usually presented diagrammatically by polar curves or isocandela diagrams, in addition to single figure designations, such as BZ-class, flux fraction ratio or floodlight type, which give some broad idea of the light distribution.

The final design result is usually given as a single average illuminance value, but more detailed information can be conveyed diagrammatically by isolux curves.

Within the design process, the behaviour of materials may also be given in graphical form, such as luminance factor curves.

The quantities given for luminaires are usually intensities (in cd or cd p.klm) or luminances (in  $\text{cd/m}^2$  or  $\text{cd/m}^2$  p.klm), but angle flux polar curves (in lm/rad or lm/rad p.klm) or sector flux polar curves (in lm/m rad or lm/m rad p.klm) can be very useful.

#### 2. INTENSITY POLAR CURVES OF LUMINAIRES

##### 2.1 Polar Curve Principles

Intensity is a directional quantity and can be expressed as a vector, which generally varies with direction. It is often given by polar curves (P.C.), which allow an easy visualization of the light distribution. Mathematically it should be noted:

- (i) Intensity pertains strictly only to a point source, but luminaires can be treated as point sources if sufficiently far away.

- (ii) The P.C. is a vector-locus; the vector origin is important and must always be given. A circular P.C. e.g. could represent a uniform source, such as a diffusing sphere (Fig. 1) or a plane diffusor (Fig. 2) dependent on the position of the vector-origin.
- (iii) The full description of light distribution of luminaires would require a polar solid; a polar curve is a section through this solid.
- (iv) Flux values or light output ratios of luminaires can be derived from their polar curves, but the character of the polar solid must be taken into account as will be shown presently.

## 2.2 The Rotationally Symmetric Source

The study of this distribution has a long history, since it is a good approximation for many incandescent luminaires. A single polar curve completely describes its polar solid, which is easily visualized from a P.C. Rectangular co-ordinates (Fig. 3) are often useful for dealing with narrow beam spotlights, since candela values are difficult to read from a P.C. when the intensity changes sharply with the angle. For obtaining flux values, one multiplies intensities by relevant solid angles:

$$\Delta\phi = I.\Delta\omega$$

With rotational symmetry, one can take solid angular rings (Fig. 4), but must allow for the variation of their diameter with direction:

$$\Delta\omega = 2\pi \sin \theta \Delta\theta \tag{2.1}$$

The flux between two angles  $\theta_1$  and  $\theta_2$  is then:

$$\begin{aligned} \phi &= 2\pi (\cos \theta_1 - \cos \theta_2) \cdot I(\theta) = ZF.I(\theta) \\ &= 4\pi \sin \left[ \frac{\Delta\theta}{2} \right] \cdot \sin \theta \cdot I(\theta) = ZF.I(\theta) \end{aligned} \tag{2.2}$$

ZF is the 'Zone Factor' (in USA called 'Zonal Constant'). Zone factor values depend on the angular spacing of measurements. The table gives values for 10° steps. (ZF = 1,095 sin  $\theta$ )

Angle*:	5°	15°	25°	35°	45°	55°	65°	75°	85°
Z.F.:	0,0954	0,283	0,463	0,628	0,774	0,897	0,993	1,058	1,091

\* from vertical, downward or upward (same zone factors for down and up fluxes).

Note that areas under an intensity polar curve for rotationally symmetrical sources do not represent flux values. These can be evaluated graphically by deriving a Rousseau diagram which does yield an area proportional to flux, or evaluated by Russell angles. The two P.C.'s in Fig. 5 represent equal fluxes.

### 2.3 The Disymmetrical Source

The study of this distribution is relatively new and less widely known, but worth while since it is a good approximation for linear sources, such as fluorescent luminaires and some floodlights.

Its polar solid can be described by two polar curves, the 'normal P.C.' and the 'axial P.C.' (Fig 6).

'Normal' means perpendicular to the axis of the line source

'axial' refers to a P.C. in a plane containing this axis.

While the normal P.C. can have any shape, the axial P.C. is usually smooth, often close to a  $\cos^p\phi$  function, commonly with p between 1 and 2. More important is the fact that the shape of the axial P.C. is often the same for different  $\theta$ -planes, it merely shrinks proportionally; let us call this 'true' disym-metry.

If only the two main P.C.'s are known, the assumption of true di-symmetry is likely to lead to a quicker and more accurate evaluation of flux values than by averaging and the use of rotational-ly symmetrical concepts.

### 2.4 Evaluation by means of the Angle Flux Concept

The evaluation is a two step process. For better understanding the 'Angle Flux' concept is very useful. It is defined as:

$$A = d\phi/d\theta \quad (\text{UNITS: lumen per radian} = \text{lm/rad}) \quad (2.3)$$

and refers to the flux between two semi-infinite planes inter-secting the source axis,  $d\theta$  apart (Fig. 7).

By introducing a 'k-factor', so that for each direction  $\theta$  of the normal polar curve:

$$A(\theta) = k.I(\theta) \quad (2.4)$$

$k$  is a constant for true disymmetry, which is usually a good approximation. The factor  $k$  is entirely determined by the shape of the axial P.C. and can be rigorously calculated as:

$$k = \int_{-\pi/2}^{+\pi/2} I(\varphi) \cos \varphi \, d\varphi / I(0) \quad (2.5)$$

For photometric data at  $10^\circ$  intervals, i.e. for  $\varphi = 5^\circ, 15^\circ \dots 85^\circ$ :

$$k = (\pi/9) \sum_5^{85} I(\psi) \cos \psi / I(0) \quad (2.6)$$

$I(\varphi)$  are averages of two values measured on either side of  $I(0)$  which refers to  $\varphi = 0$ , all obtained for one plane ( $\theta = \text{constant}$ ).

Since  $\phi = \int A(\theta) \, d\theta$ , the luminaire flux is obtained by a simple addition of angle flux values, multiplied by a factor, allowing for the spacing of measurements used. For  $10^\circ$  spacing, with measurements at  $5^\circ, 15^\circ \dots 175^\circ$ :

$$\phi = (\pi/9) \sum_5^{175} A(\theta) = k(\pi/9) \sum_5^{175} I(\theta) \quad (2.7)$$

$A(\theta)$  and  $I(\theta)$  are the averages of two measurements, one on each side of the zero direction.

No zone factors are needed to calculate flux from angle flux or  $I(\theta)$  values of the normal P.C. In a Cartesian diagram of  $A$  against  $\theta$  areas represent fluxes.

For true dissymmetry the normal P.C. can be interpreted as an Angle Flux P.C., by merely changing the scale (i.e. multiplying the candela value by  $k$  to get lm/rad).

The  $k$ -factor is usually between 1 and 1,6 (but not always). It is 1,57 for a uniform diffuser; 1,47 for a bare fluorescent tube, lower for louvres or floodlights.

A abridged formula can usually give a quick estimate for fluorescent luminaires:

$$k = 1 + I_{55}/I_0 \quad (2.8)$$

when  $I_{55}$  is measured at  $\varphi = 55^\circ$ ,  $I_0$  at  $\varphi = 0^\circ$  for the same  $\theta$  plane. If luminaires with an angle flux  $A$  are mounted in a long row, with centre spacing  $C$ , the Sector Flux of this row (in the same  $\theta$  direction) is simply:

$$J = A/C \quad (2.9)$$

It is a very useful quantity for design; a sector flux P.C. has of course the same shape as the corresponding angle flux P.C.

### 3. ISOCANDELA DIAGRAMS

#### 3.1 Aim and Definition

For irregular distributions, such as for most street lanterns and many floodlights, we require an 'isocandela' diagram. This is a plot of equal-intensity contour lines on a web of directional co-ordinates, usually in degrees.

Problems arise from the need to represent a three dimensional space in a two dimensional graph. Various web types can be used: circular, rectangular, sinusoidal, etc.

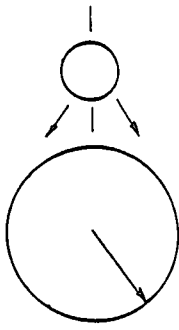
### 3.2 The Rectangular IsoCandela Diagram

Floodlight data is commonly presented in a rectangular iso-candela diagram (Fig. 8). This is convenient and allows a choice of scales to suit the beam type. Ambiguity can, however, arise, if the angular system is not clearly defined. Measurement planes are determined by the type of goniometer used for testing. Figs. 9 and 10 show two possible co-ordinate systems. Confusing them can lead to misinterpretation of the given data; the resulting errors are usually small for narrow beam floods, but may well be large for wider beams.

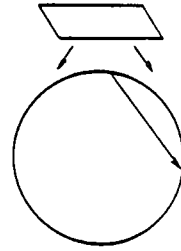
## 4. ISOLUX DIAGRAMS

Light levels computed or achieved are commonly expressed as a single average illuminance value, but the light distribution can also be stated by means of an 'Isolux diagram', a plot of equal-illuminance contours in Cartesian co-ordinates. It can be computed from given intensity data for a planned layout.

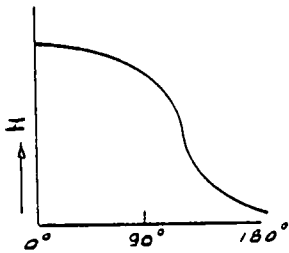
# ROTATIONAL SYMMETRY



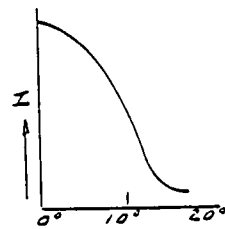
**Fig 1**  
**UNIFORM SOURCE**



**Fig 2**  
**PLANE SOURCE**

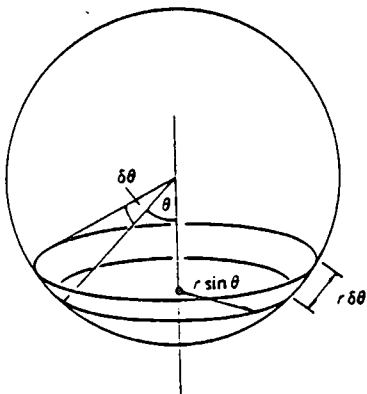


**WIDE LUMINAIRE**

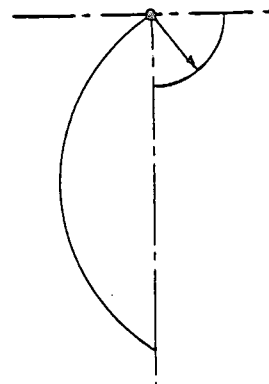


**Fig 3**

**FLOODLIGHT**

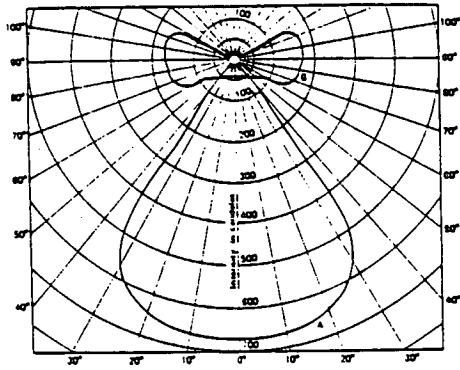


**Fig 4**  
 **$\omega$  FOR Z F DERIVATION**

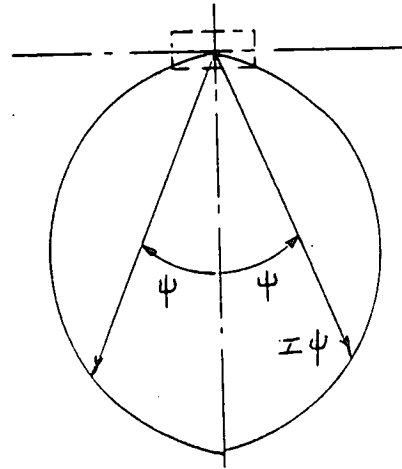


**Fig 5**  
**EQUAL FLUX**  
**ROT. SYMM. SOURCES**

# DI-SYMMETRY



NORMAL PC



AXIAL PC

Fig 6

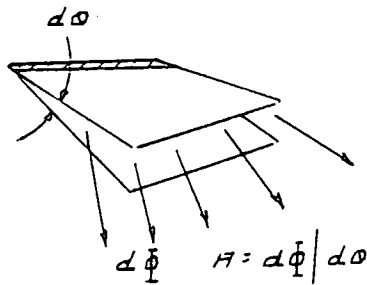


Fig 7  
ANGLE FLUX  
DEFINITION

# ISO-CANDELA DIAGRAMS

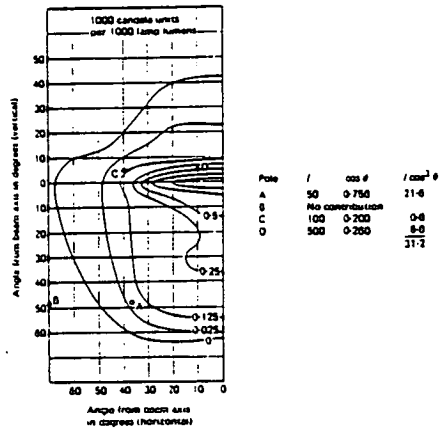


Fig 8  
POINT BY POINT  
CALCULATION

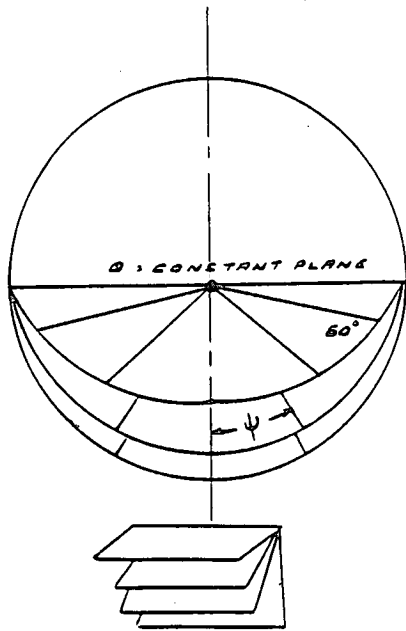


Fig 9

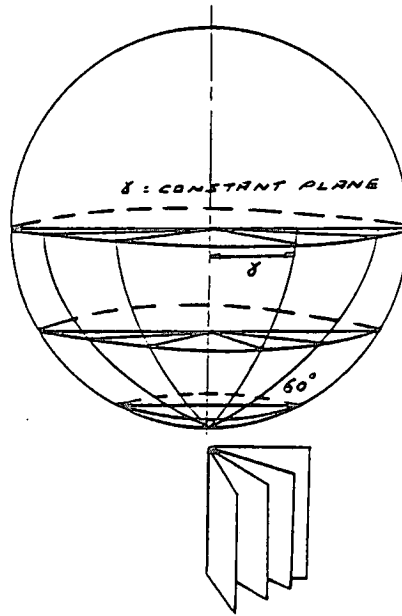


Fig 10

## GONIOMETRIC SYSTEMS

APPENDIX E

## APPENDIX E

### SYSTEMS OF COLOUR SPECIFICATION

#### 1. INTRODUCTION

Systematic, quantitative methods of colour specification may be applied to objects that are

- (i) SELF-LUMINOUS, and
- (ii) NON SELF-LUMINOUS

Objects in category (i) are what we normally term **Light Sources**, while objects in category (ii) are those things in the world around us that we are aware of by virtue of their ability to reflect, transmit or absorb light. Broadly speaking, and for most practical purposes, we can divide them into **Light Reflectors** and **Light Transmitters**.

As a general rule, it is necessary to apply different techniques of colour specification to **LIGHT SOURCES**, **LIGHT REFLECTORS** and **LIGHT TRANSMITTERS**. It is possible, however, to express the colour properties of all three varieties of objects in **physical terms** by means of a spectrum measurement - but it is necessary to exercise great care in the interpretation of a spectrum if one attempts to use it to express the subjective, visual impression of a colour.

#### 2. COLOUR SPECIFICATION OF LIGHT SOURCES

Apart from the spectrum of a light source, there are **three** quantitative techniques in common use for the specification of its colour properties:

**CHROMATICITY COORDINATES**, and

**COLOUR TEMPERATURE**

are both methods of defining the colour **appearance** of a source, while

**COLOUR RENDERING INDEX**

is a figure of merit for a light source, expressing the degree of **naturalness** with which it will render the colours in a scene lit by it.

##### 2.1 **Chromaticity Co-ordinates**

x, y z are quantities that represent, respectively, the relative amounts of:

REDNESS           (x)  
GREENNESS       (y), and  
BLUENESS         (z)

in a light source, bearing in mind that it is possible to synthesize a white source of light (in appearance at least) by an appropriate mixture of primary (i.e. red-, green- and blue-coloured) light sources.

The quantities are defined such that:

$$x + y + z = 1 \text{ always}$$

so that it is really necessary to quote only  $x$  and  $y$  to define the colour appearance of a light source unambiguously.

The CHROMATICITY DIAGRAM is a means for expressing the colour appearance of a source in terms of its chromaticity coordinates,  $x$  and  $y$ .

It is quite easy to define areas of the diagram where common colour names (or, hues) may be applied. See Fig. 1.

## 2.2 Colour Temperature

Within the chromaticity diagram, it is possible to plot a series of points representing the colours of incandescent (= hot-body) radiators of light. (These sources are often referred to generically as Black-body Radiators, although this term strictly applies only to perfect sources of this type, that convert all of the heat energy into radiant energy).

These points may be joined by a line that is commonly known as the Black-body Locus or Planckian Locus. See Fig. 2.

Most natural light sources (such as incandescent bodies, flames, daylight, etc.) have chromaticity coordinates that lie close to the Planckian Locus. It is probably for this reason that the electric light sources that we, as human beings, find most acceptable for artificial lighting are those that possess chromaticity coordinates that are also close to the Planckian Locus.

Thus, it is possible to classify the colour appearance of such a source by its **colour temperature** which is simply the temperature of the Black-body radiator whose colour appearance is the closest possible approximation to the colour of that source.

Colour temperature cannot and should not be used to define the appearance of sources whose chromaticity coordinates are far from the Planckian Locus. (These would be sources that have a strong colour character, termed a **saturated colour**).

## 2.3 Colour Rendering Index

This figure of merit has to be computed by rather complex means from a knowledge of the spectrum of the light source.

Being a single number (usually between 50 and 100), it is easy to interpret and it forms a simple basis for comparison between different lamps.

One problem is that, if the colour rendering index is low, we know only that the source spectrum is poor - but not in what wavelengths it is lacking (i.e. two sources may each have a CRI of 50; but the one may render reddish hues poorly, while the other may render bluish hues poorly; the simple index does not tell us which is which).

### 3. COLOUR SPECIFICATION OF REFLECTING SURFACES

One way of specifying a surface colour is to define its position within a region of three dimensional space often known as a COLOUR SOLID. See Fig. 3.

