The Design of Lighting Installations for Obstructed Interiors

Thesis submitted in accordance with the requirements of the University of Liverpool for the degree of Doctor in Philosophy by **Hocine Bougdah**.

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Abstract

H. Bougdah:
The Design of Lighting Installations for Obstructed Interiors

Most lighting design methods assume that the space between the working plane and the plane of luminaires is always empty. The presence of furniture and equipment however affects light distribution and may influence the final illuminance pattern in an interior.

The review of published work into lighting of obstructed interiors shows that existing research has mainly been concerned with development of illuminance simulation methods, and theoretical approaches, in examining the effect of obstructions on interior lighting conditions. Little guidance is available to provide designers with means of assessing effects of obstructions and ways of taking informed decisions to overcome them.

This investigation is concentrated into two major areas which result in a proposed design method to take account of the likely effects of obstructions in spaces where the precise nature of the room contents is not known.

The first part of the design process is based on the "obstructed SHR" concept which takes as its basis three "standard obstruction" configurations which are representative of furniture layouts within a range of commercial interiors. A computer based technique is then used to calculate a modified spacing to height ratio to maintain illuminance uniformity over the task area of the standard obstruction configurations. Various methods of representing uniformity of illuminance within the SHR calculations are put forward and their effects on these calculations are investigated.

The second part of the proposed process covers the prediction of reduction in working plane illuminance in obstructed interiors using computer programs to simulate illuminance conditions within a range of interiors both with and without standard obstructions. The contribution to working plane light loss of the various installation parameters, which include luminaire type; obstruction density, obstruction height, mounting height, and room and obstruction reflectances is assessed. The results of these calculations enable the average light loss over the horizontal working plane to be estimated in a form that can readily be used in the lumen design process. Examples of the use of the proposed design method are given.

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Chapter 1

Introduction

General lighting installations in interiors are usually designed on the basis of an installed average illuminance which when weighted against the floor area and the lumen output of the type of luminaire used gives the number of luminaires needed. These luminaires are then arranged in a layout which has to satisfy some pre-defined requirements of spacing of luminaires. These requirements which aim to ensure a minimum level of illuminance are based on the assumption that interiors are empty.

When using such a method to design general interior lighting installations it is assumed that the space between the plane of luminaires and the working plane is empty of objects which might influence the pattern of light distribution in a space. Building interiors however, when in use contain objects, furniture items and human occupants which project above the working plane and cast shadows which may have an influence on the illuminance conditions over the task.

Existing routine design methods make no specific provision for assessing the effects of room contents, despite the consensus of opinion among researchers, designers and users, that obstruction influences the distribution of light within an interior and consequently causes reductions in both quality and quantity of lighting throughout the space. Introducing obstructions into a space can affect the lighting conditions in two ways. The pattern of illuminance distribution in an obstructed interior will vary from that of an empty one due to the formation of shadow areas around the obstructions (see Figure 1.1). Furthermore, due to the presence of obstructions the level of illuminance over the working plane will drop by some amount according to the number of obstructions, their sizes and positions. The likely effects of obstructions are acknowledged in such documents as the CIBSE TM5 (1) and the Illuminating Engineering Society of North America Handbook (2). Although they recognised that obstruction may cause problems, they simply suggest to reduce the spacing of luminaires than that appropriate for empty spaces in order to overcome the variation in uniformity of illuminance. Any attempt to modify an installation to counter the effect of obstruction is left to the designer's discretion. Neither document provide any guidance as to the quality of visual conditions likely to be achieved by taking such design decisions.

At present there is little available design guidance relating to the lighting of obstructed interiors as well as the lighting conditions achieved in such spaces when the design methods developed for empty space are used. The design data relating to the lighting of obstructed interiors is made even more scarce by the lack of published research work dealing with this problem.

Research work into the lighting of obstructed interiors has been going on for several years at Liverpool University. A previous researcher (3) developed a concept by which the spacing of luminaires in an interior containing objects can be calculated. In order to make the concept generally applicable to design solutions, the author defined two configurations of work stations which could be used in offices and referred to them as standard obstructions. The work presented in this thesis has refined and developed this concept to a point where it may be used by practitioners. It specifically set out to address the problem of obstruction effect in terms of variation in illuminance and the reduction in working plane illuminance due to the presence of obstructions projecting above the working plane in office interiors.

The lack of 'official' design guidance relating to the effects of obstruction is coupled with the lack of design tools which enable the assessment of that effect. Clearly there is a need for a reappraisal of conventional design methods and development of new design tools and techniques which enable designers to take informed decisions on the design solutions for obstructed interiors and provide them with information on the lighting conditions achieved.This need is further justified by the present tendencies in the design of commercial interiors which dictate that density of obstruction in modern offices has increased in recent years due to the widespread use of partitions and Information Technology equipment to enhance the working environment.

The basis of the present work was laid down in the previous stage of the research work which was completed in 1986 (3). Then the author put forward an obstructed spacing to height ratio concept (SHROBS) which dealt with the spacing of luminaires in obstructed interiors, and a computer based method for analysis of illuminance conditions in obstructed interiors. Survey work carried out in the course of the previous stage suggested the existence of tentative relationships between characteristics of the space and its contents and the light loss.

Concepts and tools developed by the previous researcher were used as the basis of the present work. Some of the concepts however were redefined as in the case of standard obstruction configurations. Conceptual and practical deficiencies were also identified in some of the original computer programs used in undertaking the various calculations. These deficiencies were removed. In the second part of the work the representation of uniformity of illuminance in obstructed interiors was examined. Finally, the tentative relationships between space characteristics and light loss had to be investigated in order to be able to fully understand and define such relationships. A design method based on the 'lumen method', to which modifications were to be added in order to assess the variation of illuminance distribution and the drop of average illuminance, was to be put forward.

The thesis is divided into six chapters which cover three main subject areas, and a conclusion section. The first area is contained in two chapters, Two and Three, which reviews the work on obstructions in interior lighting and provides a context for the work. The second area covers two chapters; Four and Five, and looks at the redefinition of what constitutes a standard obstruction and its implications on the obstructed SHR concept. It also investigates the various ways of representing uniformity of illuminance. The third section, also made up of two chapters; Six and Seven, investigates the nature of the tentative relationships mentioned earlier, using a computer analysis program and develops a modified lumen design method for obstructed interiors.

Chapter Two reviews the various aspects of published work on the lighting of obstructed interiors. Chapter Three on the other hand deals exclusively with the review of the work on lighting of obstructed interiors at the University of Liverpool. A critical review of such work was needed since it forms the basis of the present work. This critique had pointed out to the deficiencies contained in the previous work and identified the areas were more work was needed.

Chapter Four is devoted to the discussion of the obstructed SHR concept. The work put a great deal of emphasis on the redefinition of what constitutes standard obstruction configurations. This was felt important since the standard obstruction put forward by McEwan[(3)] did not reflect the large range of office equipment and furniture arrangements used in modern offices. This work involved the survey of office furniture manufacturers data and the redefinition of the notions of working plane area and the size of the calculation points grid necessary to calculate SHR. Chapter Five examines the various methods of representing the uniformity of illuminance. These were incorporated into the obstructed SHR calculation. the results showed that using the same uniformity ratio for obstructed spaces as that of empty spaces as a design criterion may not be suitable.

In Chapter Six the effect of the physical and photometric properties of the space and its contents on the light loss is investigated. Before the analysis program was used, a statistical validation of the computed results obtained using this program was performed. Using this analysis program, a range of empty and obstructed interiors containing different combinations of obstruction configuration, height and reflectance are simulated when lit by six types of installations. Only one design parameter was isolated at any time while the rest were kept unchanged. Chapter Seven first put forward a concept of obstruction loss which is based on the results obtained in the previous chapter. This concept was then incorporated together with the improved obstructed SHR in a modified version of the lumen design method in which allowances were made for obstruction effects in terms of spacing of luminaires and light losses. The method is explained through some design examples.

Finally in the last chapter a general discussion of the work is presented and some conclusions are drawn. General recommendations for future work are put forward.