Colour solids in general employ one of two common forms of coordinate systems:

- (i) RECTANGULAR COORDINATES, and
- (ii) CYLINDRICAL COORDINATES

It is possible to construct material colour standards according to the systematic attributes of one of these forms of colour solid. Some examples of such systems are given below:

#### 3.1 Rectangular Coordinate Systems

- (i) OSA Uniform Colour Scales (OSA = Optical Society of America):
  - L = lightness
  - g = greenness
  - j = yellowness

#### 3.2 Cylindrical Coordinate Systems

- (i) Swedish Natural Colour System (SNCS):
  - s = blackness
  - c = chromaticity (meaning, approximately, **saturation** in this case)
  - $\phi$  = hue
- (ii) DIN Colour System:
  - F = Farbton (= hue)
  - S = Sattigung (= saturation)
  - D = Dunkelstufe (= lightness)
- (iii) Ostwald Colour System:
  - Hue - specified by a number
  - Isochrome = colour content )
  - Isotone = black content ) Give saturation and
  - Isotint - white content ) lightness information

(iv) Munsell Colour System:

H = hue  
V = value  
C = chroma

A colour is specified as: H V/C.

Full details are given in Section 3.3

(v) ISCC - NBS Colour Designations:

An adaptation of the Munsell System in which the colour names are given a general, descriptive character that can be easily understood. (ISCC = Inter-Society Colour Council; NBS = National Bureau of Standards, USA).

(vi) Chroma Cosmos 5000 (Japan Colour Research Institute):

An extension of the Munsell System, containing 5000 colour chips.

### 3.3 The Munsell Colour System

The system was originated in the 1920's by A.H. Munsell in his book **A Colour Notation** and it was defined in its present form in 1943.

The Munsell specification for a colour is given in the form: H V/C where:

H = hue  
V = value  
C = chroma.

The Hue nomenclature is:

R	=	red
YR	=	yellow-red
Y	=	yellow
GY	=	green-yellow
G	=	green
BG	=	blue-green
B	=	blue
PB	=	purple-blue
P	=	purple
RP	=	red-purple
R	=	red
etc.		

Each hue sector is divided into 10 equal-sized, numbered subsectors, viz:

1R, 2R, 3R ..... 10R,  
1YR, 2YR, 3YR, ..... 10YR,  
1Y, 2Y, 3Y, ..... 10Y,  
.  
.  
.  
.  
.  
.  
1RP, 2RP, 3RP, ..... 10RP

making up 100 divisions within the hue circle, all steps of the same size being judged as subjectively equal.

The **Value nomenclature** is on a scale from 0 to 10 such that:

0 = absolute blackness, and  
10 = perfect whiteness.

The intermediate grey steps are judged as subjectively equal.

The **Chroma nomenclature** is such that loci of equal chroma form concentric circles around the neutral axis. Chroma is expressed on a scale that extends from 0 upwards. The limit on the chroma scale depends on the hue and value, but does not exceed about 30 for any colour. The most highly saturated colours normally represented in physical colour samples have a chroma in the region of 10 to 15.

**Use of the Munsell System:** It is almost universally accepted as an international standard for the specification of surface colours

**Advantages of the Munsell System:**

- (i) It can be extended, subdivided or refined in various ways according to specific needs.
- (ii) It is psychologically-based, such that equal subjective colour differences are represented by equal distances within Munsell colour space.
- (iii) Its relationship to objective CIE Colour specification systems has been established and is universally recognised. See Fig. 4.

### 3.4 Colour Difference Formulae for Surface Colours

Something like 20 or 30 different colour difference formulae have been developed over the years, mainly for purposes of colour control in various production processes. The majority of these have been based on a three-dimensional colour space expressed in rectangular coordinates. The two systems that are now officially endorsed by the CIE are the ( $L^*a^*b^*$ ) system (known as CIELAB) and the ( $L^*u^*v^*$ ) system (known as CIELUV).

In these systems, the symbols have the following approximate meanings:

$L^*$	=	lightness
$u^*$ )		
$a^*$ )	=	redness
$v^*$ )		
$b^*$ )	=	yellowness

$L^*$  is on a scale from 0 to 100 and  $a^*$ ,  $b^*$ ,  $u^*$   $v^*$  typically run to maximum values in the region of 100 to 200 depending on the hue and lightness.

## 4. COLOUR SPECIFICATION FOR TRANSMITTING SURFACES

Transmitting surfaces can, in principle, be defined by any of the abovementioned techniques. It is usual then to decide whether the transmitting surface is going to **look like** a self luminous source or not, and to apply a method appropriate to that particular situation.

For example, if a transmitting material is going to be used as a coloured filter over a light source, then the filter is going to **appear** to be the source, and its colour is then best defined by one of the methods outlined in part 2. (Note that the colour so defined represents the colour of the particular filter-plus-lamp **combination** since changing the type of lamp is almost certain to change the colour of the light transmitted by the filter.

Conversely, a colour photographic print consists of a white backing sheet overlaid with thin **filters** that transmit, respectively, cyan, magenta and yellow - the shapes of these filter layers being determined by the shapes and colours of the objects photographed. The colours in this instance as best defined by one of the surface colour techniques outlined in part 3.

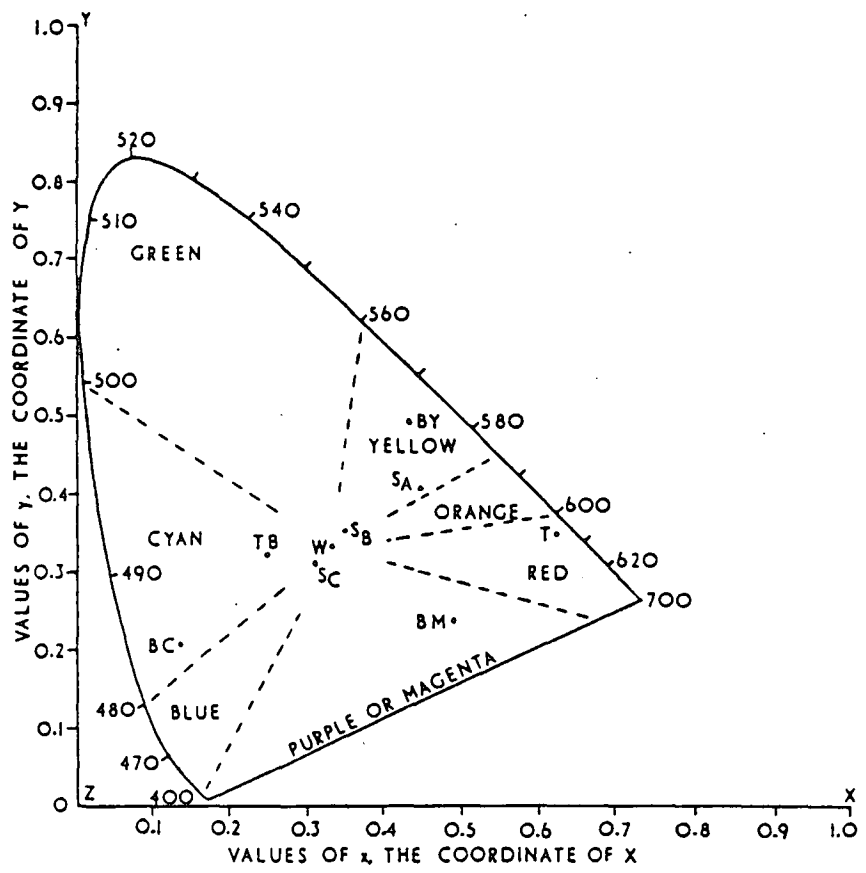


Fig. 1: CIE Chromaticity Diagram indicating approximate Hue zones.  
 [from Clulow: Colour, Fountain Press (1972) p. 125]

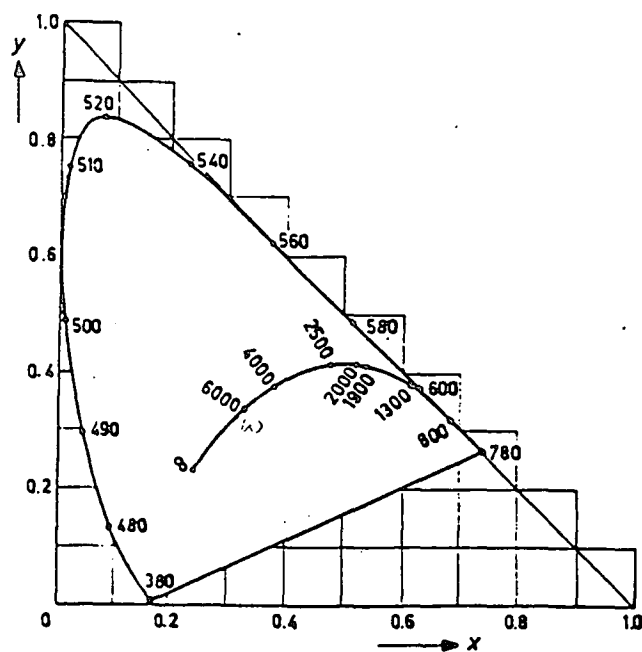


Fig. 2: CIE Chromaticity Diagram indicating the Planckian locus  
 [from Bouma : Physical Aspects of Colour, Macmillan (1971) p.84]

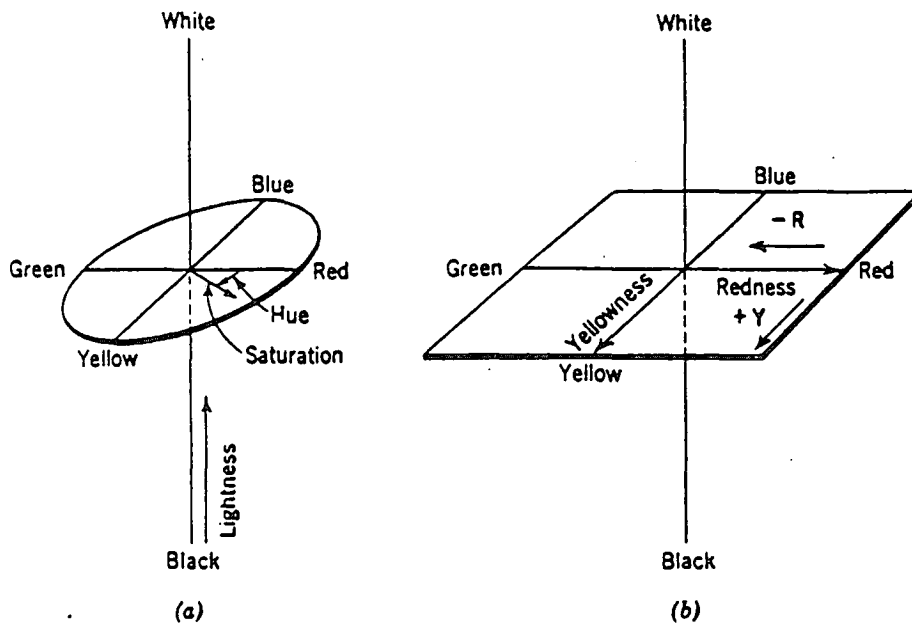
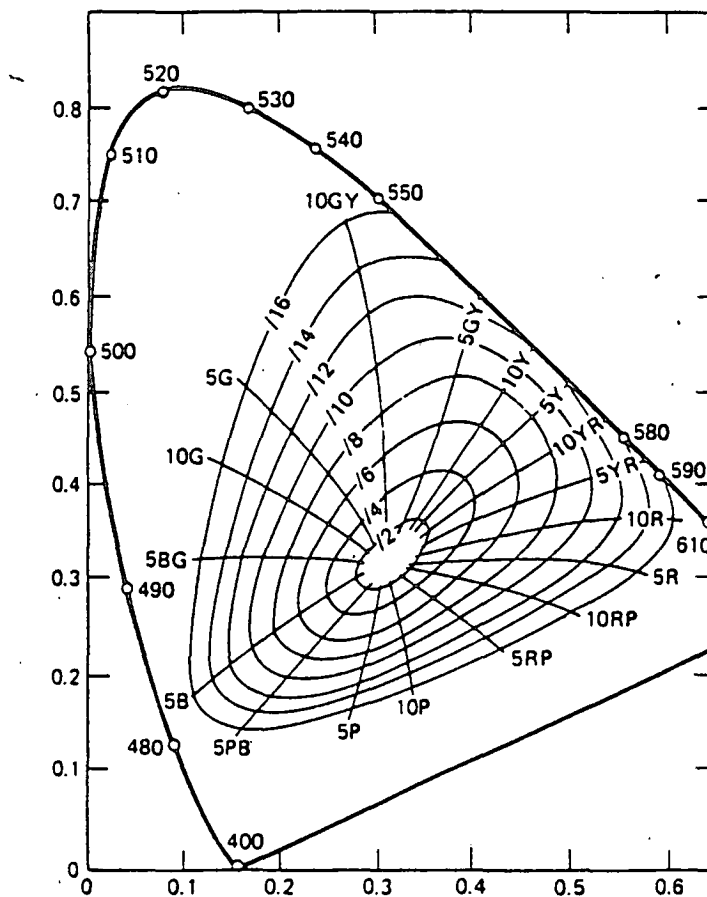


Fig. 3: Three-dimensional Colour Spaces  
 (a) Cylindrical coordinates  
 (b) Rectangular coordinates  
 [from Levi: Applied Optics, Wiley (1968) p.12]

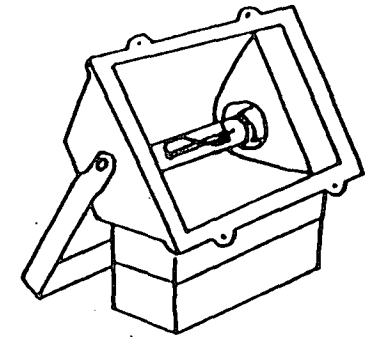
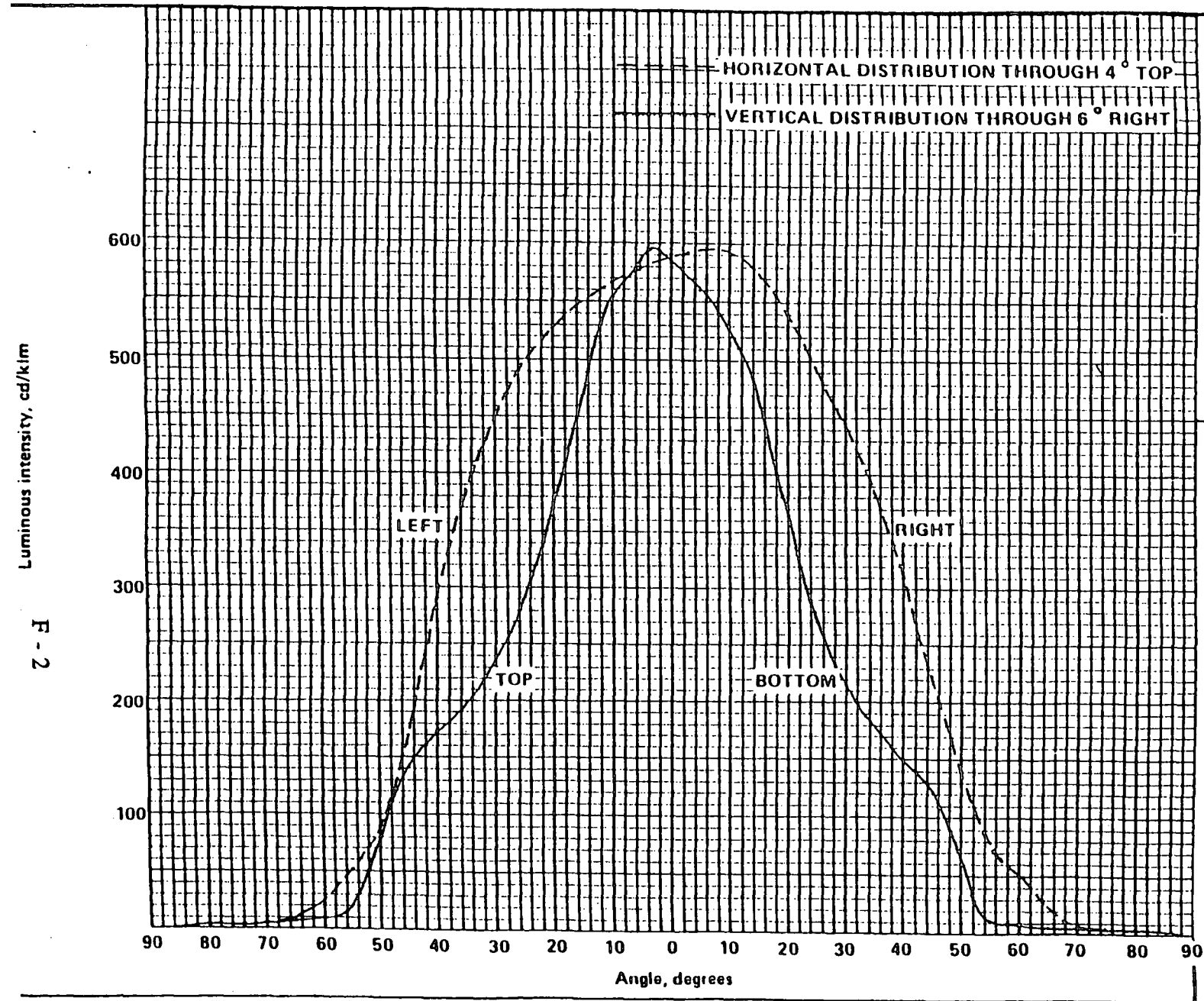


**Recommended Floodlighting Levels**

Facing Material	Illuminance in lux Surroundings			Correction coefficient Lamp type		Surface condition	
	Poorly	Well	Brightly	HP Mercury	Sodium	Fairly	Dirty
Light stone, white marble	20	30	60	1.0	0.9	3.0	5.0
Medium stone, cement, light-coloured marble	40	60	120	1.1	1.0	2.5	5.0
Dark stone, grey granite, dark marble	100	150	300	1.0	1.1	2.0	3.0
Light-yellow brick	35	50	100	1.2	0.9	2.5	5.0
Light-brown brick	40	60	120	1.2	0.9	2.0	4.0
Dark-brown brick, pink granite	55	80	160	1.3	1.0	2.0	4.0
Red brick	100	150	300	1.3	1.0	2.0	3.0
Dark brick	120	180	360	1.3	1.2	1.5	2.0
Architectonic concrete	60	100	200	1.3	1.2	1.5	2.0
Aluminium cladding: Natural finish	200	300	600	1.2	1.2	1.5	2.0
Termo-lacquer finish -saturated (10%) red, brown, yellow blue, green	120	180	360	1.3 1.0	1.1 1.3	1.5	2.0
-medium (30-40%) red, brown, yello blue, green	40	60	120	1.2 1.0	1.0 1.2	2.0	4.0
-pastel (60-70%) red, brown, yellow blue, green	20	30	60	1.1 1.0	1.0 1.1	3.0	5.0

FLOODLIGHTING LUMINAIRE: HNF 1022-250 W  
LUMINOUS INTENSITY DISTRIBUTION DIAGRAM

December 1984



NOTE: LEFT and RIGHT denotes the left and right sides of the luminaire as seen from behind the luminaire.