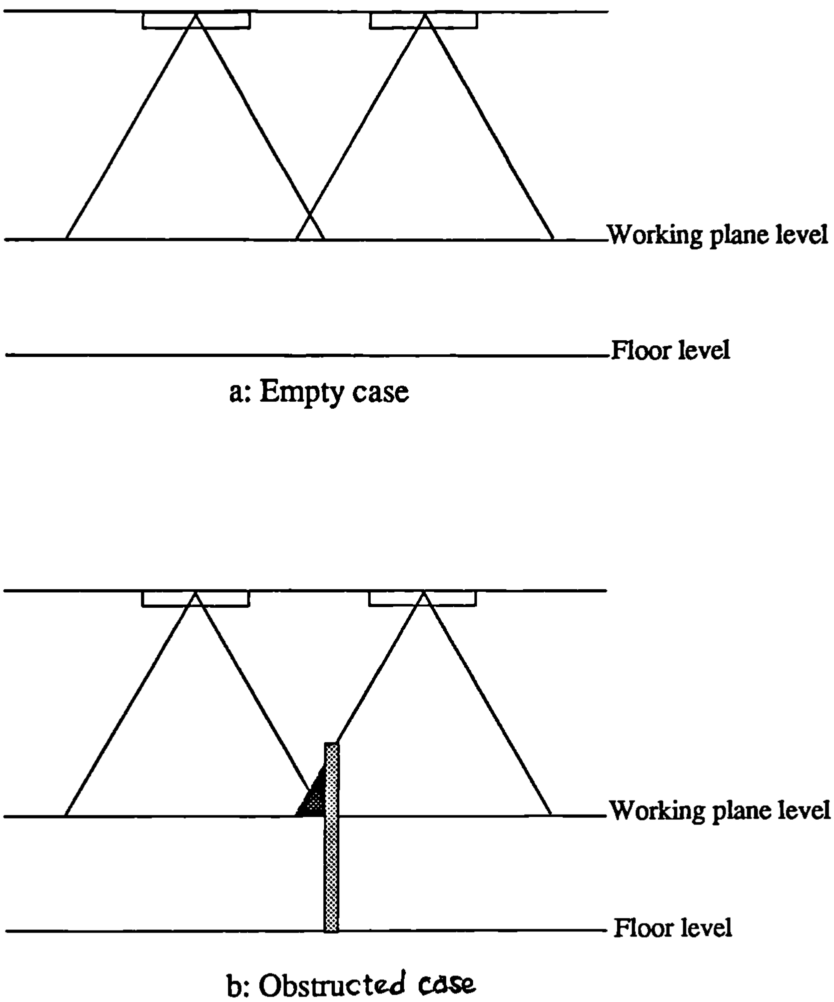

Figure 1.1: The presence of obstructions causes the formation of shadow areas.

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(2): Illuminating Engineering Society of North America, IES Lighting Handbook Reference volume, IES, New York, 1984.

(3): McEwan I., The effect of obstructions in the design of interior lighting installations, PhD thesis, University of Liverpool, 1986.

Chapter 2

Obstruction in interior lighting - A review of past work

2.1 Introduction

The majority of conventional interior lighting design methods do not make allowances for the presence of visual obstructions in interiors. When a general lighting scheme is designed, it is assumed that the space between the plane of luminaires and the working plane is empty. In practice however, it is hardly the case. Most, if not all working building interiors contain objects such as furniture, office equipment or partitions, which project above the working plane and affect the lighting conditions for which the designer assumes an empty space. This situation is not born out of ignorance of what is happening in practice but rather lack or nonexistence of design methods which account for the influence of obstructions.

Only in a minority of building types, does the lighting design process acknowledges the effect of interior obstruction. The CIBSE Guide for lighting of industrial environments, for example, suggests that the spacing of luminaires when installed should be reduced by a third of that specified by the manufacturers (1). The CIBSE Lighting Guide for libraries recommends the siting of luminaires relative to obstructions such as book stacks and the use of local lighting to offset any deficiencies in the illuminance provided by the general lighting system (2).

Despite the fact that some contents may influence the distribution of light within the space, causing local reductions in working plane illuminance and areas of shadow, the majority of available routines for design of general lighting do not make any specific allowance for light loss and shadow casting. The increasingly popular use of widespread distribution luminaires in general lighting schemes has contributed to the worsening of the situation. Their larger spacing to mounting height ratios mean that direct light reaches the task at larger angles to the vertical and with a much sharper cut-off than from conventional luminaires and means that parts of the working plane near the edge of the area are at risk from shadows (3).

Research work into aspects of the problem of obstruction loss and shadow in lighting design have been undertaken by a number of workers. Work in this area at the University of Liverpool is described in Chapter 3. This chapter reviews some of the work done in this field and discusses the various approaches used in the treatment of obstructions in interior lighting design. The review does not necessarily follow a chronological pattern, but the various approaches were classified according to their generic type.

2.2 Manual methods

These methods, regardless of the problem they address, are usually simple and do not cover detailed aspects of the light distribution and the formation of shadow patterns. In the present section three methods are described.

2.2.1 Shadow studies

In his work on the study of shadow Norden (4,5) classified shadows as either 'revealing' or 'distracting'.The former was defined as being the design requirement by which spatial and directional properties of light are clarified and which is now quantified by the concept of vector/scalar ratio. The latter was an objectionable phenomena which obscures details when cast on objects. Using a concept of 'shadow factor', Norden put forward a method of quantifying shadow intensity. The shadow factor was defined as:

$$S = \frac{E_s}{E} = \frac{E - E_r}{E} \qquad (2.1)$$

where S = shadow factor

E_S = shadowed illuminance

E = unshaded illuminance

E_r = residue illuminance

For a range of visual tasks Norden suggested some experimentally derived values for both revealing and distracting shadows.

Norden incorporated the shadow factor calculation into the lumen method. After deciding on the upper and lower limits for the shadow factor for the visual task in question, the maximum and minimum values of shadowed illuminance from the proposed lighting equipment were then calculated and the two resulting shadow factors were determined using the formula above. These two factors were then compared with their respective upper and lower limits. If the required limits were exceeded the layout was modified until agreement was achieved.

This method failed to gain general acceptability because neither tables of recommended range of shadow factors for a range of practical tasks nor diagrams of standard shadowed illuminance were produced by luminaire manufacturers for luminaires at a range of mounting heights and spacings which the procedure anticipated. Even if this data were available, the method would still have been of limited practical application since it took no account of a visual obstruction projecting above the working plane.

2.2.2 Modified lumen method

The lumen design methods for artificial lighting have as their aim the provision of some average uniform illuminance over the task, usually on a horizontal working plane and are intended for empty spaces. Spencer (6) extended this method to take account of irregularities and furniture below the notional working plane in the calculation of utilisation factors. In order to satisfy the assumptions of the lumen method, the actual room was replaced with a fictitious one with smooth surfaces for which the equivalent reflectance was calculated. This was then combined with the equivalent reflectance of the actual room. The utilisation factor which was initially calculated on the basis of the floor illuminance of the empty fictitious room was corrected to account for the modified surface reflections. The results of this work showed that in some cases the reduction in utilisation factor ranged from negligible to about 30 %.

The main shortcomings of this method were that it dealt only with reduction in indirect illuminance and was unable to consider obstructions projecting above the working plane. These have left the likelihood of shadow patterns and direct illuminance reduction not investigated.

The Zonal cavity method for calculating illuminance in empty rooms (7,8) which is the American version of the lumen method was extended by Ballman and Levin (9) to partitioned spaces containing cubicles with low partitions. The method may be used to calculate illuminance at a point or average illuminance in a cubicle. In either case, it assessed both direct and inter-reflected components separately and then added them to obtain the final illuminance.

When the average direct illuminance was assessed, two steps were involved. First the average illuminance on a plane on the top of the partitions is calculated. In this case the top zone is treated as a cavity initially with a floor reflectance of zero, the coefficient of utilisation is subsequently corrected to take account of the difference between actual and assumed floor reflectance of 20%. In the second stage the cubicle is then treated as a room with a room cavity ratio, wall and floor reflectance and an effective ceiling reflectance of the top zone as seen from the top of the cubicle. These parameters give a corresponding transfer coefficient which when multiplied by the illuminance found in the first step gives the average direct illuminance for the cubicle.

Similarly, the average inter-reflected illuminance is calculated over two stages. First the top zone is treated as a room with wall and ceiling reflectance and a floor reflectance which is an area weighted reflectance of the various cubicles across the plane. If this value is different from 20 % a correction factor is applied, and the average illuminance at the top of the zone is calculated. Considering surface reflectance is zero the average illuminance is calculated once again at the top zone. By subtracting this value from the previous one the difference in illuminance, on the plane at the top of the partitions, between black and reflective surfaces E_d is found. When the transfer coefficients of the cubicle are found from tabulated data and multiplied by E_d, the average inter-reflected component was found.

The direct illuminance at a point is calculated by determining the number of luminaires (or section of luminaires) seen by the point using a graphical method, then the inverse square law is used to calculate the direct illuminance at the point considered.

The inter-reflected component was calculated using some room and wall coefficients obtained from tabulated data. These coefficients are referred to as Room Position Multiplier (RPM) and Wall Exitance Coefficient (WEC) [9]. The expression giving the inter-reflected component is:

$$E = (WEC\,(1 - RPM) + RPM)\,E_d \qquad (2.2)$$

Where E_d is the difference in illuminance on the plane at the top of the partitions between black and reflective surfaces referred to earlier.

2.3 Empirical methods

A further way of studying the problem of lighting in obstructed interiors used empirical approaches based on survey work of actual conditions. The work described in this section is of limited application as it addresses some particular cases.