LAMP TYPE: 250 W tubular HPS

Cat. No.: Philips 126645 250 W SON/T

Lamp Position: Horizontal

Beam spread: 123° Horizontal x 106° Vertical  
Maximum luminous intensity: 594 cd/klm

Beam classification: H6V6

*J. C. Lawrence*  
DIRECTOR GENERAL

**TABLE I**  
 Floodlighting Luminaire: HNF 1022-250 W  
 Value in every square: Luminous intensity at centre of zone, cd/klm

REPORT No. 721/80800/A367  
 December 1984

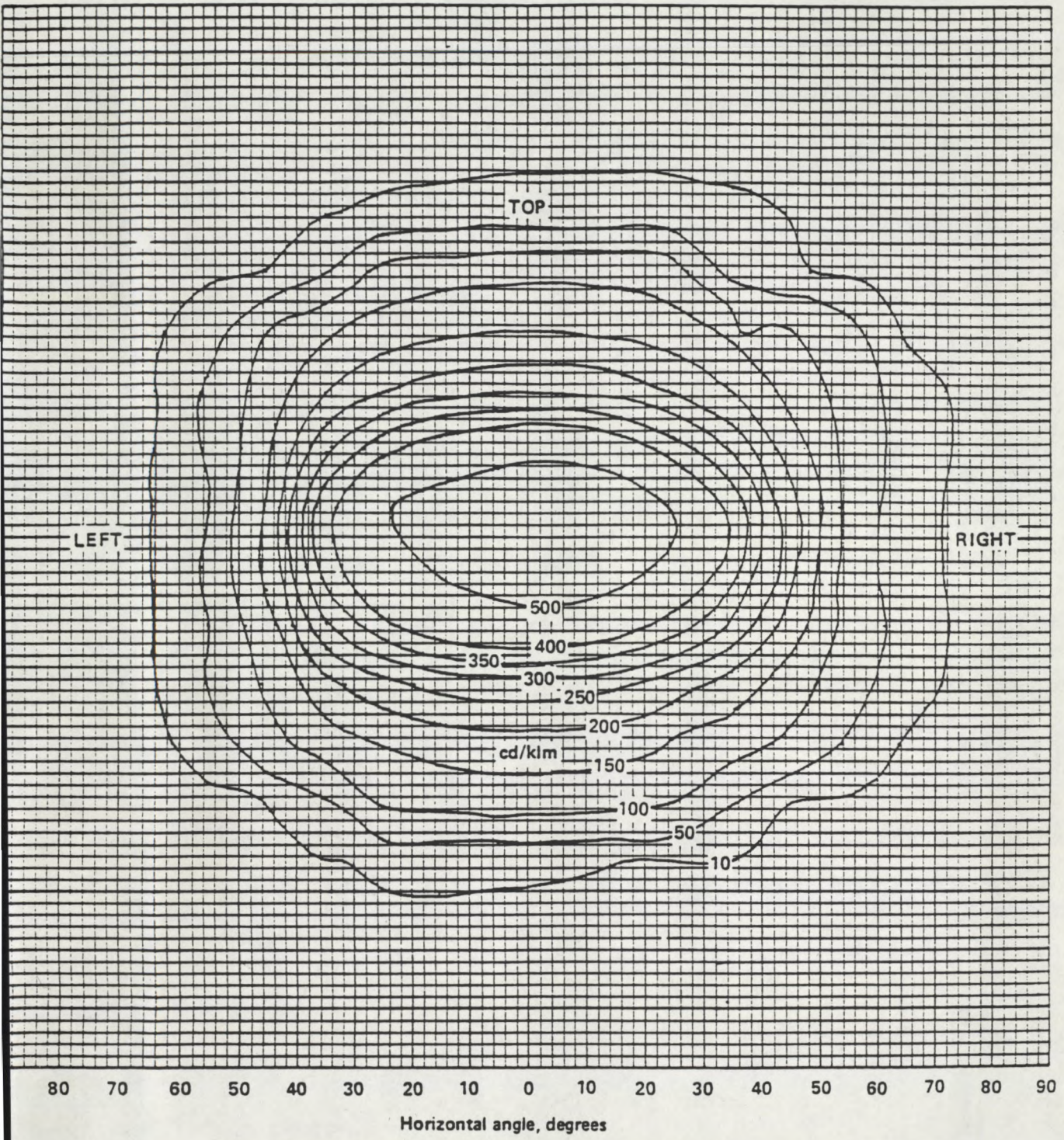
Vertical angle degrees	Horizontal angle, degrees																			Beam flux, lm	Total flux, lm			
	LEFT									RIGHT														
	95	85	75	65	55	45	35	25	15	5	5	15	25	35	45	55	65	75	85	95				
TOP	95	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	85	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	75	0	0	0	0	0	0	0	0	1	1	3	3	2	2	1	1	0	0	0	0	0	0	0
	65	0	0	0	0	1	3	4	4	5	5	6	6	7	6	5	4	3	1	0	0	0	0	1
	55	0	0	0	2	4	6	9	13	15	18	18	18	14	13	9	8	6	2	1	0	0	0	3
	45	0	0	0	1	4	10	46	117	127	136	139	134	122	36	13	5	3	0	0	0	17	19	
	35	0	1	3	5	27	99	143	171	189	197	198	189	167	140	105	64	5	1	0	0	41	42	
	25	0	1	3	5	59	121	197	249	275	291	293	279	244	197	134	77	27	0	0	0	65	68	
	15	0	1	4	8	58	138	293	382	432	463	469	444	378	293	172	85	32	4	0	0	104	107	
C - F	5	0	1	4	8	50	160	383	492	546	576	592	571	491	384	222	80	24	3	0	0	136	139	
	5	0	0	4	8	58	164	374	463	512	544	558	545	477	376	213	81	22	4	0	0	131	133	
	15	0	0	4	6	51	130	297	390	443	468	471	441	378	296	175	85	28	3	0	0	105	108	
	25	0	0	2	5	53	108	184	233	263	279	280	260	224	181	122	72	22	2	0	0	61	63	
	35	0	0	2	5	19	86	125	155	171	179	179	168	149	122	91	45	5	1	0	0	35	37	
	45	0	0	1	4	6	10	42	107	116	122	122	114	103	53	9	5	3	0	0	0	15	18	
	55	0	0	1	2	5	7	9	12	13	12	12	10	9	8	5	4	2	0	0	0	0	2	
BOTTOM	65	0	0	1	4	4	5	6	7	7	8	7	5	5	5	4	3	1	0	0	0	0	1	
	75	0	0	0	1	2	4	4	4	4	4	2	1	0	0	0	0	0	0	0	0	0	0	
	85	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
	95	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
	<b>Totals</b>																				<b>710</b>	<b>742</b>		

Beam flux: 710 lm  
 Total flux: 742 lm  
 Lamp flux: 1 000 lm

Beam efficiency: 71,0 %  
 Total efficiency: 74,2 %  
 Average maximum luminous intensity: 542 cd/klm

*M. Cass*  
 for DIRECTOR GENERAL

ISO-CANDELA DIAGRAM



Maximum luminous intensity: 594 cd/klm  
Beam spread: 123° Horizontal x 106° Vertical  
Beam classification: H6V6  
Polar axis of angular measurements: Vertical (Type A Goniometer).

APPENDIX G

# MASTERS DIPLOMA PROGRAM

EXTERIOR ILLUMINATION OF BUILDINGS

PROGRESS REPORT No. 1

J.C. Wimbush  
Student No. 922211  
M.L. Sultan Technikon

## **INTRODUCTION**

The purpose of this report is to advise on the progress made with my project, namely "External Illumination of Buildings" for the project phase of my Master's Diploma (Electrical) Heavy Current.

## **PROJECT**

The field of illumination engineering is a diverse one and has tended to be the "cinderella" component of a heavy current course. However, this perception is rapidly changing and the obvious advantages of lighting is being extended to include more of the prestigious monuments and buildings. The Europeans are very proud of their heritage and many of their buildings and structures of great antiquity are illuminated to magnificent effect. Of course, many beautiful modern buildings are included. The main focus of this project will be the external illumination of buildings for prestige, rather than purely security reasons. By so doing I hope to produce a document that may be of value to architects and at the same time encourage a desire to enhance the beauty of some of our buildings and at the same time inculcate a greater sense of pride in our cities and towns. With tourism being one of the greatest foreign currency earners we need to do everything possible to promote it.

## **STRUCTURE**

The project will take the following form:

1. **INTRODUCTION**
2. **GATHERING OF INFORMATION** (Project Research)

This will comprise the following:

- 2.1 Visits to a variety of buildings and structures during daylight and at night;
- 2.2 Meetings with luminaire suppliers;
- 2.3 Obtain catalogues;
- 2.4 Meeting with Durban Electricity to determine inter alia points of supply, supply capacity, etc.
- 2.5 Acquire copies of all relevant codes of Practice, Design guide lines (European, British and American).
- 2.6 Subject, Literature from local libraries.

3. **PRELIMINARY DESIGN REPORT**

This will be the formulation of all the information obtained above to determine the parameters of a design.

4. **AN ACTUAL DESIGN**

This will entail a description of the essential design considerations required in carrying out a floodlighting project; the lighting design and photometrics of the luminaries; environmental factors, etc.

5. **PRESENTATION**

Collation of all data and bind into a document for submission.

6. **APPENDICES**

**Progress To Date**

		<b><u>Progress</u></b>
Section 1	Introduction	50%
Section 2	Project Research	30%
Section 3	Preliminary Design	0%
Section 4	Lighting Design	0%
Section 5	Presentation	0%
Section 6	Appendices	0%

Hours to date - 32 hrs

# **MASTERS DIPLOMA PROGRAM**

## **EXTERIOR ILLUMINATION OF BUILDINGS**

### **PROGRESS REPORT No. 2**

**J.C. Wimbush  
Student No. 922211  
M.L. Sultan Technikon**

1. **PROJECT INTRODUCTION**

The aims and objectives are now defined.

2. **PROJECT RESEARCH**

The collection and collation of all appropriate information including photometric data, evaluation of this data and preliminary designs and cost appreciation. Complete overview of the requirements of a floodlighting design.

3. **DESIGN REPORT**

This will contain planning of an installation and details for carrying out a floodlighting project. Environmental factors, preferences and cost analysis.

4. **LIGHTING DESIGN**

This will contain some practical examples of building illumination together with calculation techniques.

5. APPENDIX
- A Fundamentals of Light and Vision
  - B Photometric Concepts
  - C Basic Photometric Equations
  - D Light Distribution
  - E Systems of Colour Specifications
  - F Progress Reports
  - G Guide to Exterior Security Lighting SANCI

**Progress To Date**

	<b><u>Progress</u></b>
Introduction	80%
Project Research	45%
Design Report	0%
Lighting Design	0%
Appendices	25%
Hours to date	130 hrs

# MASTERS DIPLOMA PROGRAM

## EXTERIOR ILLUMINATION OF BUILDINGS

### PROGRESS REPORT No. 3

J.C. Wimbush  
Student No. 922211  
M.L. Sultan Technikon

1. **INTRODUCTION**

The purpose of this report is to advise on the progress that has been made with my project, viz: "Exterior Illumination of Buildings" for the research project phase of my Masters Diploma (Electrical).

2. **PROJECT PROGRESS**

2.1 **Research**

The collection and collation of most of the appropriate data has now been completed. Miscellaneous Design data, drawings and tables have also been obtained.

3. **DESIGN REPORT**

This report has been compiled in a basic format.

4. **LIGHTING DESIGN**

Preliminary study of Design Techniques and of computer programmes used in the aid of design has been completed.

5. **PROGRESS TO DATE**      **Progress**

Introduction	95 %
Project Research	75 %
Design Report	20 %
Lighting Design	5 %
Appendices	40 %
Hours to date	280 HRS

# MASTERS DIPLOMA PROGRAM

EXTERIOR ILLUMINATION OF BUILDINGS

PROGRESS REPORT No. 4

J.C. Wimbush  
Student No. 922211  
M.L. Sultan Technikon

1. **INTRODUCTION**

The purpose of this report is to advise on the progress that has been made with my project, viz: "Exterior Illumination of Buildings" for the research project phase of my Masters Diploma (Electrical).

2. **PROJECT PROGRESS  
RESEARCH - complete**

3. **DESIGN PREPARATION - complete**

4. **DESIGN REPORT - complete**

5. **APPENDICES - complete**

6. **PROGRESS TO DATE      Progress**

Introduction	100%
Project Research	99%
Design Report	99%
Lighting Design	99%
Appendices	95%
Presentation and Binding	85%
Hours to date	475 HRS

APPENDIX H

SOUTH AFRICAN NATIONAL COMMITTEE ON ILLUMINATION



# GUIDE FOR EXTERIOR SECURITY LIGHTING

AUGUST 1984

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## C O M M I T T E E

D.H. Culley (Chairman) -	South African Transport Services
B.C. Bakker -	Lascon Lighting Industries (Pty) Ltd
P.A. Davies -	Barlite Lighting (Pty) Ltd
M.J.F. Dempster -	Consulting Engineer
J.T. Grundy -	Phosware (Pty) Ltd
T.E. Harrison -	Plate Glass Holdings
Maj. Gen. G.A.D. Rawlins -	National Keypoints Committee
A. Van Zeil -	Consulting Engineer
L.J. Von Maltitz -	Barlite Lighting (Pty) Ltd

## 1.0 INTRODUCTION

The purpose of this document is to provide guidance in the design and application of exterior security lighting systems.

Exterior lighting in any form will enhance the night security of premises, but lighting that is specifically designed to discourage and to defend against intrusion or night attack will perform this function more effectively.

Security lighting should form part of a total security system incorporating strong physical defences such as guards and fences and may be used in conjunction with any intruder detector system, as well as closed circuit television. Furthermore it can aid in fire detection, as smoke would be seen far more easily at night in the beams of security lighting.

Planning of a security system should be carried out in collaboration with security specialists and where necessary, police, the National Keypoints organization, or other government agencies. Consideration must be given to the degree of risk involved and for the best results, a careful examination of the overall needs of each particular situation is essential.

## 2.0 OBJECTIVES

The objectives of security lighting are to promote safety and to assist in the night defence of premises, property and personnel, against the threat of :

- Sabotage
- Terrorism
- Vandalism and violence
- Illegal entry and theft

These objectives can be achieved by the creation of a visual environment that will :

- Deter any would-be intruder and so prevent a possible incident occurring.
- Reveal and where possible disorientate and delay any intruder during, or after, unlawful entry.
- Conceal the location of security personnel.

In meeting these objectives, care must be taken to prevent glare affecting adjacent premises, or causing a hazard to road users and rail, marine and air transport systems.

### 3.0 ASSESSMENT OF RISK

In order to identify the security lighting requirements of an establishment, it is necessary to evaluate the security risk.

Risk encompasses the product of the amount or value that may be destroyed, immobilised, or lost and the probability of this occurring.

The amount or value must be assessed in terms of the importance of the loss and the consequences for the individual, organisation, or State.

The probability must be assessed in terms of the nature of the anticipated threat e.g. sabotage, terrorism, etc., the location as it affects the vulnerability and sensitivity of the establishment and the provision, or lack of, other security measures such as fencing, alarms, guards, etc.

In view of the foregoing, it is not possible to quantify precisely the security risk classification and lighting requirements.

For the purpose of this guide, the following three classes of risk are considered :

#### Extreme Risk

This is related to establishments where :

- If the threat succeeded, it would have a CRITICAL effect, i.e. stopping or seriously affecting production or supply of services completely, or for a considerable period of time.
- Materials and equipment of strategic importance are manufactured/stored.

#### High Risk

This is related to establishments where :

- If the threat succeeded, it would have a SEVERE effect, i.e. whilst affecting production and supply of services for a limited period, will not bring the operation to a complete standstill.
- Materials and equipment which are attractive to thieves, are manufactured/stored.

#### Moderate Risk

This is related to establishments where :

- If the threat succeeded, whilst it would have a SIGNIFICANT effect on production or supply of services, it would not be of serious consequence and production or supply of services could be resumed almost immediately.
- Materials and equipment which are not particularly attractive to thieves, are manufactured/stored.

In assessing the applicable class of security risk on the above basis, the factors previously discussed, viz :

- Nature of threats
- Location of property
- Other security measures

should be taken into consideration and the lighting requirements modified accordingly.

#### 4.0 OTHER SECURITY MEASURES AFFECTING SECURITY LIGHTING REQUIREMENTS

Lighting forms only part of the overall security package and is complementary to other security measures such as guards, fencing, detector and alarm systems and closed circuit television (CCTV).

Correctly designed and located lighting can improve the performance of security guards and in many instances reduce the number of guards normally required to patrol a property. It is important that guards are not subjected to glare from the luminaires, as this would reduce their ability to see and their effectiveness.

Careful consideration must be given to the type, finish and arrangement of fencing used and to the location of the security lighting in relation to the fencing. Vision through a fence by a security guard could be impaired by incorrectly located security lighting, his position in relation to the fence, or unsuitable fencing material. (See Section 5.0).

Where lighting is not switched on throughout the hours of darkness, there would be a need to illuminate an area if intrusion is suspected. This action can be achieved in a number of ways, viz :

- The alarm activating agent can transmit a signal to the guard post, thereby warning the guard that intrusion is taking place and allowing him to manually switch the lighting system.
- The alarm activating system can be directly connected to the lighting system for automatic switching of the lighting. This arrangement is generally known as "trip-lighting".

The various types of alarm mechanisms used, include :

Electrical contacts on security fencing, gates, etc., break beams, trip wires and various types of sensors, viz. vibration, noise, heat, ultraviolet, infra-red radiation, ultrasonic, microwave, etc.

The main disadvantages of "trip-lighting" are

- An intruder could use the system to test the reaction, or divert the attention of the guards, by activating the alarm, thereby causing the lights to be switched on at a certain point in the installation and when the guards are drawn to this point, effect entry at another point out of sight of the guards.
- If the detection equipment is highly sensitive, it may be subject to nuisance tripping and false alarms and the situation could arise whereby the guards would eventually ignore the triggering of the system and in extreme cases, switch the system off.