2.3.1 Briggs's studies

Based on the results of a survey , Briggs put forward an empirical method to calculate illuminance on the working plane in open plane offices partitioned into cubicles [10]. The experimental work was undertaken in a test room for which the various parameters were adjusted in order to give a large variety of cubicle configurations. Five parameters were manipulated, these were; luminaire type, position of luminaire with respect to the cubicle, size of the cubicle, height and reflectance of partitions. As a result 20 different configurations were obtained. For each case the illuminance was measured at both the top of partition plane and the working plane. A relationship between the empty case illuminance (top of partition plane) and the obstructed illuminance (working plane) was expressed as a transfer matrix.

The designer using the data calculates the average illuminance at the top of partition plane using a point by point calculation and this value is multiplied by the appropriate transfer matrix to generate values for the working plane. Briggs also showed that the calculated illuminance values using his method compared favourably with measured ones when the luminaires were positioned above the centres of cubicles. On the other hand a poor agreement was obtained for luminaires sited so as to straddle the partitions.

This method could probably be used to give rough estimations for the illuminance variations. It is not suitable as a general design tool as it is only applicable to unique combinations of layout, luminaire type and partition size.

2.3.2 Kajima *et al*

The authors carried out a number of surveys in office buildings in order to examine the lighting environment and to compare it to the subjective assessment of the users (11). The part of the work which was of interest to this review was the measurement of working plane illuminance in offices before and after the installation of furniture.

Measurement were carried out in three offices on the same floor of a high rise city centre building for which the area of external wall occupied by windows was 63 %. The measurement took place at different times of the day with blinds both open and shut.

The results obtained with blinds shut (exclusion of day light) showed a difference in average working plane illuminance of 20% between the empty and obstructed cases. This work also referred to earlier survey work conducted by Yasutomi *et al* for which the results showed an average illuminance drop of 10 % . In both cases, there was no indication to the density of furniture in the offices surveyed which makes the interpretation of the results difficult. Nonetheless, this survey work showed that obstructions have a considerable effect in reducing working plane illuminance.

2.4 Computer methods

The computer methods used in the analysis of lighting conditions in interiors are mainly of three types. These are Finite Element methods, Fourier Series analysis and Monte Carlo methods. The following sections describe some of the techniques developed using these methods.

2.4.1 Finite Element methods

Unlike the manual methods mainly based on the lumen design methods which use only three elements; ceiling , walls and working plane in the representation of the photometric performance of a system, finite element methods use a set of discreet, non-overlapping areas of elements for the representation of each surface. The photometric behaviour of each element is analysed and the contribution of all elements is summed and the resulting set of simultaneous equations is solved by matrix methods.

The calculation of the illuminance at points in a plane requires the luminance distribution of interior surfaces which is due to the initial flux output of the luminaire and the inter-reflected flux received from all surfaces. Each surface element in the room has an emittance which is given by the general finite element equation:

$$M_i = M_{oi} + P_i \sum_{j=1}^{n} M_j F_{ji} \qquad (i=1\ldots n) \tag{2.3}$$

where M_i = final emittance of element i

M_{oi} = initial emittance of element i

P_i = diffuse reflectance of element i

F_{ij} = radiant exchange form factor between element i and j

The form factor was defined (12) as the proportion of flux leaving element i that is received by element j as:

$$F_{ij} = \frac{1}{A_i} \int_{A_i}\int_{A_j} \frac{\cos\theta_i \cos\theta_j}{\pi r^2} dA_i \, dA_j \qquad (2.4)$$

where A_i and A_j are the areas of the two surfaces assumed to be uniform diffusers, r is the distance between the two surface elements dA_i and dA_j and θ_i, θ_j are the angles between the line joining the two surface elements and the normals to the respective surfaces (see Fig. 2.1).

For each of the n elements considered equation 2.3 is created and the resulting set of equations is solved using a matrix inversion technique, then the horizontal illuminance at a point P may be calculated from:

$$E_p = \sum_{i=1}^{n} M_i C_{ip} \qquad (2.5)$$

where C_{ip} = radiative exchange configuration factor relating the zone i to the point P on the horizontal plane.

When introducing obstructions into a space the inter-reflection calculation process is affected since the number of elements to be considered is increased by the number of obstructions. These obstructions will also affect the radiant exchange factor between room surfaces since they reduce the ability of elements to 'see' others. This effect is described by the view factor which is equal to unity if the centres of the two elements considered see each other and zero otherwise. Introducing the view factor concept changes the finite element equation for radiant exchange (Eq. 2.3) into :

$$M_i = M_{oi} + P_i \sum_{j=1}^{n} M_j C_{ij} V_{ij} \qquad (i = 1......n) \qquad (2.6)$$

where V_{ij} is the view factor between elements i and j.

The assessment of the view factor is based on testing the line of sight between the two elements considered for a blocking by a third plane. The evaluation of the form factor is of a major importance to the inter-reflection process. Several methods of evaluating the form factor were put forward by research workers [13,14,15]. The most commonly used method is the well known unit hemisphere method the implementation of which is explained in detail by Toups [13].

The Finite Element method for analysis has been used by several workers as a means to study the effect of obstruction in interiors. This section describes some of these examples.

2.4.1.1 Egger's work

Egger developed a Finite Element method based microcomputer program to investigate the effect of obstructions on illuminance distribution on room surfaces including the working plane [16]. One of the major objectives of the program was that the calculation was not to be limited to rectangular obstructions, nor be unable to deal with non-orthogonal positions of obstructions with respect to the room surfaces. The method was based on the assumption of uniform diffusing room and obstruction surfaces. This assumption reduced both the number of element considered in the inter-reflection process and the level of accuracy.

When direct illuminance was calculated, luminaires were subdivided into smaller light sources and the line of sight between the calculation point and the "source" was checked for any obstructing planes.

Computation of the flux transfer between room surfaces was performed using form factors and configuration factors methods. These methods were based on a geometrical interpretation of the Phillips and Prokhovnik equation [12]. Using a hemisphere of unit radius constructed over a point on the receiving plane (Figure 2.2), the locus of the points of intersection of the hemisphere and the line joining the point A with the emitting surface perimeter B, is projected onto the base of the hemisphere to give an area C which is the "silhouette" of area B. The configuration factor from area B to point A is the ratio of the silhouette C divided by the area of the hemisphere base. By extending this concept to every point on the receiving surface, thus

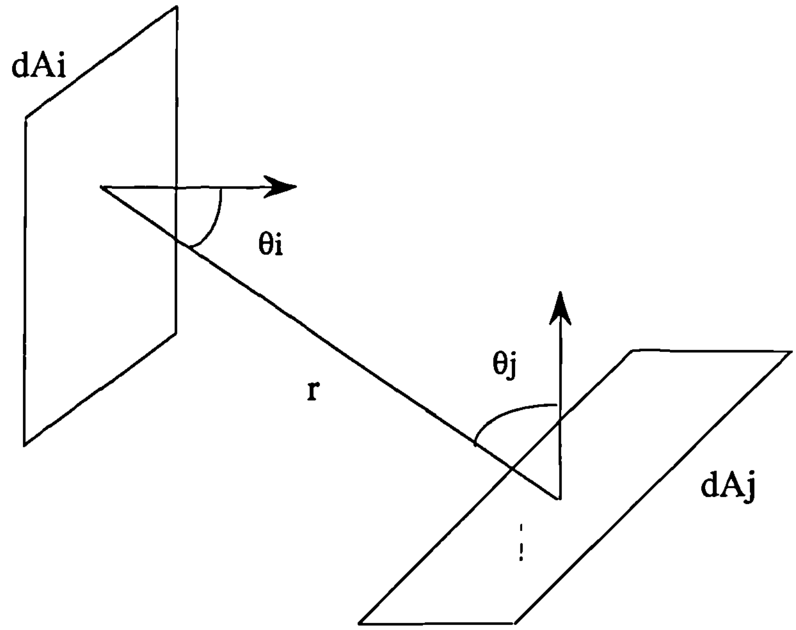

Figure 2.1: The relationship between two surfaces in the calculation of the form factor.

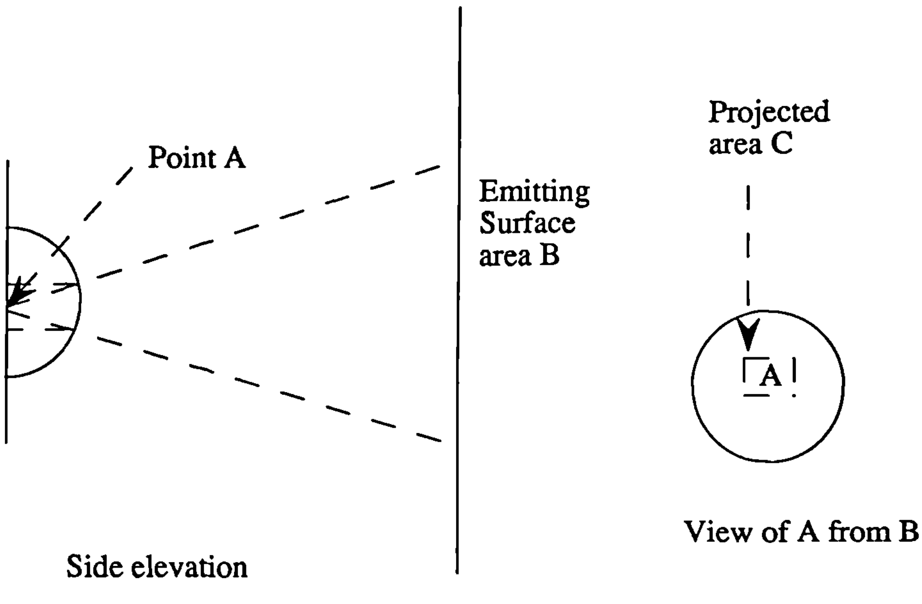

Figure 2.2: The Unit-hemisphere method.

performing a numerical integration over this surface the form factor between the two surfaces is assessed. In the same way form factors between other surfaces are estimated.