Closed circuit television (CCTV) is increasingly applied to supplement the activities of guards and lighting plays an important role in its application. While some sophisticated and expensive cameras can operate with little, or no, artificial lighting, a reasonable level of lighting is required for the successful operation of the more moderately priced CCTV cameras.

T.V. camera manufacturers should be approached to supply the following details to enable the surveillance system to function satisfactorily :

- The average and minimum illuminances required
- The ratio of maximum to minimum illuminance which the camera can accommodate within the field of surveillance.
- The colour response characteristics of the camera.

Visibility of objects to the eye, or the camera, depends on contrast between the object and its background and under certain conditions, (eg. a person in dark clothing viewed some distance away against a dark sky), may be difficult to achieve, even with high levels of illuminance.

Lighting for CCTV must be designed to prevent glare from the luminaires affecting the operation of the cameras.

## 5.0 LIGHTING TECHNIQUES AND CONSIDERATIONS

Every security lighting installation should be designed to suit local conditions, such as the topography of the area, the construction and location of the buildings and other structures, surrounding premises and the extent and types of boundary walls and/or fences.

There are five basic lighting techniques and considerations that can be adopted, either separately, or in combination, to suit the majority of situations, viz :

- Perimeter lighting
- Checkpoint lighting
- General area lighting
- Floodlighting of buildings and structures
- Topping up lighting

### 5.1 PERIMETER LIGHTING

The majority of properties are enclosed at the perimeter by some form of fence, or wall, or a combination of the two. The most common type of arrangement in use, is the open type chain link fence. Lighting used in conjunction with this type of fence should enable security guards to observe both the fence and the area beyond and conceal the location of the guards.

Figure 1 page 11, illustrates a typical arrangement of perimeter lighting. Floodlighting luminaires are arranged in a single row, within and parallel to the fence.

The "stand-off" is the distance between the fence line and the luminaire supports. It is the width of the area inside the fence, covered by the lighting, which an intruder would have to cross, and should be kept clear of obstructions. The minimum recommended "stand-off" distance for floodlighting luminaires is 6 metres although 10 metres is preferred if space is available. Luminaires mounted closer to the fence increase the fence luminance, reduce the length of fence illuminated for a given luminaire spacing and significantly reduce visibility of the surveyed field.

The surveyed field should extend outside the fence for a minimum distance of 20 metres and should be reasonably flat and level. It should be cleared of all obstructions which could provide concealment to persons viewed from within the defended area. If the surveyed field cannot be levelled, or the natural ground either falls away rapidly, or rises, special attention must be given to luminaire mounting heights and aiming angles (Fig. 2 page 11).

The lighting should be arranged to illuminate the whole inner surface of the fence and surveyed field, as uniformly as possible. Care should be taken to avoid luminaire spill lighting falling behind the line of luminaires. The possibility of detection of persons seen through a fence is significantly reduced as the luminance of the fence increases above the luminance of the field against which potential intruders are seen. The best detection occurs when the fence luminance is lower than that of the field of view. Fence luminance should be reduced by decreasing the reflectance of the fence, by the use of dark coloured fencing material (reflection factor < 25 %, black or green PVC covered, or painted).

In extreme risk situations, or where the surveyed field is less than 20 metres, or unavoidably obstructed in that it contains person cover, the provision of a double fence should be considered.

Where a double fence system is used, the luminaires may be mounted at the inner fence, (Fig. 3a page 12), or on supports behind it (Fig. 3b page 12). The distance between the two fences should be at least 6 metres to make bridging difficult.

If space is not available in a single fence arrangement to set the luminaires back from the fence, where glare is a problem, for example in built up areas, or where background area lighting within the defended area reduces the effectiveness of the glare system, streetlighting luminaires can be used.

This type of lighting could also be used if the property is enclosed by a solid wall, in which case the lighting should be arranged to cover both the inside and outside of the defended area (Fig. 4a page 13), or where there is a conveniently located building of suitable height in the vicinity of the boundary wall or fence (Fig. 4b page 13). In the latter case floodlighting luminaires could also be used if sufficient stand-off distance is available (Fig. 4c page 13).

In extreme risk situations where the property is enclosed by a solid wall, it may be necessary to create a sterile zone within the defended area by the erection of an inner fence (Fig. 5 page 13). The sterile zone and inner face of the wall should be illuminated by floodlighting luminaires located within the fenced area, approximately level with the top of the wall. The inner face of the wall and the surface of the sterile zone, should be finished in a light coloured material.

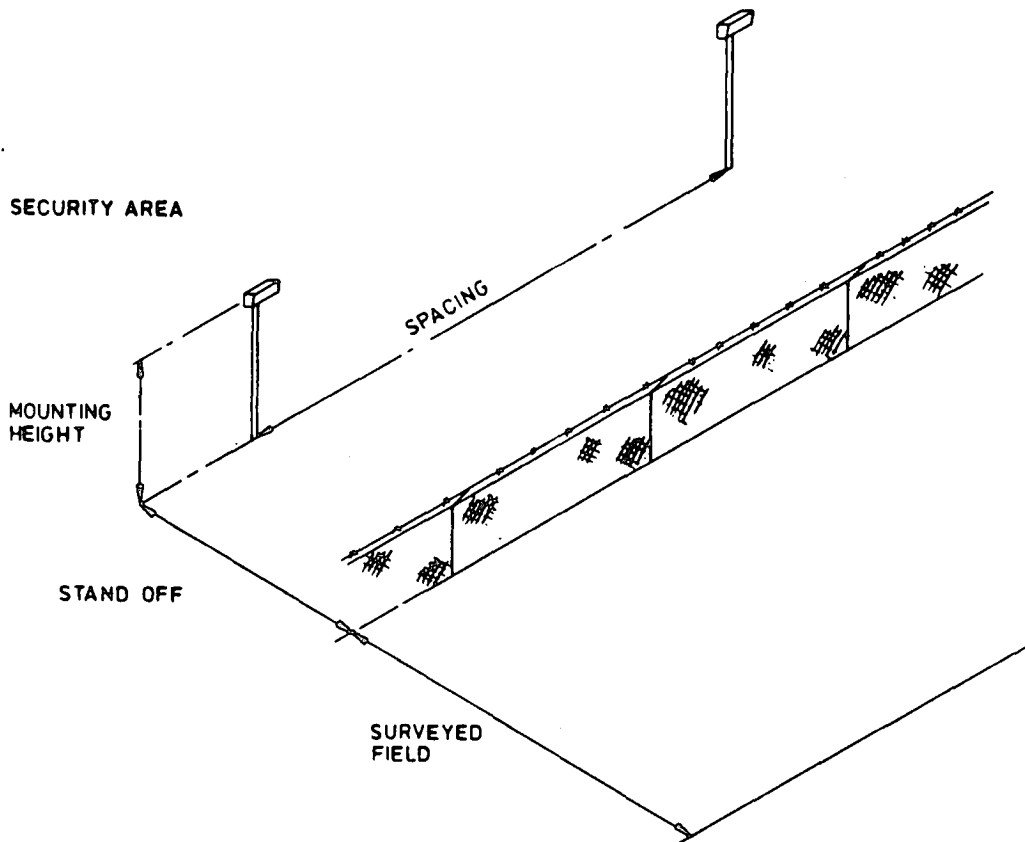


FIG. 1

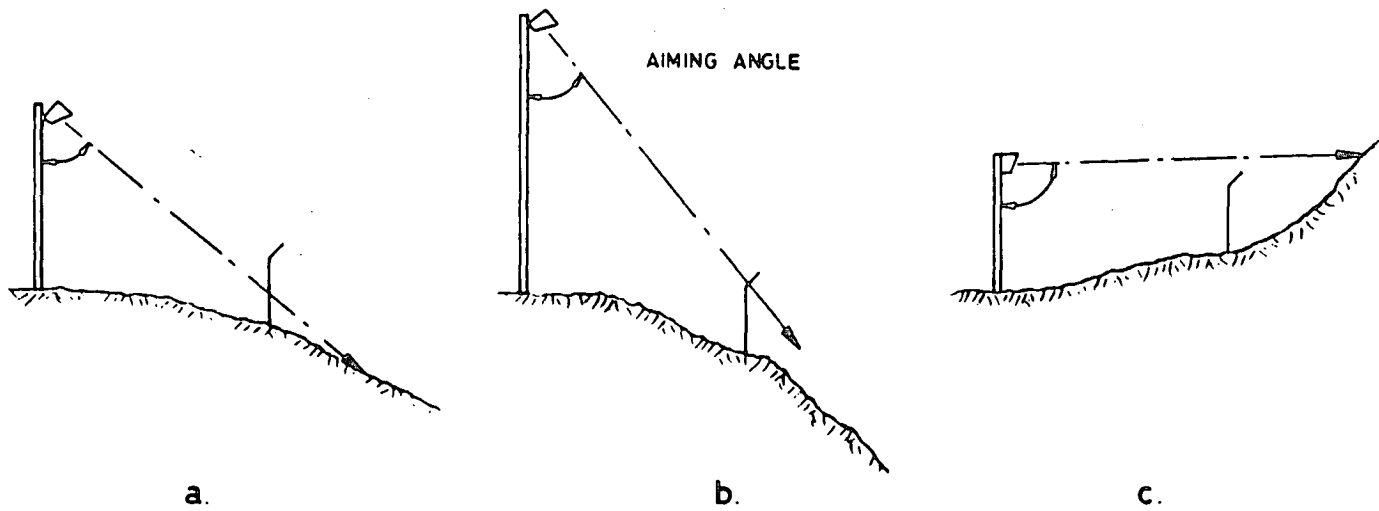


FIG. 2

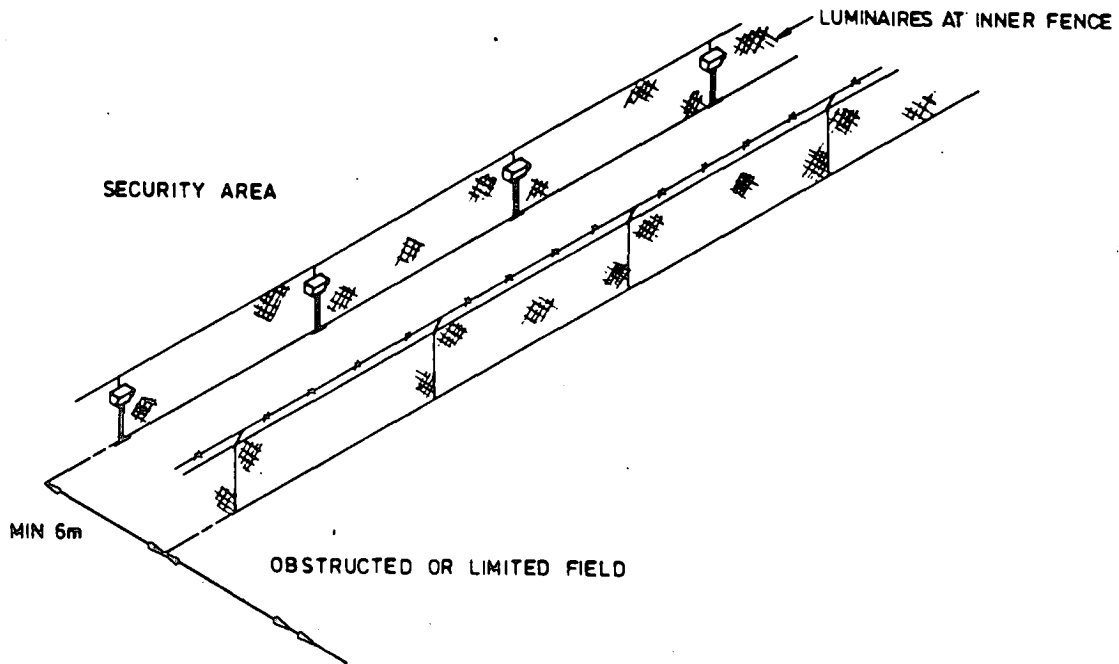


FIG 3a

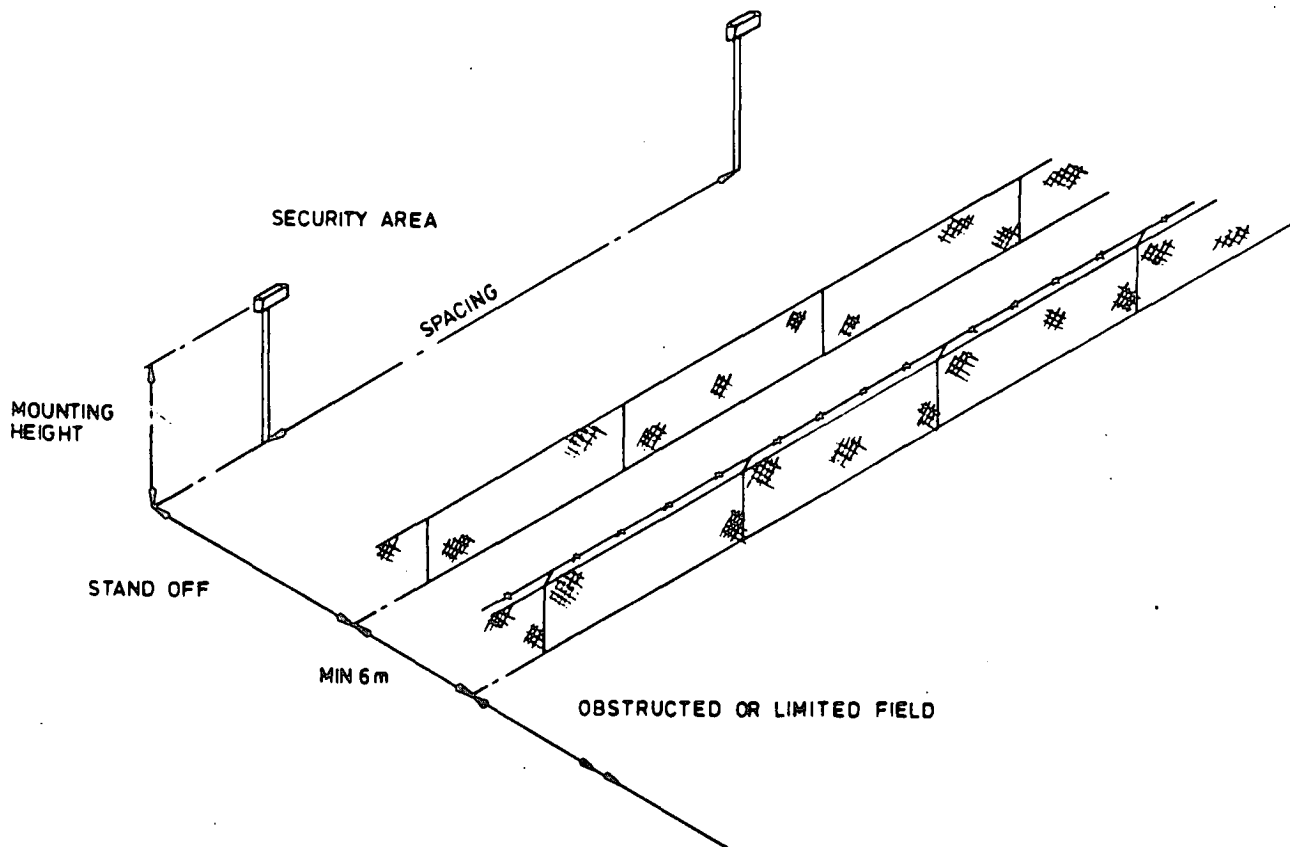


FIG. 3b



FIG 4a

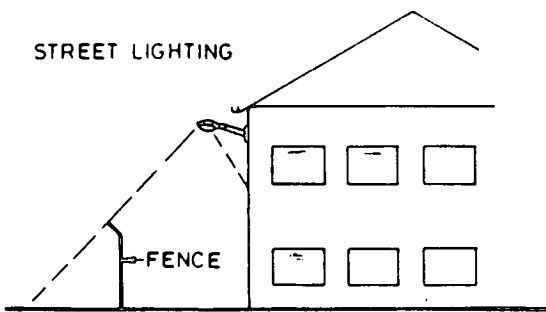


FIG 4b

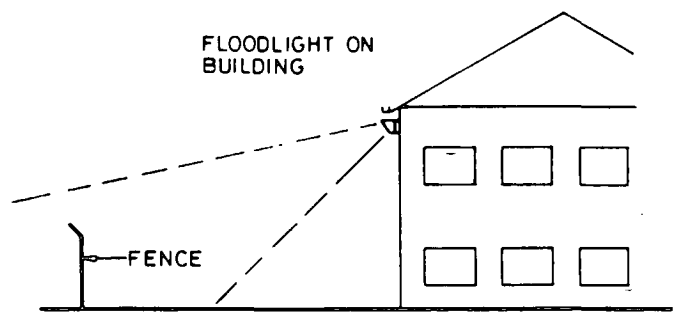


FIG 4c

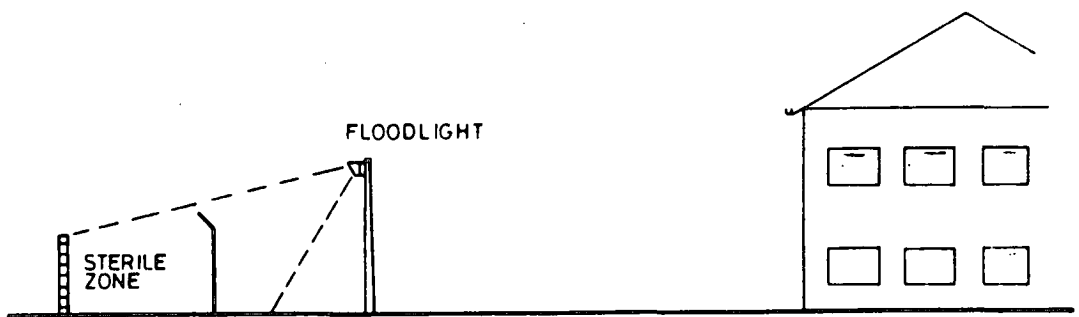


FIG 5

## 5.2 CHECKPOINT LIGHTING

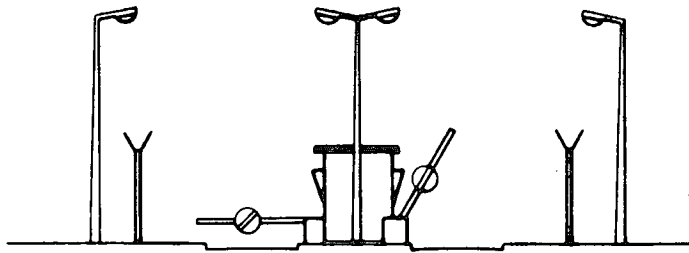
The illumination of entry/exit areas, (checkpoints), should be significantly higher than that of the adjoining area or perimeter fence and designed to allow easy identification of persons in vehicles, or on foot and comprehensive checking of vehicles, goods and documents.