The silhouette method is also used in checking on the blocking effect of obstructions. The silhouette of the emitting surface is calculated and all the remaining surfaces, which are potential receivers, are checked to determine if their silhouettes intersect that of the emitting surface. If that is the case the obstructed area silhouette is eliminated and a new form factor is estimated using the same process described above.

This analysis method was shown to compare favourably with other methods based on the mathematical integration of the form factor expression given in equation 2.4 earlier.

2.4.1.2 Jensen and Lewin method

This method was developed on a Finite Element basis to work out the percentage of flux blocked between each two elements due to obstructions using the concept of shadow factor for partially obstructed elements [17].

After an unspecified number of checks for obstruction between elements a decision on the calculation of flux exchange is taken. If the elements considered see each other the standard form factor calculation is performed. If there is a total obstruction there is no flux exchange. In partially obstructed elements the method is innovative in its treatment of the flux exchange. Both elements considered are split into sub-elements tested to determine the number that are prevented from exchanging flux. Assuming that all surfaces are uniformly diffuse the quantity of flux exchange between partially obstructed elements is proportional to the number of sub-elements that are unobstructed.

2.4.1.3 Numan and Moore

Numan and Moore developed a method to assess the flux exchange in obstructed spaces based on the Finite Element method [14]. Partially obstructed surfaces were considered to be composed of zones without obstructions, separated by dummy planes projecting from the edge of the obstruction, which have full view of all surfaces of the zone they separate. These dummy planes were considered as transparent windows through which radiation travels from one surface to an other. The method uses the form factor concept between fully viewed surfaces in order to approximate the form factor between partially obstructed surfaces. The radiation travelling between surfaces of neighbouring zones is first received at a dummy plane and then distributed to the surfaces of neighbouring zones. The radiant energy received on each surface is determined by the form factor. If the dummy plane is assumed to be a secondary diffuse source, the fractions of the radiant energy received on each of the surfaces, through the dummy plane, can be determined by the form factor between the dummy plane and the surfaces under consideration.

2.4.2 Fourier Series Analysis methods

In the finite element methods for flux transfer, the calculation time is critically dependent on the number of elements considered. When obstructions block direct light exchange and the surface luminance is rapidly varying, the required number of elements is increased in order to achieve accuracy. This leads to the calculation time being computationally infeasible.

In his study of flux exchange DiLaura [18] used a Fourier Series Analysis technique. Each obstruction side was represented by two surfaces parallel to the exchange surface giving twelve surfaces as shown in figures 2.3 and 2.4. Using a co-ordinate system to position the various surfaces, The flux transfer equation may be written as:

$$M_i(x_i,z_i) = M_{oi}(x_i,z_i) + P_i(x_i,z_i) \sum_{\substack{j=1 \\ j\neq 1}}^{L} \int_0^{x_j}\int_0^{z_j} M_j(x_j,z_j)\, C(x_j,z_j,x_i,z_i)\, V_{ij}(x_i,z_i,x_j,z_j)\, dx_j\, dz_j \quad \text{.....(2.7)}$$

where $M_i(x_i,z_i)$ = final emittance at location (x_i,z_i)

$M_{oi}(x_i,z_i)$ = initial emittance at location (x_i,z_i)

$P_i(x_i,z_i)$ = diffuse reflectance at location (x_i,z_i)

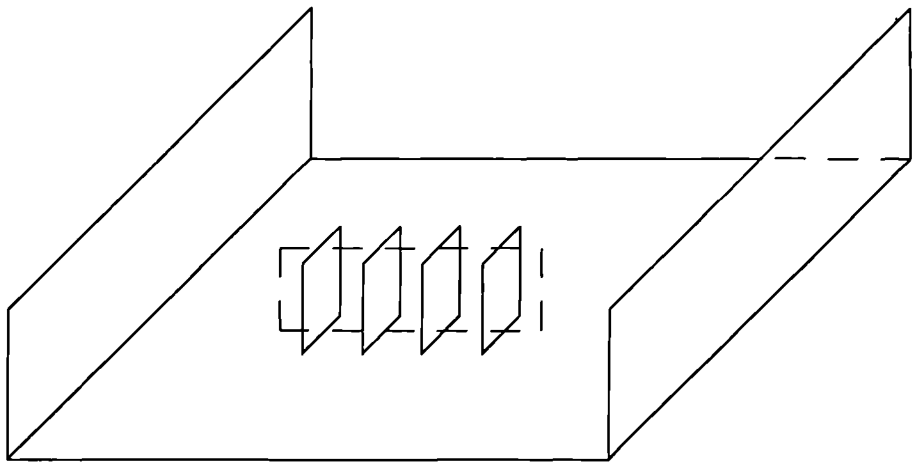

Figure 2.3: Representation on intervening surface perpendicular to the exchange surface pair by means of multiple intervening surfaces that are parallel to the exchange pair.

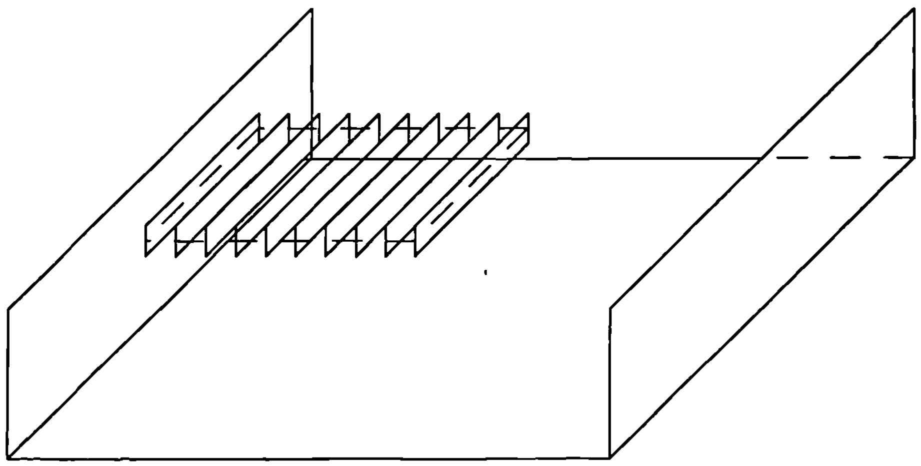

Figure 2.4: Representation of intervening surface perpendicular to exchange pair by means of multiple intervening surfaces that are parallel to the exchange pair.

$M_j(x_j,z_j)$ = the emittance at location (x_j,z_j)

$V_{ij}(x_i,z_i,x_j,z_j)$ = view factor for surface pair (i,j) evaluated at locations (x_i,z_i) and (x_j,z_j)

$C(x_i,z_i,x_j,z_j)$ = radiative exchange form factor for the surface pair (i,j) evaluated at locations (x_i,z_i) and (x_j,z_j).

DiLaura developed a complex set of representations of emittance function, radiative exchange factors and view functions. These representations were used to derive Fourier Series coefficients which were satisfied by the Fourier Coefficients of final emittance. The newly derived coefficients were substituted in Equation 2.7 and a system of linear equations for the unknown emittance function coefficients was obtained.

The work is a comprehensive theoretical treatment of the problem but there is little evidence of implementation. DiLaura's approach to the problem of flux transfer has admitted serious limitations when representing the flux exchange between perpendicular surfaces by a series of parallel ones.

2.4.3 Monte Carlo methods

The early development and application of the Monte Carlo method was mainly in the field of physics for computing flux transfer (19), particularly in applications where direct solution of analytical equations is very difficult (20). A number of workers used the method in lighting calculations (20,21,22).

The method is based on tracing the actual path of a particle of light from its source to its eventual absorption at a surface. At each change of direction of the particle which could be caused either by reflection or by transmission, the new direction is calculated.

Using the Monte Carlo method, Tregenza (20) developed some techniques for its application in interior lighting calculations. The simulation of the light particle path described above is repeated many times since accuracy is proportional to the square root of the number of particles traced. The illuminance of an area of a surface is taken to be proportional to the total number of times a surface intercepts a particle path.