The lighting should be arranged on both sides of the entrance, to ensure adequate cover all around the vehicle. The use of streetlighting luminaires is recommended to avoid glare causing a hazard to drivers entering or leaving the premises, or to security personnel in the execution of their duties (Fig. 6a and 6b, pages 15 and 16).

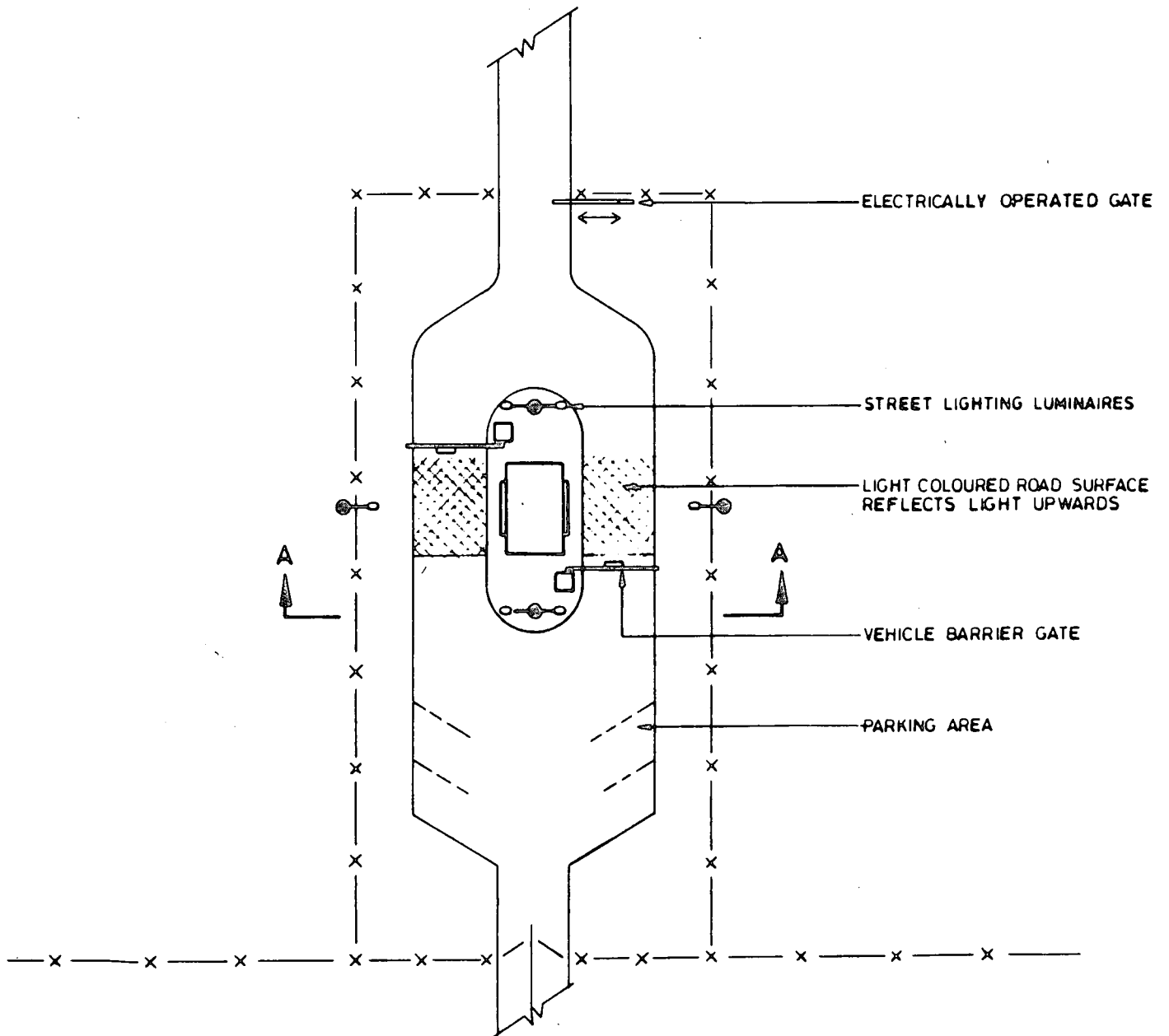
Vandalproof bulkhead or fluorescent luminaires mounted above the gatehouse window, will enable guards to see into the driver's cab. Incandescent spotlights, while causing some glare, are useful for this purpose when the gatehouse is set back some distance from the roadway. By coating the road surface with a non-slip white paint, light is reflected upwards and facilitates inspection of the underside of vehicles.

The gatehouse (Fig. 7 page 17), should be designed to offer protection and concealment to the guards. The interior paint finish should be in a dark colour and the lighting of the work surfaces well shielded. One way mirror type glass may be used to enhance the concealment of the occupants of the gatehouse. Lighting is important where this type of glass is used and it is essential that the lighting level inside the gatehouse is lower than that on the outside. The glass should be sloped away from the viewing position, about seven degrees to the vertical is adequate, to prevent reflections of light coloured objects obstructing the guards view of the outside. It is useful to have the lighting above the working surface on a dimming device within easy reach of the guard. For this reason incandescent lighting is preferred.

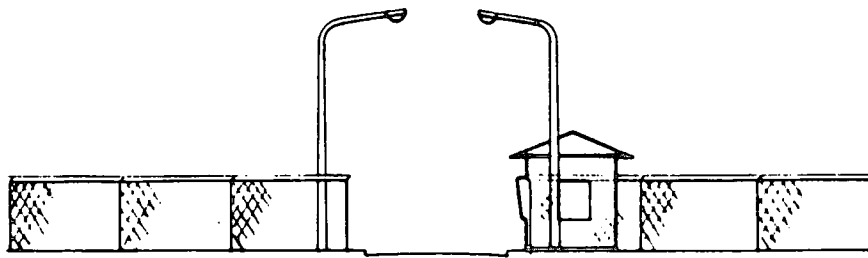
In many large business organizations such as produce markets,



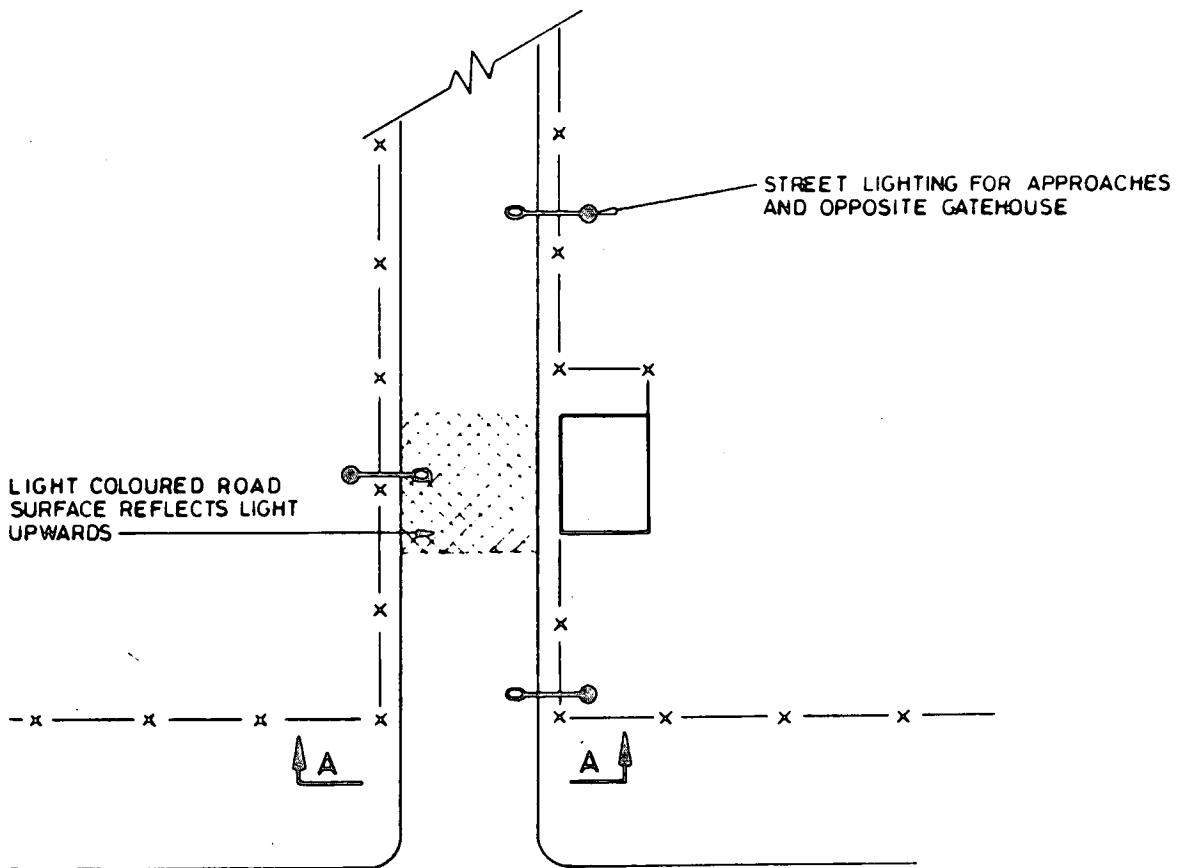
SECTION A-A



TYPICAL CHECKPOINT LIGHTING  
DOUBLE LANE FIG. 6a



SECTION A-A



TYPICAL CHECKPOINT LIGHTING

FIG 6b

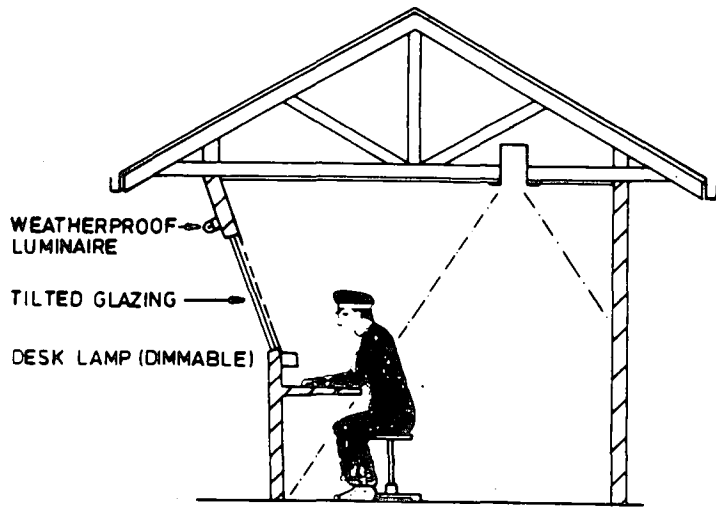


FIG 7

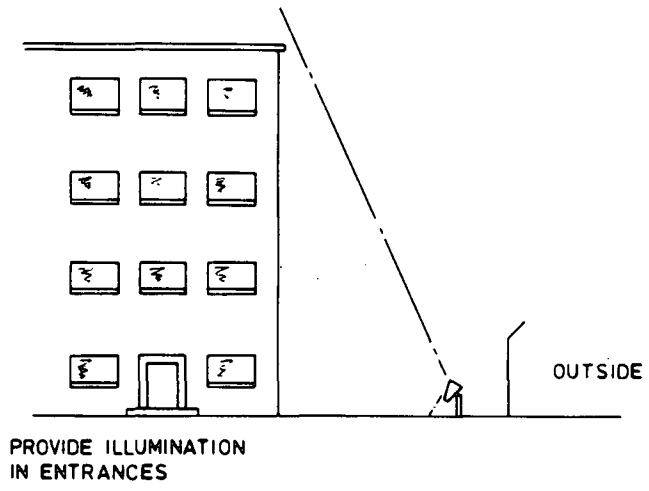


FIG 8a

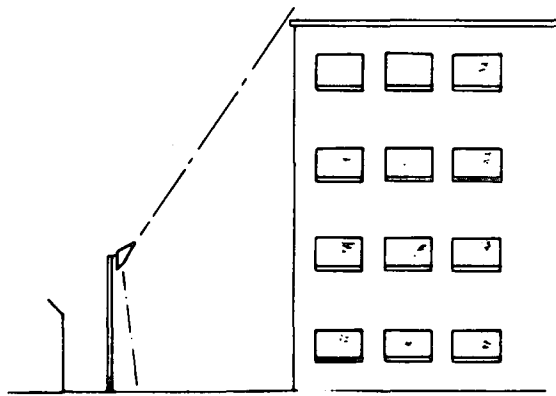
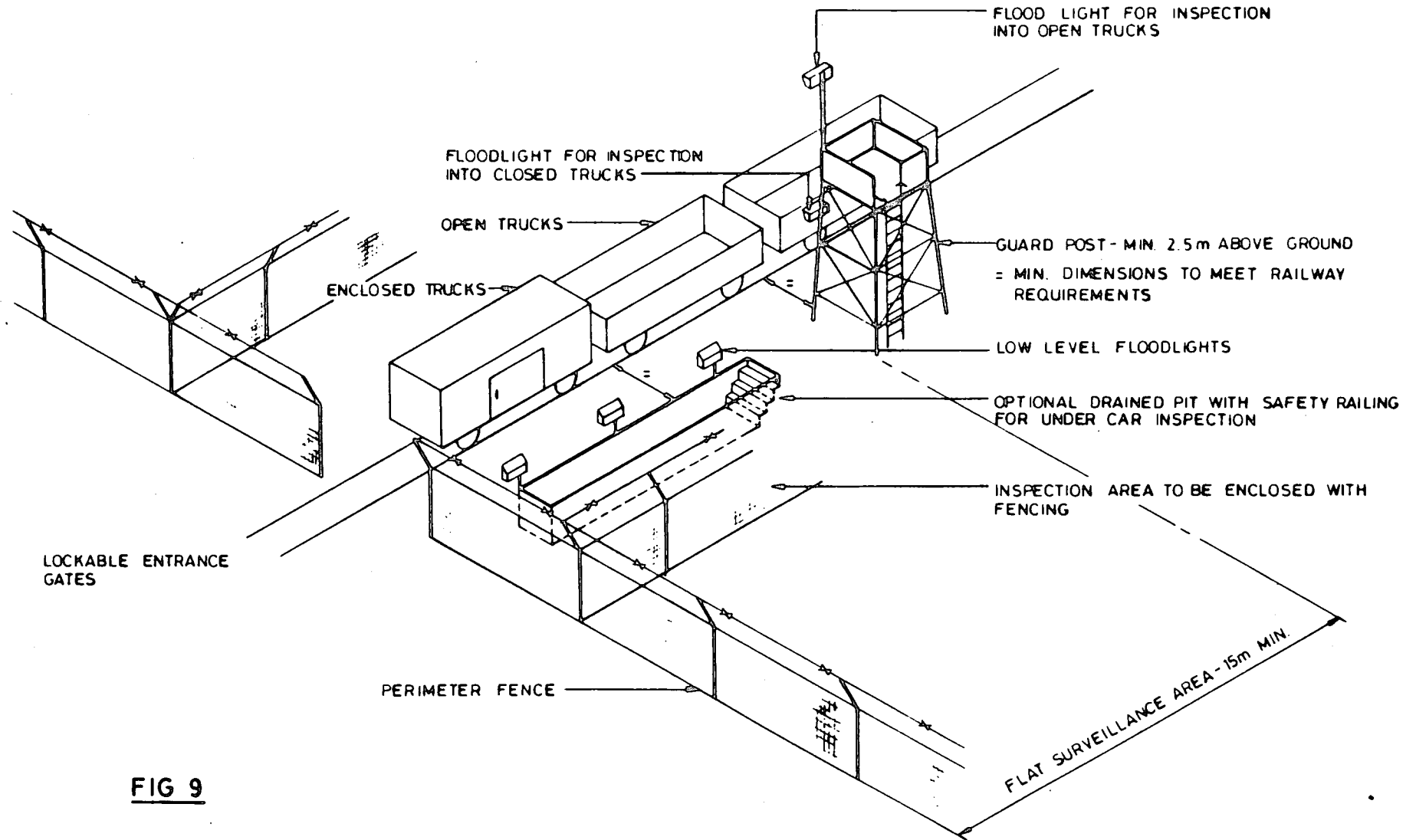


FIG 8b

# TYPICAL RAILWAY GOODS ENTRANCE LIGHTING



**FIG 9**

electricity power stations etc., goods are frequently moved into rail sidings or marshalling yards on site during the night. It is important that special security lighting be provided at the entrance points to ensure that unauthorised people do not enter the premises in or under trucks.

A typical railway checkpoint is shown in (Fig. 9 page 18). Where it is not possible to stop the train at the checkpoint it may be necessary for guards to escort the train to the stopping area. It is then important that the total length of the track be illuminated on both sides of the train in order that the escorting guards can check that no person alights from a truck in this area.

The lighting of railway checkpoint areas is normally only required when inspections are carried out and for this reason local switching should be provided. At all other times the normal security lighting should operate.

### 5.3 GENERAL AREA LIGHTING

Perimeter lighting will be more effective if the interior of a site is in darkness, or is provided with a low level of lighting. However, a perimeter lighting installation may need to be supplemented by general area lighting within the site, where a large complex layout can offer concealment to an intruder who has breached the perimeter defences, or night work is carried out. The National Keypoints organization recommends that the interior of certain sites, eg. fuel storage depots, explosive magazines, etc, be kept in darkness to offer less of a target in a terrorist attack.

If area lighting is required for night work, or circumstances indicate that more benefit will be derived from lighting the area than by concealment of the guards at the perimeter, then general area lighting only need be provided.

The illumination of outdoor areas such as stores, parking bays, unused open spaces, etc., for security purposes, can be achieved in a number of ways, viz :

- By mounting luminaires on buildings which are of suitable height and conveniently located for the purpose.

- By the use of low mounted systems using columns up to approximately 12 metres in height.
- By the use of high masts or towers for the lighting of larger areas.

Luminaire types recommended for use, are the streetlighting luminaire and the floodlighting luminaire. The choice of luminaire will depend on the shape and size of the area to be covered, the practical mounting height and the glare restriction imposed.

Care must be taken in the design of outdoor area lighting for security purposes, to ensure an acceptable level of uniformity and the avoidance of dark shadows, which can occur in situations where light comes from one direction only. When light comes from several directions, shadows are less dense and visibility is improved. It is for this reason that multi-directional lighting should be employed where possible.

It is generally more economical to use a smaller number of lamps with a high lumen output than a larger number of lamps with a low lumen output and to mount several luminaires on a single support, rather than to mount them individually. However care must be taken in the design of such an installation as the area of darkness would be greater in the event of an electrical fault on a column or tower.

In general, the lower the mounting height of the luminaires, the greater their vulnerability to damage and the greater degree of glare they will cause. The use of greater mounting heights enables large areas to be efficiently and uniformly illuminated from relatively few positions and luminaires are less vulnerable to deliberate damage in sensitive locations such as hostels and compounds.

#### 5.4 FLOODLIGHTING OF BUILDINGS AND STRUCTURES

Floodlighting of the vertical surfaces of buildings, structures, storage tanks, etc., creates a light background against which an intruder can be readily seen by guards, policemen or passers-by. Building floodlighting used for security reasons can also serve the purpose of advertising, prestige and publicity.

Floodlighting luminaires are usually ground mounted (Fig. 8a page 17), or column mounted (Fig. 8b page 17). For security purposes column mounted luminaires are preferred, as ground mounted luminaires are prone to vandalism and the possibility of the light from the luminaires being obscured by the growth of vegetation or other obstructions.

The types of floodlighting luminaires and light sources used, will depend on the shape, size and texture of the building or structure to be illuminated and the setback distance of the luminaire from the building or structure. Normally for security purposes, the setback should be as great as available space permits to give the most efficient and economical solution. In certain cases, especially where decorative floodlighting is concerned, a lesser setback is desirable.

The design of the floodlighting should ensure that the main outlines of buildings are visible and that shadows around doors and windows are avoided.

This type of lighting is not recommended in situations where a terrorist attack using weaponry is a consideration, as a well illuminated vertical surface of a building or structure, provides easy orientation for an attacker. However if used in this type of situation, provision should be made for extinguishing the lighting in the event of an attack.

#### 5.5 TOPPING UP LIGHTING

Despite the provision of the aforementioned forms of security lighting, there may be certain areas which are shadowed by obstructions and require additional lighting to ensure that an intruder is not afforded concealment. This topping up lighting of dark areas should also cover emergency exits, fire escapes and routes used by patrolling guards.

Topping up lighting can be achieved by the use of local or remotely mounted luminaires. Bulkhead or wellglass type luminaires are most commonly used for this purpose. Floodlighting luminaires can be used, to direct light from a distance into plant, restricted areas or hazardous locations.

Topping up luminaires can be installed to place additional light at particularly dangerous points that security guards have to pass on patrol and they may well be connected automatically to an auxiliary power supply in the event of mains failure.

## 6.0 LIGHTING DESIGN AND CALCULATIONS

### 6.1 LIGHTING DESIGN.

Except in the simplest situation, a fairly wide range of factors has to be considered in security lighting design. To assist in this process, a flowchart (Fig. 10 page 24) has been provided which includes most of these factors and puts them into a logical sequence, thus simplifying the design process.

From Section 3.0, the class of risk can be determined and by reference to Section 5.0 the system of lighting chosen, ie. perimeter, area, checkpoint, or floodlighting of buildings. Section 5.0 also assists in determining the type of luminaire that should be used.

Having selected the light source and luminaire combination from Section 7.0, the mounting height from Table 1 page 23, and the illuminance from Table 2 page 23, the spacing between luminaires for perimeter lighting or the number of luminaires in the case of area lighting or building floodlighting, can be calculated.

Simplified methods of calculation are shown in Section 6.2. If a greater degree of accuracy is required, further calculation methods which are included in the Appendix should be used. Such calculations may necessitate, or be facilitated by, the use of a computer.

TABLE 1 : RECOMMENDED MOUNTING HEIGHTS (AREA AND PERIMETER LIGHTING)

Lumen Output per Lamp (refer Table 6 pages 39 to 41)	Mounting Height (Metres)
Less than 4 000	3
4 500 to 15 000	3 to 6
10 000 to 25 000	5 to 8
20 000 to 33 000	7 to 9
40 000 +	10 and above

N.B. Avoid using the top end of the lumen output range with the lowest mounting height. In cases where perimeter lighting with glare is desirable, the mounting height could be reduced.

TABLE 2 : RECOMMENDED ILLUMINANCES

2a : Area Lighting And Perimeter Lighting For Both Horizontal And Vertical Planes In Lux.

Risk Class	Moderate	High	Extreme
Average Illuminance	2,5	5	10
Minimum Illuminance	0,5	1	2
Uniformity *	0,2	0,2	0,2

\* Minimum to Average

2b : Building Floodlighting In The Vertical Plane In Lux.

Finish of Building Surface	Light	Medium	Dark
Average Illuminance	10	20	50
Minimum Illuminance	2	4	10
Uniformity *	0,2	0,2	0,2

\* Minimum to Average

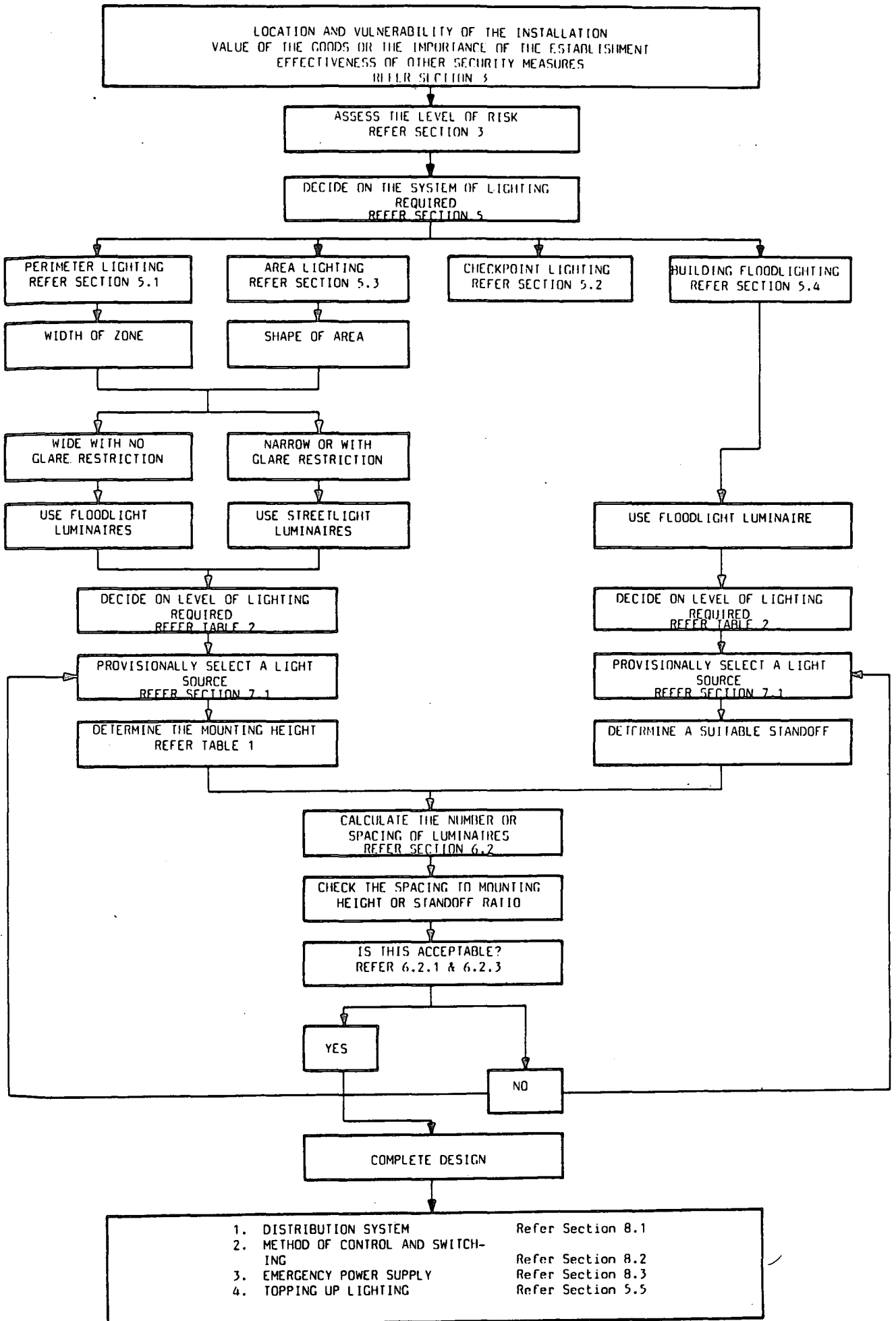


FIG. 10

NB : If the floodlighting is required for aesthetic purposes these values should be increased.

2c : Checkpoint Lighting On The Horizontal Plane In Lux.

Exterior	50 - 100
Gatehouse (interior general) (excluding desk lamp)	20 - 50

TABLE 3 : DETERIORATION FACTORS

3a : Lamp Lumen Deterioration Factors (LLD).

High Pressure Mercury Vapour and Metal Halide lamps	0.8
High Pressure and Low Pressure Sodium Vapour lamps	0.9
Tungsten Halogen lamps	1.0

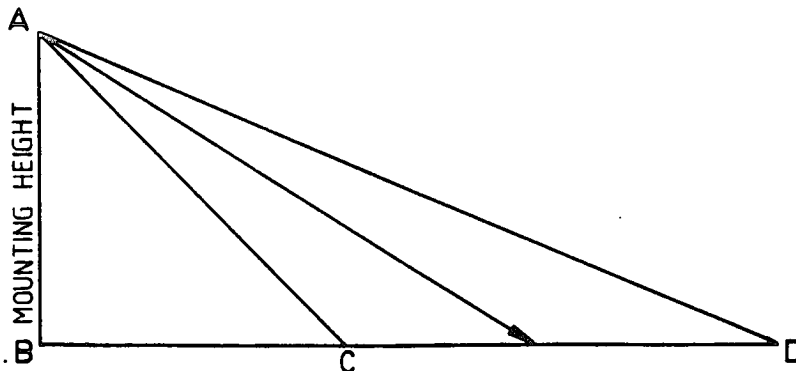
3b : Dirt Factor (D.F.)

Open Luminaires	0,75
Enclosed Luminaires	0,85

6.2 CALCULATIONS

6.2.1 Perimeter Fence Lighting (Refer Section 5.1).

Horizontal Illuminance :



$$S = \frac{\phi \text{ Lamp} \times UF \times LLD \times DF}{Eh \times CD}$$

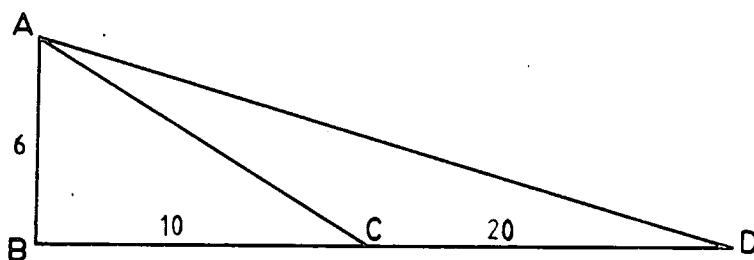


- (a) 5 x the mounting height AB for "cut-off" luminaires and  
 (b) 6 x the mounting height AB for "semi-cut-off" luminaires

The above methods of calculation will give an approximate design for the illumination of perimeters. If however a more precise design is necessary it is recommended that one of the methods in the Appendix is used. In extreme risk areas consideration should be given to reducing the spacing between columns to ensure that a completely dark area would not occur after failure of a single lamp.

#### EXAMPLE 1

To illuminate a perimeter with the columns set back 10 metres from the fence and the illuminated zone to be 20 metres wide. It is a high risk area.



Proposed Luminaire - Floodlight Type G, Table 7, Page 43

Required illuminance	= 5 lux (Table 2a page 23)
Lamp type	= 150 W. high pressure sodium
Lamp flux	= 15,000 lumens (Table 4 page 36)
Column height	= 6 metres (Table 1 page 23)
LLD	= 0,9 (Table 3a page 25)
DF	= 0,85 (Table 3b page 25)
Horizontal utilization factor (UF)	= 0,41 (Table 4 page 36)
Vertical utilization factor (UF)	= 0,30 (Table 4 page 36)

$$S = \frac{\phi \text{ Lamp} \times \text{UF} \times \text{LLD} \times \text{DF}}{\text{Eh} \times \text{CD}}$$

$$S = \frac{15,000 \times 0,41 \times 0,9 \times 0,85}{5 \times 20} = 47 \text{ metres.}$$

Check the spacing to mounting height ratio

$$S/AB = 47/6 = 7,83 < 8 \text{ acceptable uniformity.}$$

Check the spacing to setback distance.

$$S/BC = 47/10 = 4,7 < 5 \text{ acceptable uniformity.}$$

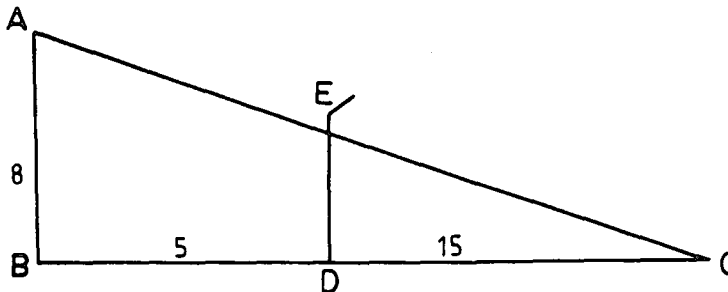
Check the vertical illuminance.

$$E_v = \frac{15,000 \times 0,30 \times 0,9 \times 0,85}{47 \times 2} = 36,6 \text{ lux} > 5 \text{ lux acceptable.}$$

Using a 150 W high pressure sodium floodlighting luminaire on 6 metre high columns, spaced 47 metres apart, the uniformity requirements are acceptable and the vertical illuminance is well above the minimum requirement as will always be the case when using floodlighting luminaires at low mounting heights.

#### EXAMPLE 2

To illuminate a perimeter roadway 5 metres wide inside a perimeter fence and a zone 15 metres beyond the fence. As the columns cannot be set back, streetlighting luminaires must be used. It is an extreme risk area .



Proposed Luminaire - Streetlight Type I, Table 7 page 43 with "cut-off" distribution

Required horizontal illuminance	= 10 lux (Table 2a page 23)
Lamp type	= 250 W high pressure sodium
Lamp flux	= 25,500 lumens (Table 4 page 37)
Column height	= 8 metres (Table 1 page 23)
Horizontal utilization factor UF (in zone BC)	= 0,43 (Table 4, Page 37)
Vertical utilization factor UF (on fence DE)	= 0,06. (Table 4, page 37)
LLD	= 0,9 (Table 3a, page 25)
DF	= 0,85 (Table 3b, page 25)

$$S = \frac{\phi \text{ Lamp} \times UF \times LLD \times DF}{E_h \times BC}$$

$$= \frac{25,500 \times 0,43 \times 0,9 \times 0,85}{10 \times 20} = 42 \text{ metres}$$

Check the spacing to mounting height ratio

$$S/AB = 42/8 = 5,25 > 5 \text{ unacceptable uniformity. Reduce } S \text{ to } 40 \text{ metres}$$

$$E_v \text{ on fence} = \frac{25,500 \times 0,06 \times 0,9 \times 0,85}{2 \times 40} = 14,6 \text{ lux} > 10 \text{ lux acceptable}$$

### 6.2.2 General Area Lighting (Refer Section 5.3)

The following method of calculating the number of luminaires required to provide a certain illuminance on a given area will be reasonably accurate.

$$N = \frac{E_h \times L \times W}{\phi \times UF \times LLD \times DF}$$

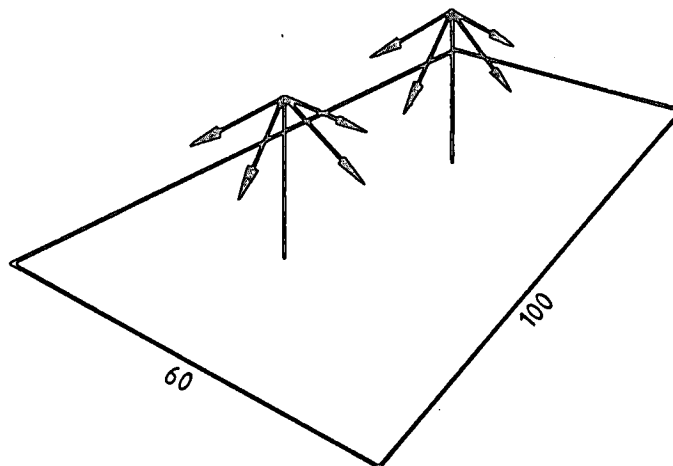
- N = Number of luminaires  
 Eh = Required average horizontal illuminance (lux)  
 L = Length of area in metres  
 W = Width of area in metres  
 UF = Utilization factor (Refer Table 4, pages 36,37)  
 LLD = Lamp lumen deterioration factor (Refer Table 3a, page 25)  
 DF = Dirt factor (Refer Table 3b, page 25)  
 Ø = Luminous flux of lamp in lumens (Refer Table 6, pages 39 to 41)

NB. To achieve acceptable uniformity it is recommended that the ratio of the spacing between columns to the mounting height should not exceed :

- (a) 3,5 when "cut-off" luminaires are used.  
 (b) 5 when "semi-cut-off" luminaires are used.  
 (c) 6 when floodlighting luminaires are used.

### EXAMPLE 3

To illuminate an area 100 metres long by 60 metres wide. It is an extreme risk installation without any glare restriction.



Proposed Luminaire -  
 Required Illuminance  
 Length of Area  
 Width of area  
 Lamp type

Floodlight Type G, Table 7, page 43  
 = 10 lux (Table 2a, page 23)  
 = 100 metres  
 = 60 metres  
 = 250 W high pressure sodium

Lamp flux	= 25 500 lumens (Table 4, page 36)
Utilization Factor	= 0,45 (Table 4, page 36)
LLD	= 0,9 (Table 3a, page 25)
DF	= 0,85 (Table 3b, page 25)

$$N = \frac{E_h \times L \times W}{\phi \times UF \times LLD \times DF}$$

$$N = \frac{10 \times 100 \times 60}{25\,500 \times 0,45 \times 0,9 \times 0,85} = 6,28 \text{ say } 8 \text{ luminaires}$$

If two 15 metre masts were used, each supporting 4 floodlights, the spacing would be  $100/2 = 50$  metres along the length of the area which is 3,3 times the mounting height. This layout would be acceptable.

### 6.2.3 Building Floodlighting (Refer Section 5.4)

The facade of a building can be considered as a vertical area and treated in the same way as a normal area i.e. if we have a building W metres wide and H metres high, the number of floodlights to illuminate the facade can be calculated as follows :

$$N = \frac{E_v \times W \times H}{\phi \times UF \times LLD \times DF}$$

$E_v$  = Required average vertical illuminance (lux)

$\phi$  = Luminous flux of lamp in lumens.