Using a scaled random numbers assignment to the direction of a particle emitted from the source, the intercepting surface is then determined. The same method is again used to determine whether the particle is absorbed or reflected. If it is absorbed, the sequence begins again with further emission from the luminaire, otherwise the new direction of the particle is assigned with random numbers. The source could alternatively be modelled using a weighted particle values method. Each particle is assigned a weighting proportional to the luminous intensity in the direction of travel. The source is then assumed to emit particles evenly over equi-angular steps. When the particle strikes a surface, its weighting value is added to the total for that surface instead of the number of impacts at each surface being simply counted. Using a rectangular system of co-ordinates all surfaces including the room and obstruction surfaces, and the light sources were defined with respect to an arbitrary origin.

Using a probability distribution to represent the intensity distribution of the source, Stanger developed a computer program to analyse the inter-reflected component for a room lit by point sources near the ceiling [(21)]. The method used similar techniques as in the Tregenza's work [(20)] described earlier. It was claimed that this method can model arbitrarily shaped surfaces by determining the intersections of the surface considered with the path of the travelling particles.

The illumination distribution of a room with low partitions was simulated by Kajiyama and Kodaira using Monte Carlo techniques [(22)]. The probability density function including uniform random numbers was used in the modelling of the characteristics of emission and reflection of particles.

The computed results were shown to compare favourably with measured values. The computation time was enormously long, in the order of 18 CPU hours for a small office 6.9 m by 4.75 m by 2.88 m containing four cubicles and four light fixtures.

2.4.4 Unit Distance Illuminance Plane

In a study of the illuminance in an obstructed space, Bracket *et al* [(23)] developed a computer program for calculation of a point-by-point illuminance matrix. The calculation method dealt with orthogonal geometry of rooms and obstructions having uniform diffusing surfaces and assuming that each luminaire is composed of point sources each of them having the same intensity distribution as the actual luminaire.

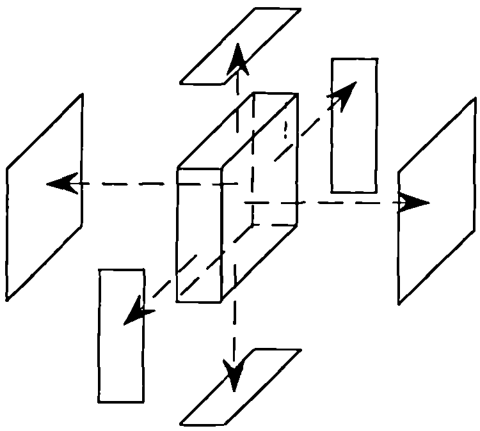

Figure 2.5: Explosion of a piece of furniture into six panels.

In this technique the illuminance is calculated at points on a plane one unit distance from the source in each of the six perpendicular directions before obstructions are considered. The points are displaced roughly 10^o from each other in order to reduce interpolation of intensity distribution. The direct illuminance at a point on the plane is assessed by interpolating amongst the Unit Distance Illuminance Plane illuminances.

Each obstruction is exploded into six surfaces (see Figure 2.5) and a test is carried out to determine which of the surfaces is likely to obstruct a given ray of light. The checking of obstruction blocking is performed using a directional cosine technique [24,25]. The direct illuminance is calculated for room and obstruction surfaces which are not blocked using the method described above.

The final room surface emittance is found using the basic flux transfer equation (eq.2.3) for which N solutions of N simultaneous flux transfer equations for N unknowns is sought using an iteration method. The effective reflectance of the task plane is determined using a modified version of the O'Brien formula [26]. Form factors between surfaces are calculated assuming an empty space. Then the form factors where an obstruction is present are modified as follows:

$$F_{ijm} = F_{ijp} \frac{(1 - Z_a)}{Z_b} \qquad (2.8)$$

where
Z_a = sum of the form factors unaffected by obstruction
Z_b = sum of form factors affected by obstruction
F_{ijm} = modified form factor
F_{ijp} = form factor ignoring obstruction

Once the final surface emittance has been determined, the effect of obstruction on the indirect illuminance on the task plane is assessed. The calculation is performed by creating a hemisphere of 48 sections around the point of interest and tracing a ray through the centre of each section to determine the luminance of wall, ceiling or obstruction intercepted by the ray. The final indirect component at the point is calculated using the 48 luminance values.

2.5 Computer graphics in visualisation

What separates the illuminating engineer from the lighting designer is the way they evaluate a lighting environment. The former relies on quantitative aspects, such as illuminance level, to make decisions. The latter however, is guided by experience and aesthetic sense to illuminate environments. His evaluation more often depends on visual qualities more than numerical quantities. The recent developments in visualisation has combined calculations with computer graphics producing a simulation that predicts quantity and displays quality (27). In this section a review of the work in this field is presented.

2.5.1 Ray-tracing techniques

Ray-tracing is a technique for computing luminance by back tracing light from the point of measurement to the source. Each ray of light is taken as a luminance value resulting either directly from an emitting source or indirectly from a reflecting surface.

Based on this method, Ward and Rubinstein (28) developed a particular application for computed luminance called synthetic imaging, which is a two-dimensional map of calculated luminance values. Calculation of luminance and hence illuminance involves an intersection test for each surface in the path of the ray to be traced. The testing method used in this technique is that of the Octree sorting method developed by Glassner(28). In order to compute direct illuminance, the location and size of the light source is used in the ray-tracing. If the surface considered is unblocked the calculation becomes a straightforward one. In the case of total obstruction the illuminance is zero and the surface is in the shadow. When the surface is partially blocked, a Monte Carlo method is used to determine the direct illuminance value.

The computation of indirect illuminance is performed by sampling reradiated luminance values over a hemisphere defined by the surface element position and normal direction. Both diffuse and specular components are dealt with.

These calculation methods were incorporated into the Radiance computer program. Images of the scenes modelled were obtained on display screens using the computed luminances. The results are impressive in terms of quality of representation but the computation time required to produce them was enormous. For instance modelling a simple office scene lit by four fluorescent tubes, with a desk, a chair and few items on the desk top took 20 CPU hours to produce an image of high resolution. This technique could be a useful lighting design tool, particularly if the computation time is cut down to make it more cost effective.

The same techniques were incorporated into a computer program which is capable of modelling any scene either internal or external, artificially lit or day lit (27). The program calculates luminance, illuminance and other information, then a picture of the scene based on computed information is produced and displayed on a visual display unit.

The images produced were very high quality but too time consuming. The author claims the results compare favourably with other lighting simulations and scale model measurements.

2.5.2 Applicability of computer generated pictures to lighting design

DiLaura *et al* (29) developed a method to test the validity of computed images against images produced using measured illuminance values. This method was applied to four identical test rooms lit by different lighting systems. After luminance measurements, photographs were taken in the test rooms and luminance calculations were performed using the photometric and physical properties of luminaires and room surfaces. The method used in the computation was a Fourier- like transform method developed by Mistrick and DiLaura (30). Images were generated from calculated luminance which were then compared to the real environments and their photographs. An assessment of computed images was then performed to determine the ones which failed to be sufficiently similar to the real environments and their photographs.

A study of the difference between the photometric characteristics of computed images and those of the real environments lead to the development of a metric which predicts significant changes in the response to the computed images from that of the real environment. For each of the cases studied, the results showed differences between computed images and those produced using measured luminances.The luminance ratios or quantities derived from them did not map those judged differences. The spatial shift is defined as the distance between a point of a grid on a room surface with measured luminance and a position nearest this point having a matching calculated luminance. The spatial shift was found to map the judged differences. This metric could be useful for evaluating computational methods leading to computed images. If, for instance, small changes in the calculation method generate large mean deviations of the spatial shift, then the method is not sufficiently robust to generate computed images.

2.6 Discussion

It appears from the literature reviewed that there is a consensus of opinion that the effect of light loss caused by obstructions is a problem in the design of interior artificial lighting. The majority of the published work on the lighting of obstructed interiors is concerned with the development of analysis approaches to the problem. These approaches lead to the development of calculation methods to enable designers to investigate lighting conditions in a quantitative and / or qualitative way for particular configurations of room geometry, room contents and lighting systems. The various methods described in this review range from empirical techniques to manual calculation ones to more complicated computer modelling techniques which in some cases include sophisticated synthetic imaging techniques.

The empirical studies carried out by research workers, although they were based on actual environments and measured date, were too specific to be of general practical use. Nonetheless they remain one of the few published sources of quantitative data on obstructed spaces. If empirical methods are developed on the basis of representative non-specific data they certainly would be useful in the design of lighting for obstructed spaces.

The manual methods attempt to provide quick approximate solutions to the problem of obstructions in interior lighting. The shadow factor calculation of Norden failed to gain general acceptability since it did not take into account the visual obstruction projecting above the working plane. The modified Lumen method of Spencer dealt only with the reduction in the indirect component of the utilisation factors. The zonal cavity method of Ballman and Levin is an improvement in that it enabled the direct component to be considered but its reliance on tabulated data makes it difficult to incorporate in any computer calculation. As an approximate initial calculation, it could be useful for designers.