UF = Utilization factor (Refer Table 4, page 36 )

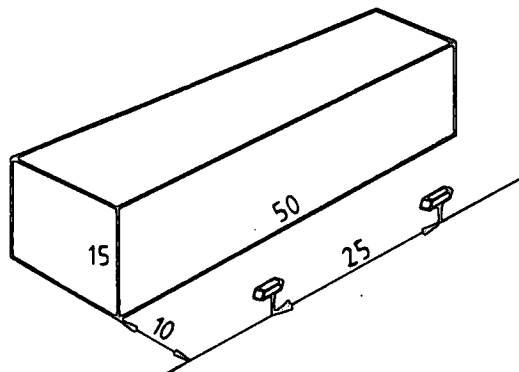
LLD = Lamp lumen deterioration factor (Refer Table 3a, page 25)

DF = Dirt factor (Refer Table 3b, page 25)

NB : To achieve a reasonable uniformity, the spacing between luminaires having a wide horizontal beam should not exceed 3 x the setback i.e. the distance from the facade to the floodlight.

## EXAMPLE 4

To illuminate the light coloured facade of a building 50 metres wide and 15 metres high for security reasons in an area with a high risk factor. The maximum distance that the floodlights can be set back is 10 metres.



Proposed Luminaire - Floodlight Type G, Table 7, page 43

The number of floodlights required can be determined as follows :

Required average vertical illuminance	= 10 lux (Table 2a, page 23)
Width of area	= 50 metres
Height of area	= 15 metres
Lamp type	= 150 W high pressure sodium
Lamp flux	= 15 000 lumens (Table 4, page 36)
Utilization factor	= 0,45 (Table 4, page 36)
LLD	= 0,9 (Table 3a, page 25)
DF	= 0,85 (Table 3b, page 25)

$$N = \frac{E_v \times W \times H}{\phi \times UF \times LLD \times DF}$$

$$N = \frac{10 \times 50 \times 15}{15,000 \times 0,45 \times 0,9 \times 0,85} = 1,45 \text{ say } 2 \text{ floodlights}$$

This would result in a spacing between floodlights of  $50/2 = 25$  metres, which is 2,5 times the setback distance, thereby ensuring an acceptable uniformity for security purposes.

## 7.0 SELECTION OF LAMPS AND LUMINAIRES

### 7.1 LAMPS

The following parameters are normally the most significant in the choice of a lamp for security lighting purposes :

Restrike time - should be short enough to be insignificant for the location and risk involved, or back-up systems must be provided.

Luminous efficacy - should be as high as possible for economy in power consumption and cabling costs.

Life - should be as long as possible for reliability and economy in maintenance costs.

Size - should be small relative to the reflector lens system where good optical control is required, such as in narrow beam floodlights.

Colour - may be significant for aesthetic reasons, detection purposes or for the definition of a specific zone e.g. a checkpoint.

A number of incandescent and discharge lamps satisfying one or more of the above parameters are available for use in security situations and a comparison of their costs, operating conditions and various other properties as well as descriptive sketches are shown in Tables 5 and 6, pages 38 to 41.

High pressure sodium lamp.

These are the most widely used lamps in security lighting installations because of their short restrike period, (when used with an external ignitor), high luminous efficacy, long life and acceptable colour rendering properties for most security applications. In situations where the restrike time (less than one minute), is unacceptable, hot restrike circuits may be used. These are however expensive and back-up systems using incandescent lamps are usually preferred.

#### Low pressure sodium lamp

These lamps have a higher luminous efficacy than high pressure sodium lamps and when used with suitable electronic control gear will restrike immediately with full light output, if briefly extinguished by a power interruption. The lamp is not suitable where good optical control is required because of the large source size. The lower wattages are often used for lighting around the perimeter of buildings, topping up lighting etc. The lamp has poor colour rendering properties and is not suitable for detection of intruders where colour contrast is required to aid visual separation of intruder from background.

#### Tubular fluorescent lamp

Although restrike time is almost instantaneous, these lamps are unsuitable for the majority of exterior applications because of their low power and large physical size. They may however be used for checkpoint, topping up and domestic lighting. In such instances an enclosed weatherproof luminaire is recommended.

#### Incandescent lamp

These lamps give full light output immediately they are switched on, making them ideal for instantaneous area and emergency lighting. They have good colour rendering properties and the tungsten halogen lamp is particularly suitable where good optical control is required. The lamps have a much lower efficacy than discharge lamps and a relatively short life. This makes them uneconomical for continuous burning, from a power consumption and maintenance point of view.

#### High pressure mercury vapour lamp

These lamps have reasonable colour rendering properties but are not normally recommended for security purposes because of their long restrike period after a power interruption.

### Metal halide lamp

These lamps have a higher luminous efficacy than high pressure mercury vapour lamps and very good colour rendering properties. The lamp is more expensive and has the same long restrike period as the high pressure mercury vapour lamp and is thus not normally recommended for security applications.

### Mercury tungsten (also known as mercury blended or self-ballasted) lamp

These lamps are not normally recommended for security purposes. Although the lamp does not require external control gear and has a reasonable life, it suffers the disadvantages of low efficacy and a long restrike period.

## 7.2 LUMINAIRES

Luminaires used for security lighting purposes should be designed and constructed so as to be capable of providing the service for which they are intended without undue deterioration in their safety, performance and appearance during normal life and under the conditions prevailing on site. Luminaires of corrosion resistant material or with corrosion resistant finishes should be used in coastal or other corrosive environments.

In certain areas, (refer to SABS 0108 - Classification of Hazardous Locations), special luminaires of increased safety, dust ignition proof, non-sparking design, etc., may be required.

Streetlighting and floodlighting luminaires should comply with the requirements of SABS 1277 and 1279, respectively.

Luminaires should be of compact design so as to present the smallest possible target to missiles. Lamp compartment covers, of vandal resistant plastic material, (e.g. polycarbonate, ultra-high impact acrylic), are preferred to glass at low mounting heights if the design of the luminaire is such that the plastic cover is not affected by heat from the lamp. Plastic covers should be suitably resistant to the effects of ultra-violet radiation.

TABLE 4: UTILIZATION FACTORS.

PERIMETER FENCE LIGHTING									BUILDING / AREA FLOODLIGHTING
Type of luminaire	Light distribution type*	Lamp Flux lumens	Mounting height metres	Distance to zone metres	Zone width metres	Horizontal utilisation factor UF	Plane height metres	Vertical utilisation factor UF	Vertical utilisation factor for building floodlighting Horizontal utilisation factor for Area Floodlighting
500w	Medium	9500	4	10	20	0.37	2	0.25	
Tungsten	Vertical		4	10	30	0.39	2	0.31	0,4
Halogen	beam		6	5	10	0.41	2	0.34	
floodlight	H5V3		6	10	20	0.42	2	0.28	
1500w	Medium	33000	6	10	20	0.56	2	0.38	
Tungsten	Vertical		6	20	20	0.38	2	0.24	
Halogen	beam		6	20	30	0.39	2	0.24	0,4
floodlight	H6V4		6	20	40	0.40	2	0.24	
			8	20	20	0.39	2	0.24	
			8	20	30	0.43	2	0.24	
			8	20	40	0.44	2	0.24	
150w	Narrow	15000	6	5	10	0.40	2	0.34	
High pressure	Vertical		6	5	20	0.48	2	0.34	0,45
sodium vapour	beam		6	10	20	0.41	2	0.30	
floodlight	H5V2		6	10	30	0.43	2	0.30	
250w	Narrow	25500	6	10	20	0.41	2	0.30	
High	Vertical		6	10	30	0.43	2	0.30	
Pressure	beam		6	20	20	0.30	2	0.22	
sodium	H5V2		6	20	30	0.32	2	0.22	
vapour			6	20	40	0.33	2	0.22	
flood-			8	10	20	0.44	2	0.29	
light			8	10	30	0.46	2	0.29	
			8	10	40	0.47	2	0.29	0,45
			8	20	20	0.32	2	0.22	
			8	20	30	0.35	2	0.22	
			8	20	40	0.38	2	0.22	
400w	Narrow	48000	8	20	20	0.25	2	0.14	
High	Vertical		8	20	30	0.30	2	0.14	
pressure	beam		8	20	40	0.31	2	0.14	0,45
sodium	H5V3		8	20	60	0.33	2	0.14	
vapour			10	20	40	0.34	2	0.14	
floodlight			10	20	60	0.36	2	0.14	

TABLE 4 cont.

PERIMETER FENCE LIGHTING									AREA FLOODLIGHTING
Type of luminaire	Light distri- bution SABS type *	Lamp Flux lumens	Mounting height metres	Distance to zone metres	Zone width metres	Hori- zontal utili- sation factor UF	Plane height metres	Verti- cal utili- sation factor UF	Horizontal utilisation factor
70w High pressure sodium vapour street light	Semi cut-off	6000	4 4 4 6 6 6	0 0 0 0 5 5	6 8 10 10 10 20	0.32 0.35 0.36 0.33 0.11 0.12	2 2 2 2 2 2	N/A N/A N/A N/A 0.06 0.06	0,4
150w High pressure sodium vapour streetlight	Semi cut-off	15000	6 6 6 6	0 0 5 5	10 20 10 20	0.33 0.37 0.07 0.11	2 2 2 2	N/A N/A 0.04 0.04	0,4
250w High pressure sodium streetlight	Semi cut-off	25500	8 8 10 10 10	0 5 0 5 10	20 20 20 20 20	0.50 0.22 0.48 0.24 0.08	2 2 2 2 2	N/A 0.07 N/A 0.06 0.05	0,4
250w High pressure sodium vapour streetlight	Cut-off	25500	8 8 10 10 10	0 5 0 5 10	20 20 20 20 20	0.43 0.17 0.42 0.21 0.09	2 2 2 2 2	N/A 0.06 N/A 0.05 0.04	0,4
400w High pressure sodium vapour streetlight	Semi cut-off	48000	10 10 10 12 12 12	0 5 10 0 5 10	20 20 20 30 30 30	0.48 0.24 0.08 0.51 0.31 0.16	2 2 2 2 2 2	N/A 0.06 0.05 N/A 0.07 0.11	0,4
400w High pressure sodium vapour streetlight	Cut-off	48000	10 10 10 12 12 12	0 5 10 10 5 10	20 20 20 30 30 30	0.42 0.21 0.09 0.43 0.24 0.13	2 2 2 2 2 2	N/A 0.04 0.03 N/A 0.03 0.03	0,4

\* REFER SABS 1277 STREETLIGHTING LUMINAIRE  
REFER SABS 1279 FLOODLIGHTING LUMINAIRE

Table 5: Survey of lamp types for exterior usage.

The information in this table should only be seen as an approximate guide. Further information should be obtained from manufacturers.

Lamp type	Lamp cost	Luminaire cost	Cabling cost	Efficacy <sup>①</sup> lumens/ watt	Practical lamp life (hours)	Lamp run-up time <sup>②</sup> (mins)	Hot re-strike time (mins)	Control gear		Approximate ratio mains starting current/ running current	Colour Appearance
								ballast	ignitor/ starter		
Incandescent :											
General lighting service	low	low	high	8-20	1 000	instant	instant	no	no	1	white
Tungsten halogen	low	low	high	20-22	2 000	instant	instant	no	no	1	white
Low Pressure Discharge :											
Tubular fluorescent	low	medium	low	18-60	9 000	instant	instant	yes	some circuits	1	white
Low pressure sodium	high	high	low	65-120	6 000	15-20	instant <sup>④</sup>	yes	some circuits	1	orange
High Pressure Discharge :											
High pressure sodium	high	very high	low	82-106	12 000	3	1	yes	yes <sup>③</sup>	1,5	yellow
High pressure mercury	medium	very high	medium	38-59	12 000	4	7-14	yes	no	1,8	blue/white
Metal halide	very high	very high	medium	68-88	6 000	3	7-14	yes	yes <sup>③</sup>	1,8	white
Mercury tungsten	medium	medium	high	16-23	6 000	instant to 5	7-14	no	no	1,4	blue/white

① Including ballast losses and based on lamp lumen output after 100 burning hours : See table 6 for graphic appearance.

② To 80 % lumen output.

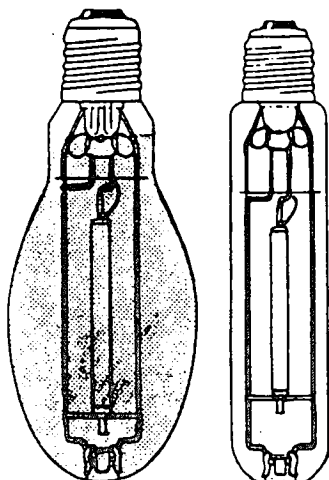
③ Recommended that ignitors be compatible with any make of ballast and/or lamp.

④ When using ignitor circuits.

TABLE 6:

DISCHARGE LAMPS.

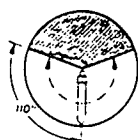
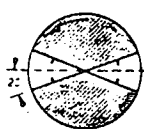
HPS

HIGH PRESSURE SODIUMUNIVERSAL  
BURNING

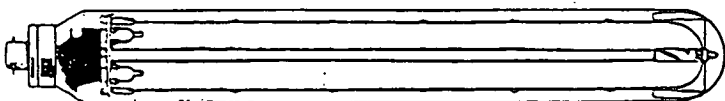
<u>Lamp Wattage</u>	<u>Power Input (W)</u>	<u>Light Output (lm)</u>
70	85	6000
150	170	15000
250	280	25500
400	440	48000

(Light outputs for clear lamps)

LPS

LOW PRESSURE SODIUM18W  
35W  
55W90W  
135W

BURNING POSITIONS



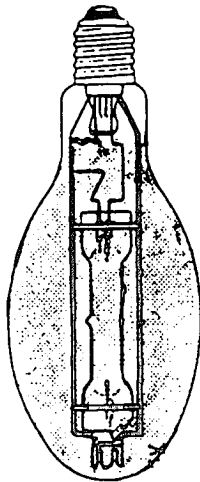
<u>Lamp Wattage</u>	<u>Power Input (W)</u>	<u>Light Output (lm)</u>
18	27	1800
35	52	4600
55	85	7700
90	127	12700
135	192	22000

TUBULAR FLUORESCENTUNIVERSAL  
BURNING

<u>Lamp Wattage</u>	<u>Power Input (W)</u>	<u>Light Output (lm)</u>
20	34	1100
40	50	3000
65	77	5100

HPMV

HIGH PRESSURE MERCURY VAPOUR



<u>Lamp Wattage</u>	<u>Power Input (W)</u>	<u>Light Output (lm)</u>
80	94	3800
125	140	6300
250	275	13500
400	430	23000
1000	1055	55000

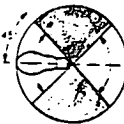
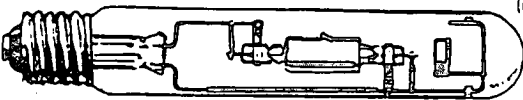
MH

METAL HALIDE

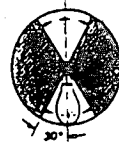
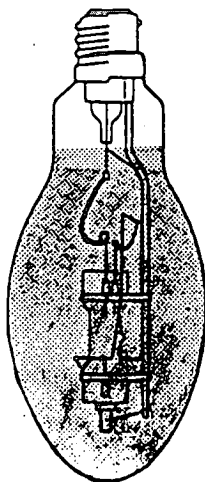


BURNING POSITIONS (depending on type)

<u>Lamp Wattage</u>	<u>Power Input (W)</u>	<u>Light Output (lm)</u>
250	280	19000
400	440	28000
1000	1050	90000
2000	2150	190000



MERCURY TUNGSTEN



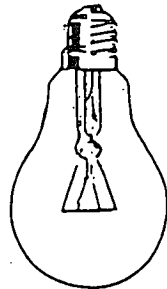
BURNING POSITIONS

<u>Lamp Wattage</u>	<u>Power Input (W)</u>	<u>Light Output (lm)</u>
160	160	3100
250	250	5600
500	500	12500

# INCANDESCENT LAMPS

## GLS

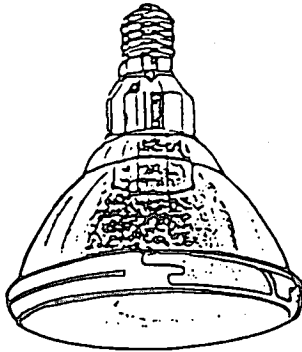
## GENERAL LIGHTING SERVICE



<u>Lamp Wattage</u>	<u>Power Input (W)</u>	<u>Light Output (lm)</u>
40	40	380
60	60	650
100	100	1250
150	150	2090
200	200	2920
300	300	4550
500	500	8220

## PAR 38

## PRESSED ALUMINISED REFLECTOR

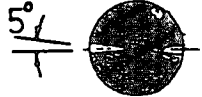


### 150 W

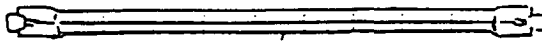
Available in two beam spreads: -  
 Spot - beam angle = 50  
           peak intensity = 6400 cd  
 Flood - beam angle = 66  
           peak intensity = 3700 cd

## TUNGSTEN HALOGEN

double ended



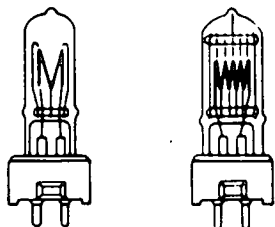
BURNING POSITIONS



double ended linear

<u>Lamp Wattage</u>	<u>Power Input (W)</u>	<u>Light Output (lm)</u>
300	300	6600
500	500	9500
1000	1000	21000
1500	1500	33000

single ended

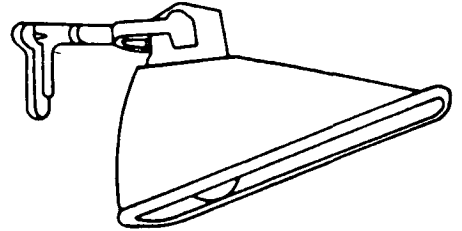


single ended

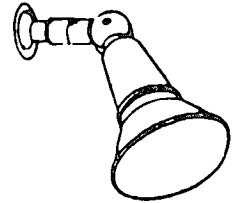
<u>Lamp Wattage</u>	<u>Power Input (W)</u>	<u>Light Output (lm)</u>
300	300	6600
500	500	9500

TABLE 7.

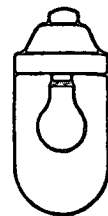
- A. Area floodlight for use with general lighting service (higher wattage) and high pressure discharge lamps.



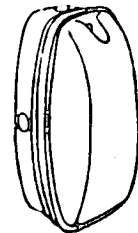
- B. PAR-lamp luminaire with weatherproof lampholder. Used for topping up, checkpoint areas, home lighting, etc.