The computer-aided analysis methods are of three types, namely, Finite Element, Fourier Series and Monte Carlo methods. These methods range from the wholly theoretical treatment of the problem to computer packages. The main consideration in these approaches is the balance between accuracy and realism. While the former is a function of the calculation method for the distribution of direct and indirect illuminance, the latter is related to the way of representing physical and photometric characteristics of the room and obstruction surfaces, and the size and light distribution of luminaires.

A comparison of the Finite Element calculation techniques reveals differences in the methods of surface description and indirect illuminance calculation, but broad similarities in the method of calculation of direct illuminance and of checking for obstruction effect. All the methods assume that room and obstruction surfaces exhibit diffuse reflectance properties. As part of the indirect illuminance calculation, all the techniques used the form factor calculations which differ from one technique to an other. There are major differences between the various techniques in the way the effect of obstructions on the indirect illuminance is assessed. The Numan and Moore method replaced obstructions by dummy planes which were treated as extra surfaces seeing all neighbouring areas. The methods which used single surface representation employed techniques of modifying surface to surface form factors to take account of obstructing surfaces.

The Fourier Series approaches described in DiLaura's work are too theoretical and is not yet fully developed to a point where it could be used by lighting designers. The Monte Carlo methods differ from other numerical techniques in that they trace each light particle from the source until absorption. The number of elements traced , if accuracy is sought, is very large. They seem to yield more accurate results but at a cost of large amount of computation time.

The recent development in computer graphics added a new dimension to the lighting design in that quality as well as quantity could be assessed. The methods described here used the techniques of ray-tracing to produce synthetic images of obstructed spaces. They are of little use as a tool to aid the visualisation of the appearance of the actual installation, however, since the output devices used can not operate over the same luminance range as the human eye.

2.7 Conclusion

Conventional design methods available to the lighting designer do not allow for the effect of obstructions in the design of interior lighting schemes. Contrary to what the available design guidance could cater for, most if not all building interiors contain objects which project above the working plane and affect the lighting conditions.

Research work has shown a consensus of opinion which stipulates that the effect of light loss caused by obstruction is a problem in the design of interior artificial lighting. The majority of published work on this subject is concerned with the development of analysis approaches to the problem. Although these approaches provided a much needed better understanding of the problem of obstruction effects, they remain short of providing the designer with adequate design tools and methods which would enable him to address this problem at the design stage.

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Chapter 3

A Review of Work on lighting of obstructed spaces at Liverpool

3.1 Introduction

Chapter two reviewed approaches that have been put forward for the treatment of obstructions in lighting design. Work at the University of Liverpool on the design of interior lighting has been going on since 1980 and has been concerned with the effects of obstructions on lighting conditions and luminaire spacing primarily within commercial interiors. The work carried out by the earlier researcher, Ian McEwan (1) had three main themes.

The first part of the work developed a concept of general design guidance for obstructed spaces for use at the initial "synthesis" stage of the design process for the lighting of a building such as a speculative office where the eventual nature of the space is not known. The work developed the existing guidance for lighting design for empty rooms, by modifying the maximum spacing to height ratio to allow for some "standard obstruction loss". It resulted in an obstructed spacing to height ratio that could be used as well as the empty maximum spacing to height ratio in installation design.

The second part of the work developed and tested an "analysis" computer program which was capable of investigating the lighting conditions within spaces lit by any defined range of artificial lighting equipment. The analysis approach is appropriate only if the lighting designer knows the space to be lit in detail and is used to test quantitatively the consequences of earlier design decisions.

In the third part of the work, the measured effect of obstructions was assessed. This was done by means of a number of surveys carried out in offices before and after they were furnished.

This chapter describes and discusses the work to date on lighting in obstructed spaces at Liverpool. Together with Chapter Two it sets out the "state of the art" of the treatment of lighting in obstructed spaces when the author commenced his work in November 1987.

3.2 Development of the obstructed SHR concept

McEwan developed the existing CIBSE method for determining the Spacing to Height Ratio (SHR) for empty rooms so as to make allowance for obstructions of known sizes and positions. The work took as a starting point the standard UK method for calculation of SHR in empty rooms as described in the CIBSE Technical Memoranda No. 5 (2). This defines the SHR as the ratio of the spacing in a stated direction between photometric centres of adjacent luminaires to the mounting height of the luminaires above the horizontal reference plane. Using a standard array of sixteen identical luminaires in a square grid (see Figure 3.1) the luminaires are positioned, at first, very close together and then moved apart in ordered steps so that the SHR is increased until the uniformity ratio defined by the minimum to maximum illuminance falls below the 0.7 threshold value. In order to calculate uniformity, the illuminance is calculated over a grid of points in the central area of the standard array of luminaires. Under these conditions it is assumed that uniformity is only marginally affected by the addition of more rows of luminaires. In the case of Point Source luminaires, point by point calculation methods are used whereas the Aspect Factor Method is used for linear luminaires. In both cases inter-reflected light was not accounted for. Two SHR's are defined in the calculation: the maximum (SHRMAX) and the nominal (SHRNOM) spacing to height ratio. SHRMAX is the value of SHR which gives the widest spacing at which a ratio of minimum to maximum illuminance greater or equal to 0.7 is achieved over the central area. SHRNOM is the greater value of SHR in the preferred series of steps to achieve the 0.7 min./max. uniformity ratio.

3.2.1 Obstruction configurations

The work developed a modification to the TM5 method of calculating SHR to take account of light loss caused by defined obstructions positioned within the central

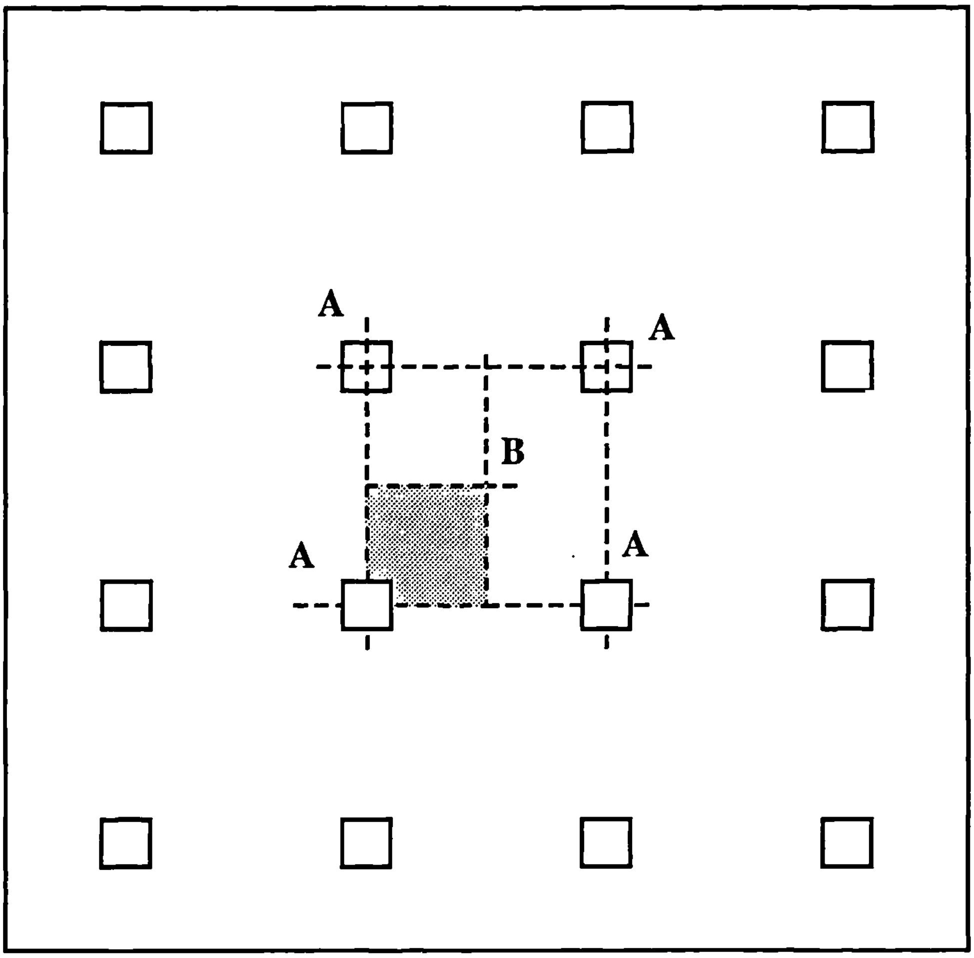

Figure 3.1: Square array of luminaires showing the positions of maximum (A) and minimum illuminance (B) and the task area.

area of the standard square array. Illuminance was calculated over a grid of 36 points positioned over a quarter of the central area, this being assumed to be representative of the whole area. It was demonstrated that using 100 points instead of 36 made no appreciable difference to the calculated illuminance values. The centre of the luminaire array was at a point defined physically as (2 x SHR, 2 x SHR) (see figure 3.1), and was taken as a reference point for positioning the obstructions around the task. Based ostensibly on the results of a survey carried out in an open plan office in the University of Liverpool (1), standard obstructions were developed comprising of a desk with either a partition or a filing cabinet positioned at one end, together with a person seated at the desk. These are illustrated in Figures 3.2 and 3.3. The dimensions of obstruction used were:

Partition	2.0 m wide	1.0 m high	at 0.7 m from centre of array
Filing cabinet	0.6 m wide	0.6 m high	at 0.7 m from centre of array
Human form	0.5 m wide	0.5 m high	at 0.2 m from centre of array

Alternatively obstructions of different types and sizes could be defined by the user.