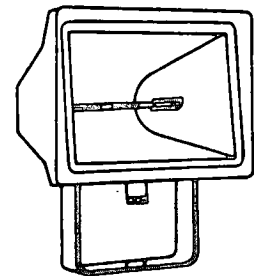
- C. Well-glass luminaire for small general lighting service lamps. Used for topping up, doorways etc.



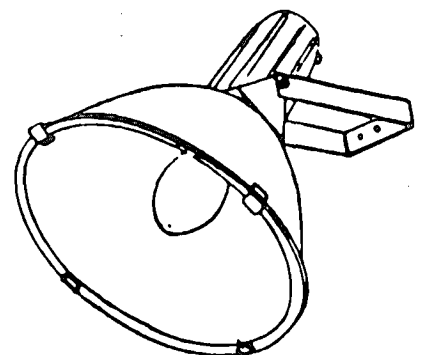
- D. Bulkhead luminaire for small general lighting service lamps. Used for topping up, doorways etc.



- E. Area floodlight with asymmetrical beam distribution, for use with tungsten halogen lamps.

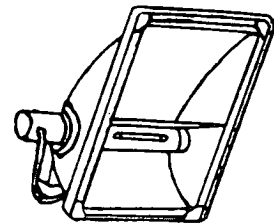


- F. Area floodlight with symmetrical beam distribution, for use with high pressure discharge lamps.



## TABLE 7 cont.

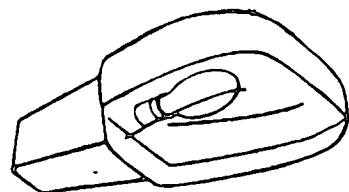
- G. Area floodlight with asymmetrical beam distribution for use with high pressure discharge lamps.



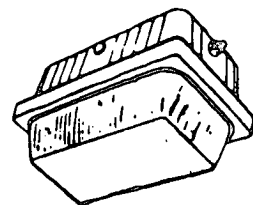
- H. Streetlighting luminaire for use with low pressure sodium lamps.



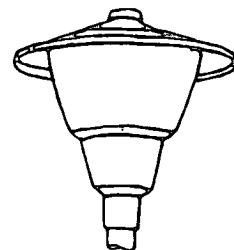
- I. Streetlighting luminaire for use with high pressure discharge lamps.



- J. Bulkhead luminaire for use with low wattage high pressure discharge and low pressure sodium lamps.



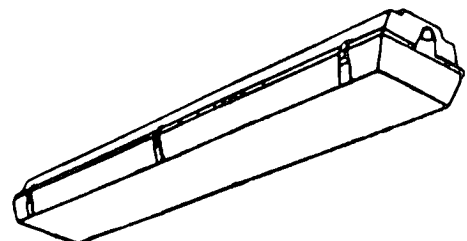
- K. Post-top luminaire for general lighting service or high pressure discharge lamps. Used for area lighting.



- L. Low-level bollard luminaire for general lighting service or small high pressure discharge lamps. Used for area lighting.



- M. Corrosion proof fluorescent luminaire. Used for topping up, checkpoints etc.



Ease of maintenance is an important consideration in the selection of a luminaire and lamp replacement is greatly facilitated if the luminaire is relatively easily opened for this purpose. It should be possible to replace lamps in floodlighting luminaires without affecting aiming angles.

Luminaires of different manufacture may differ in construction and lamps may not be interchangeable. Relamping with lamps of a different type to that specified by the manufacturer of a luminaire may lead to overheating, reduced lamp life, damage to control gear and unacceptable light distribution.

Typical luminaires used in security lighting applications are shown in Table 7, pages 42 and 43

## 8.0 DISTRIBUTION, CONTROL AND EMERGENCY STANDBY

### 8.1 DISTRIBUTION

The use of armoured cables, buried to a minimum depth of 600 mm, is preferred for all installations and recommended in all extreme and high risk security lighting distribution systems.

Cables should be concealed within columns from below ground level. Where surface mounting is unavoidable, (e.g. wooden columns), the cable should be secured to the surface facing away from the security fence and protected against mechanical damage to a minimum height of 1 200 mm above ground level.

Columns should be manufactured of durable material most suited to local climatic conditions and environment. Access openings in the bases of columns should be completely weatherproof and secured by means of tamperproof locking devices.

In extreme risk situations, it is recommended that access openings in the bases of columns be omitted and the power supply to the luminaire effected by the use of underground 'T' boxes with the cable terminating at the top of the column.

Luminaires should be supplied via a three-phase, four wire distribution system and be individually protected at each column by a circuit breaker. Consecutive luminaires should be connected to alternate phases in rotation to prevent the creation of dark areas in the event of a fault on one phase of the system.

As numerous distribution systems are possible, evaluation of the most suitable network should be related to the economics of the scheme and the degree of risk involved.

## 8.2 CONTROL

Automatic switching for the control of security lighting systems is preferred. However secured facilities for manual overriding of automatic switching systems should be provided in control rooms.

Automatic switching is normally effected by the use of time switches, photo-electric control units or intruder sensing devices.

Time switches utilised, should be of the type that are unaffected by power disruptions.

Photo-electric control units must be protected against mechanical and wilful damage and be positioned where they will not receive illumination from artificial lighting systems but be accessible for maintenance purposes. Photo-electric control units should incorporate a time delay facility to obviate hunting of the system.

## 8.3 EMERGENCY STANDBY

The provision of an alternative source of supply in case of mains failure is recommended for extreme risk areas and should be considered for high risk areas.

Standby diesel alternator plant to start automatically on mains failure generally proves the most economical solution. However static battery operated inverter systems can also be considered.

On mains failure a short delay occurs while the diesel alternator set is starting up and in installations where high pressure discharge lamps are used, a further delay occurs because the lamps have to cool down before they will restrike, unless special high voltage starting equipment is installed. The restriking delay varies with the type of lamp (see Section 7.0, Table 5, page 38).

The hiatus caused by restriking time can be partly overcome by the installation of auxiliary tungsten lamps, either incorporated in the luminaire or separately mounted and arranged to be disconnected when the discharge lamps reach a certain luminous output. Cognizance should be taken of the combined starting currents of the two light sources when cable sizes are determined.

At installations where diesel alternators are used and the emergency load consists largely of discharge type light sources, problems could be experienced with high voltages damaging the alternator and specialist advice should be sought.

## 9.0 ECONOMICS

Determination of cost effectiveness of a security lighting scheme and a comparison of different schemes should take into account :

- The initial capital cost of luminaires, lamps, columns, cables, etc. and their installation, as well as switchgear and transformers installed specifically for security lighting and
- Annual operating costs, which include :
  - (i) energy consumption (lamps and control gear).
  - (ii) lamp replacement (material and labour).
  - (iii) maintenance (cleaning, painting, repairs and replacement of parts).

Comparisons should be made between alternative engineering proposals. Inflation accounting and discounted cash flow methods lie outside the scope of this guide but the following simplified method will assist in comparing the annual cost of different schemes.

The comparison is usually between :

- (i) a lower initial cost with relatively high running costs and
- (ii) a higher initial cost with relatively low running costs

The initial capital cost has to be amortized over a period of years "n" with an assumed rate of interest "i" (decimal), which is the worth of the capital if it was invested.

The annual cost of amortizing the capital "C" over "n" years at an interest rate "i", is

$$\frac{C}{\left[ \frac{1 - (1 + i)^{-n}}{i} \right]} \quad \text{--- (a)}$$

or C x factor F where

$$F = \frac{1}{\left[ \frac{1 - (1 + i)^{-n}}{i} \right]} \quad \text{--- (b)}$$

Typical values of F are shown in TABLE 8 below.

n =	10 years	15 years	20 years
i = 5%	0,12(0,15)	0,09(0,12)	0,08 (0,1)
i = 10%	0,15(0,20)	0,12(0,17)	0,11(0,15)
i = 15%	0,17(0,25)	0,15(0,22)	0,14(0,2)

A simplified formula to approximate F is :

$$F = i + \frac{1}{n}$$

Values of F obtained using this formula are shown in brackets in TABLE 8 above.

The annual cost of energy and maintenance i.e. the operating cost, is likely to escalate at a variable rate. The escalation can be ignored but it is probably unrealistic to do so. An approximation to the mean annual operating cost can be obtained by dividing the sum of the initial and final operating cost by two.

The operation cost after "n" years at escalation "e" (decimal) is obtained from :

$$OC_n = OC_1 \cdot (1 + e)^n$$

Where e = escalation rate (decimal)

$OC_1$  = operating cost in year 1

$OC_n$  = operating cost in year n

Typical values of  $(1 + e)^n$  are shown in TABLE 9 below.

n =	10 years	15 years	20 years
e = 5 %	1,63	2,08	2,65
10 %	2,59	4,18	6,73
15 %	4,04	8,14	16,37

The annual amortized cost is therefore :

Annual capital payment as given by (a) + annual operating cost (either present) or estimated future average  $\frac{(OC_1 + OC_n)}{2}$

2

**EXAMPLE :**

Scheme 1 : - 3 km of 750 watt tungsten halogen luminaires at 30 metre spacing

Scheme 2 : - 3 km of 150 watt high pressure sodium luminaires at 30 metre spacing.

	SCHEME 1	SCHEME 2
(1) Lamp type	750W(TH)	150W(HPS)
(2) Lumen output	15 000	15 000
(3) Wattage including control gear	750	180
(4) Lamp life (hours)	2 000	12 000
(5) Lamp cost (each)	R9	R35
(6) Installation cost "C" including luminaires	R35 000	R45 000
(7) Annual maintenance including relamping (labour)	R800	R500
(8) Annual lamp replacement assume 4 000 burning hours per annum $\frac{100 \times 4\,000 \times (5)}{(4)}$	R1 800	R1 166
(9) Energy cost per annum at R0,03 per kWh $\frac{100 \times (3) \times 4\,000 \times 0,03}{1000}$	R9 000	R2 160
(10) Cost $OC_1$ (7) + (8) +(9)	R11 600	R3 826
(11) Escalation rate = 10%		
(12) Amortization period $n = 10$ years		
(13) Interest rate = 15%		
(14) Operating cost at end of 10 years $OC_n = OC_1 \times 2,59$ (Table 9, page 48)	R30 044	R9 909
(15) Average $OC = \frac{OC_1 + OC_n}{2}$	R20 822	R6 867
(16) Amortized capital cost per annum $= C \times F$ where $F = 0,17$ (Table 8, Page 47)	R5 950	R7 650
(17) Capital amortization cost plus annual average operating cost (15) + (16)	R26 772	R14 517
(18) Ratio	1,844	1,0

## APPENDIX

## 1.0 POINT BY POINT METHOD OF CALCULATION

This method is used when actual values at various points need to be calculated in the horizontal, vertical or normal planes.

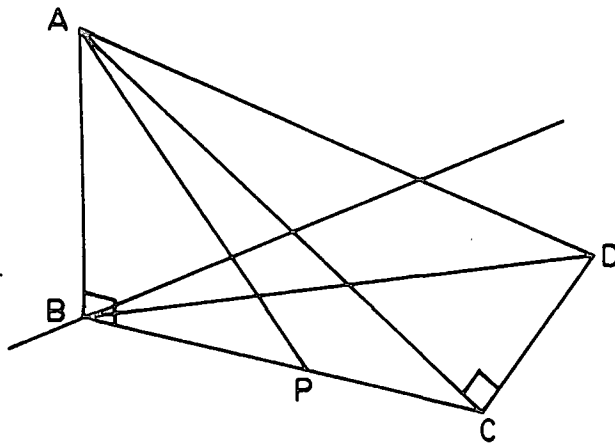


FIGURE 11

## 1.1 Horizontal Values (Figure 11 refers).

$$E_h = \frac{I \cos^3 \theta}{H^2}$$

$E_h$  = Horizontal illuminance in lux at point D.

$I$  = Luminous intensity in candelas from tables or iso-candela diagram for vertical angle  $\widehat{PAC}$  and horizontal angle  $\widehat{CAD}$  with the floodlight aimed at point P.

$\theta$  = Angle  $\widehat{BAD}$ .

$H$  = Mounting height AB.

1.2 Vertical Values (Figure 11 refers).

$$E_v = \frac{I \cos^2 \theta \sin \theta}{H^2} .$$

$E_v$  = Vertical illuminance in lux at point D in the direction of the luminaire.

$I$  = Luminous intensity in candelas from tables or iso-candela diagram for vertical angle  $\hat{PAC}$  and horizontal angle  $\hat{CAD}$  with the floodlight aimed at point P.

$\theta$  = Angle  $\hat{BAD}$ .

$H$  = Mounting height AB.

1.3 Simple Method of Converting Horizontal Illuminance Values at a Point to Vertical Values in Various Directions (Figure 12 refers).

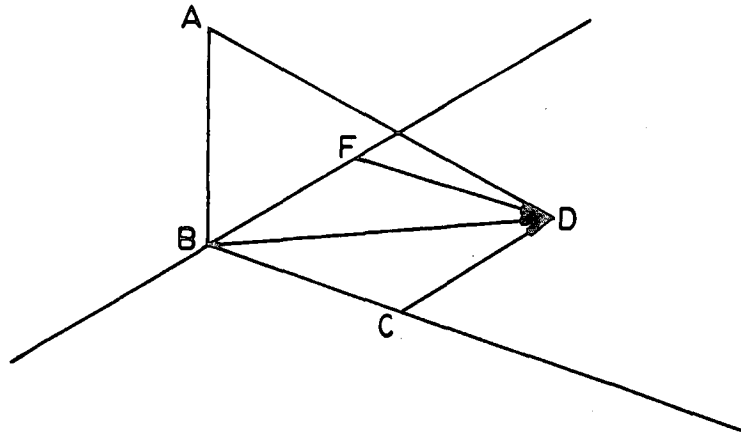


FIGURE 12

$$E_v \text{ in direction CD} = \frac{E_h \times CD}{H}$$

$$E_v \text{ in direction FD} = \frac{E_h \times FD}{H}$$

$$E_v \text{ in direction BD} = \frac{E_h \times BD}{H}$$

## G L O S S A R Y

## LIGHTING TERMS USED IN THE GUIDE

Ballast	Equipment used with discharge lamps for stabilizing the discharge.
Beam	A distribution of light from a luminaire in which the flux is concentrated into a restricted angle ; a floodlight 'beam' is a familiar example.
Beam angle or spread	The total angle over which the luminous intensity of a beam drops to a given fraction (usually half or one-tenth) of the peak value. Also known as the beam divergence.
Candela (cd)	The SI unit of luminous intensity.
Circuit watts (Power Input)	The lamp watts plus the watts dissipated by the control gear used with the lamp. See lamp table.
Colour appearance	A term used of a light source. Subjectively, the degree of warmth associated with the source colour. Lamps of low correlated colour temperature are usually described as having a warm colour appearance and lamps of high correlated colour temperature as having a cool colour appearance.
Colour rendering	A general expression for the colour appearance of objects when illuminated by light from a given source compared, consciously or unconsciously with their appearance under light from some reference source. 'Good colour rendering' implies similarity of appearance to that under an acceptable light source, such as daylight. The colour rendering properties of a lamp relate to this effect under specified conditions.

- Coefficient of Utilization      See Utilization Factor.
- Contrast      A term which, when used subjectively, describes the difference in appearance of two parts of a visual field seen simultaneously or successively. The difference may be one of brightness or colour or both. Objectively, the term expresses numerically the luminance difference by various formulae.
- Control gear      A general term that refers to the equipment used for starting a discharge lamp and controlling the current passing through it. The equipment includes chokes, transformers, ignitors, capacitors and starter switches as appropriate to the type of lamp.
- Dirt Factor      The ratio of the illuminance provided by an installation in the average condition of dirtiness expected in service, to the illuminance of the same installation when clean.
- Emergency lighting      Lighting provided (preferably automatically) from an independent system when the mains lighting fails.
- Floodlight      A luminaire designed specifically for floodlighting. A floodlight is usually capable of being aimed in any direction and is of weatherproof construction.
- Two types may be distinguished.
- Asymmetric floodlight : a floodlight in which the distribution of light is not the same in all planes through the main axis ; for example, the beam spread may be wide in the plane containing the axis of the lamp and narrow in the plane at right angles to it.
- Symmetric floodlight : a floodlight in which the distribution of light is substantially similar in all planes through the main axis.

Flux	See luminous flux.
Glare	The discomfort or impairment of vision experienced when parts of the visual field (e.g. lamps) are excessively bright in relation to the general surroundings.
Ignitor	A device for starting certain discharge lamps.
Illuminance	The luminous flux incident on unit area of a surface. The unit is the lux which is one lumen per square metre.
Illumination	The process of lighting an object or surface.
Intensity	See luminous intensity.
Lamp Lumen Deterioration	The light output of all lamps falls progressively with time, but the relationship is different for different types of lamps. See table 3a.
Local lighting	Lighting designed to illuminate a particular small area.
Lumen (lm)	The unit of luminous flux, the unit in which the light output of a lamp or luminaire is measured.
Luminance	The amount of light emitted by a source or surface per unit area in a given direction. Known colloquially as brightness. Measured in candelas per square metre.
Luminaire	Formerly known as 'lighting fitting'. The apparatus which controls the distribution of flux from a lamp or lamps, and which includes all the components necessary for fixing and protecting the lamps and for connecting them to the supply circuit. Floodlights and some other luminaires retain their individual names.

Luminous efficacy	The ratio of the luminous flux emitted by a lamp to the electric power consumed by it. The unit is the lumen per watt (lm/W).
Luminous flux (flux)	The light emitted by a source, or received by a surface. The unit is the lumen (lm).
Luminous intensity (intensity)	The power of a source or illuminated surface to emit light in a given direction. The unit is the candela (cd).
Luminous intensity distribution	A curve, generally polar, which represents the luminous intensity in a plane passing through the source as a function of the angle measured from a given direction, such as the downward vertical.
Lux	The unit of illuminance ; one lumen per square metre.
Mounting height	The vertical distance between a luminaire and the ground.
Spacing/mounting height ratio	The ratio of the distance between luminaires to their mounting height. If the recommended ratio is exceeded the uniformity ratio may be unacceptable.
Spill light	Luminous flux outside the beam of a floodlight. Not to be confused with 'waste light'.
Uniformity ratio	In this Guide, the ratio of the minimum illuminance to the average illuminance over a given area.
Utilization factor	The total flux reaching a given plane, divided by the total lamp flux.
Visual Field	The full extent of what can be seen when looking in a given fixed direction.

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- SABS 0108 The classification of hazardous locations and the selection of electrical apparatus for use in such locations.
- SABS 1277 Street lighting Luminaires.
- SABS 1279 Floodlighting Luminaires.