3.2.2 Calculation procedures

Two separate computer programs were developed to deal with different types of luminaires. The first represented point source luminaires with rectilinear obstructions (PT2OB PASCAL), and the second handled linear luminaires and introduces the same obstructions either parallel or perpendicular to the luminaire axes (LIN2OB PASCAL). For each SHR value of the preferred series the program calculated the direct illuminance at each calculation point on the grid taking into account the presence of the obstructions. The uniformity ratio based on minimum/maximum (or minimum/average) was then determined. The SHR required to give an acceptable uniformity of illuminance over the task area was derived. The program used the intensity distribution of luminaires as provided by manufacturers, this being values for 0^{o} to 90^{o} in elevation in steps of 5^{o}, and in steps of, 45^{o} in azimuth for point source, and 30^{o} azimuth for linear sources. A flow chart of the calculation procedure is given in Figure 3.4. In the point source program the check for the effect of an obstruction was either "see" or "no see" and the

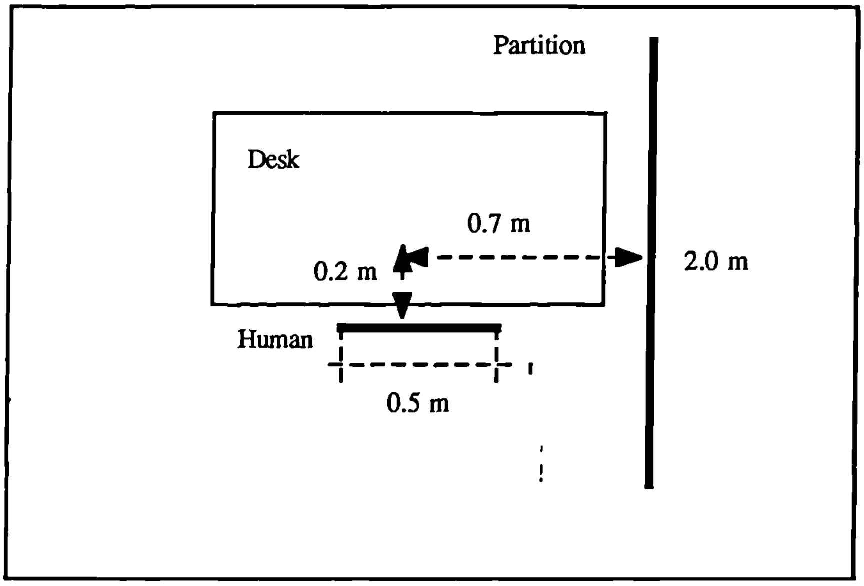

Figure 3.2: Partition standard obstruction situation

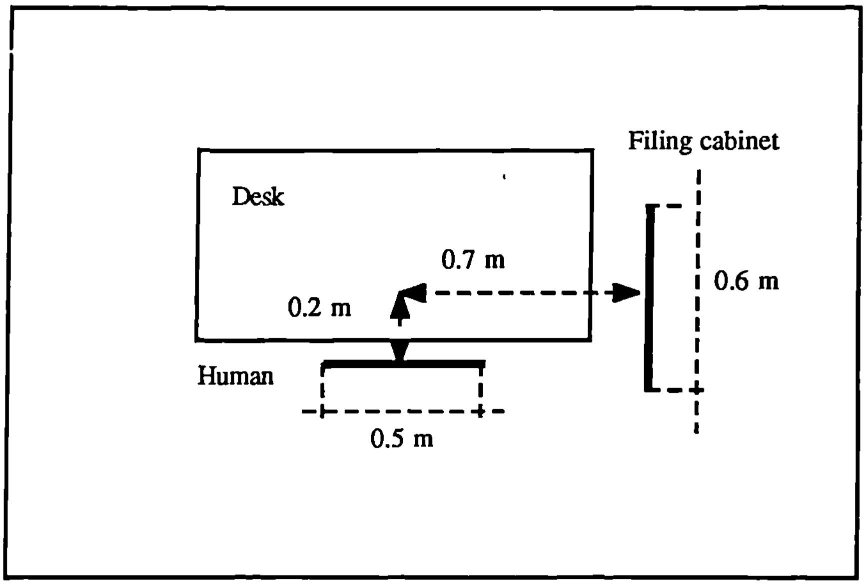

Figure 3.3: Filing cabinet standard obstruction situation

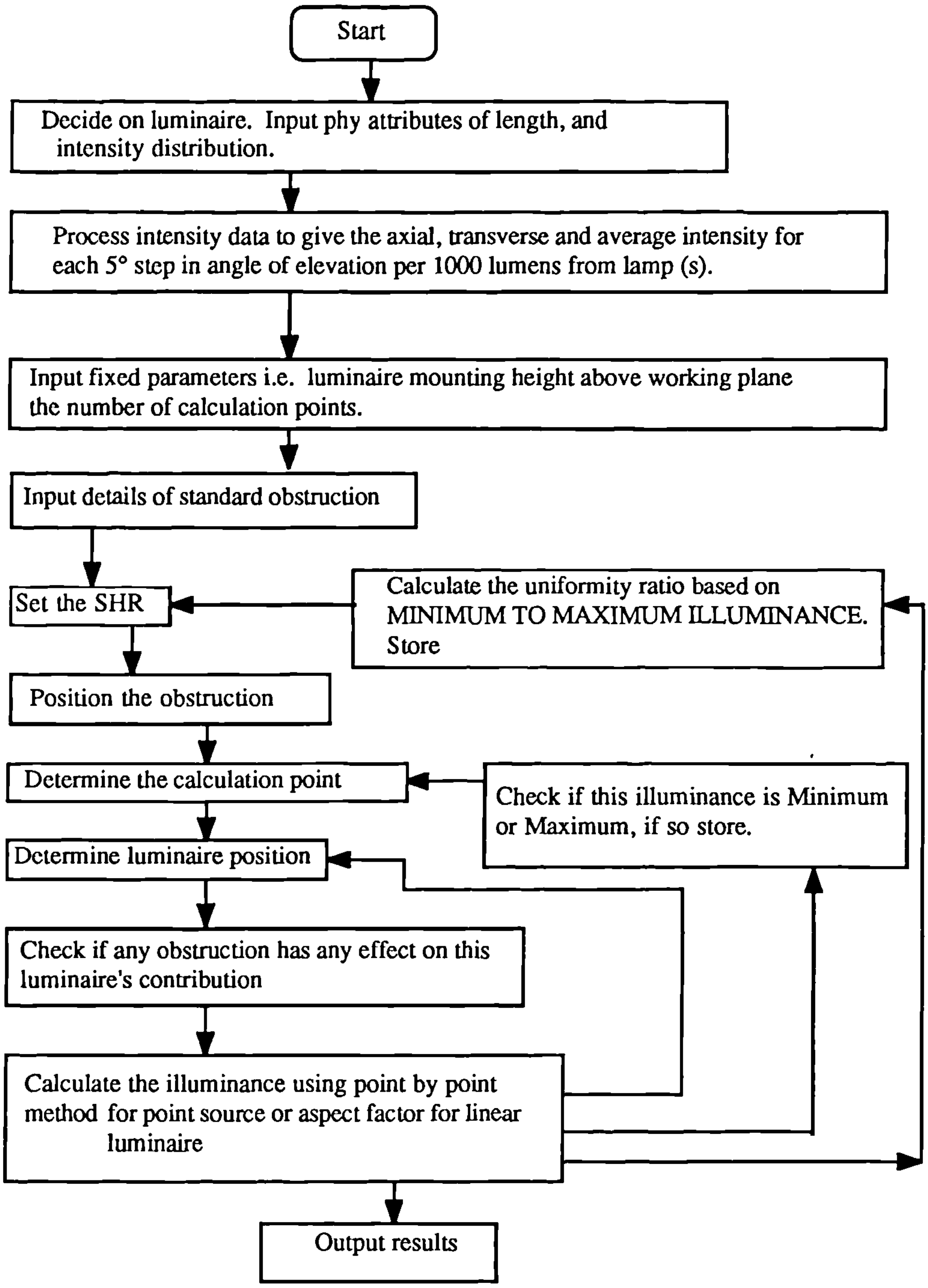

Figure 3.4: Flow chart diagram showing the method of calculating the spacing to height ratio for obstructed interiors

illuminance was calculated using a point by point method.

The calculation method in the case of linear luminaires used that of Aspect Factors (3) and the luminaires were assumed to be linear with no width. Checking for the effect of an obstruction in such case was more complicated since the obstruction could obliterate only one end of the luminaire or both ends but not the middle and vice-versa. Before calculation of the illuminance at any point, two checks were made to prevent wasted calculations. In the case of obstructions running perpendicular to the linear luminaire; the first check was to determine, for the luminaire in question, if the obstruction was positioned in plan within the angle of azimuth subtended by the luminaire at the calculation points. This check was applied in both X and Y directions (see Figure 3.5). In the second check the angle of elevation of the luminaire at intervals (usually 0.1 m) along its length was evaluated and compared to the angle of elevation subtended by the top of the obstruction at the calculation point. The comparison of angles subtended by each end of the luminaire and of the obstruction on plan would result in one of the following:-

a) All of the luminaire was seen and that is when *LUMANG2* is greater than or equal to *OBANG2*

b) The luminaire was completely obstructed, i.e. *LUMANG1* is less than or equal to *OBANG2*, in this case it is necessary to check the angles of elevation of both the luminaire and the top of obstruction.

c) One end of luminaire was seen i.e. *LUMANG1* is greater than *OBANG2* and *LUMANG2* is less than *OBANG2*.

d) Both ends of luminaire were seen but the middle part is obstructed, that is when for instance *LUMANG1* is greater than *OBANG2* and *LUMANG2* is less than *OBANG1*.

In the case of obstructions positioned parallel to the luminaires axis, or obstructions beneath point source luminaires, the same principles apply, but the calculations procedure is simplified as it is not necessary to calculate angles of elevation of the luminaire and obstruction more than once.

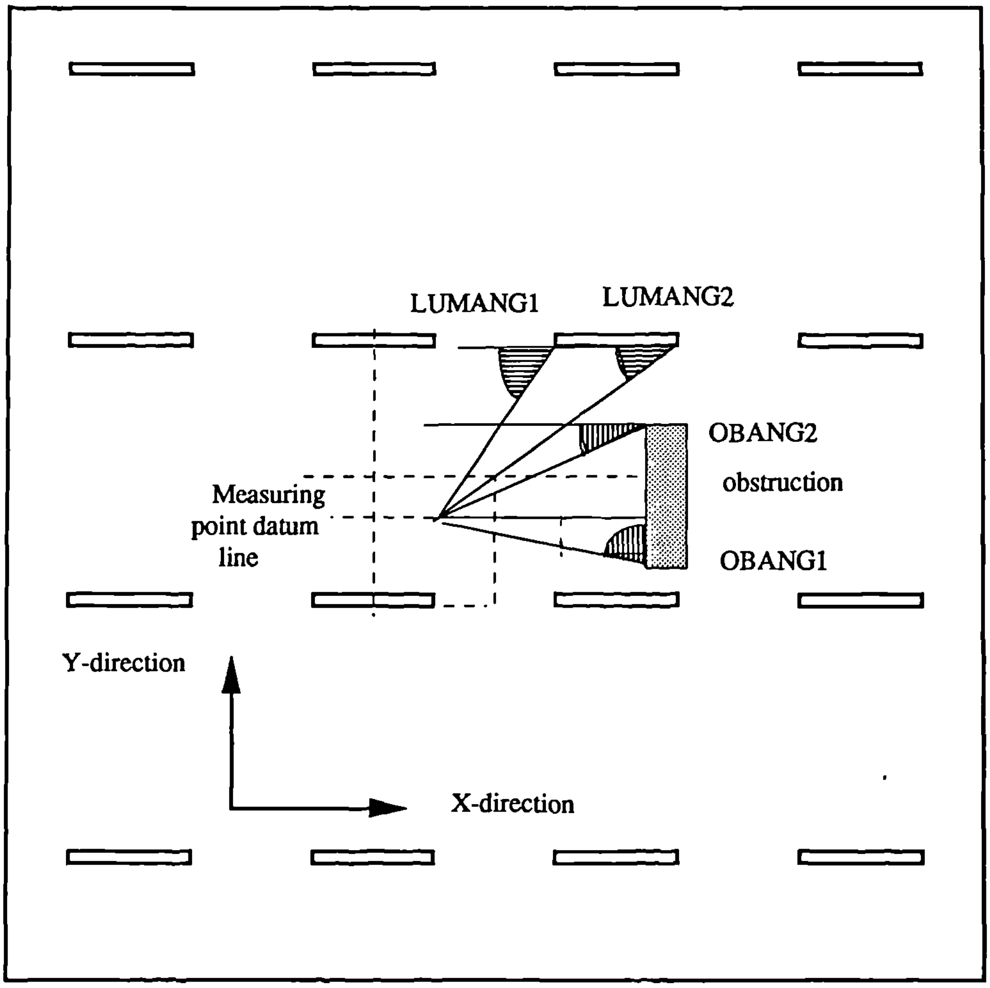

Figure 3.5: Plan view of a room showing the relevant angles subtended by the obstruction and luminaires from the datum line .

3.2.3 Discussion of the Obstructed SHR concept

When developing the method for calculating the spacing to height ratio for obstructed interiors, McEwan adopted the standard CIBSE method developed for empty rooms as the basis. This method was taken at face value with all the assumptions it had laid down when the empty room case was considered, and then the obstructions were introduced with defined size and position. The use of those assumptions did not discredit the model, on the contrary it has the advantage of building on a known and accepted model. Some of these assumptions however, needed development and some others needed modification. In the following section some aspects of the obstructed SHR work described in earlier are discussed and suggestions are made to improve and extend the method.

3.2.3.1 Task area

The original model calculates illuminance over a quarter of the central area of the 16 luminaire array, this being taken as representative of the whole central area by symmetry as is the case in the TM5 calculations. There appears to be two problems associated with this assumption. The first is that it is only valid when the space above the working plane is empty. By introduction of a standard obstruction the symmetry of illuminance within the central area is broken. The results of McEwan's SHR calculation may thus not be valid under conditions where the illuminance in the four quadrants of the central area varies greatly. The second problem is that the size of the quarter of the central area (SHR/2 x SHR/2) which is assumed to be the task area increases with increasing SHR. The effect of this is illustrated in Figures 3.6 and 3.7. If the "task area" is taken as a typical desk top of size 0.85 *m* by 1.6 *m* then at an SHR value of 0.5, a quarter of the central area covers about 20 % of the total surface area of the task. If the SHR is increased to 2 the notional area of the "task area" covered by the illuminance calculation is about 35 %, but in neither case covers the whole "task area". Furthermore, to assume that the other parts of the task area necessarily have illuminance conditions similar to those calculated is completely misleading.

A more reasonable approach would be to define physically the task area in the same way as the obstructions. The adoption of such a solution would give the advantage of having a task area for which the size is predetermined and independent of that of the luminaire array.

3.2.3.2 Grid size and task area relationship

In the empty room model discussed in the CIBSE TM5 there is no indication as to the size of the grid of points where the illuminance is calculated. It is merely indicated that to determine SHRMAX and SHRNOM a reasonably fine grid of illuminance over the central region must be prepared. McEwan adopted a 36 point square grid over one quarter of the central area. Having fixed the number of calculation points without defining the size of the task area, the computer model produced different calculation grids for different SHR values for which the same criterion of uniformity is applied. For instance, in the case of an SHR value of 0.5 the distance between two adjacent points is 0.09 *m* whereas in the case of 2.5 SHR it is 0.45 *m* (see Figures 3.6 and 3.7). The same criticism applies here as in the case of the task area. It seems incompatible to apply the same criterion of uniformity ratio to different sized grids of calculation points. Using different sized grids over the same area will produce different uniformity ratio results particularly if illuminance conditions vary sharply over the task area. There are two possible ways of dealing with the problems of grid size. One is to predetermine the distance between adjacent points and let the number of points increase with the increase in the size of the area. Alternatively the number of calculation points and the distance between adjacent points may be predetermined. The latter seems more appropriate since this is in effect defining the size of the task area which has already been advocated for in the previous section.

3.2.3.3 Obstruction configurations

Two obstruction configurations were considered in earlier versions of the programs. The first consisted of a person seated behind a desk with a partition to one side perpendicular to the axis of the desk. In the second case, the partition was replaced by a filing cabinet located in the same position. Those configurations were ostensibly based on a survey carried out in an office in the University of Liverpool but were essentially arbitrary in nature. In reality both standard obstructions were similar since both were positioned at 0.70 *m* away from the reference point on the same side (see Figures 3.2 and 3.3) and their effect on illuminance conditions in the lower half of the desk was not very different. There is doubt if the two standard obstructions are capable of representing the range of contents found in a typical office there is therefore a need for a wider range of "standard obstructions" to take account of

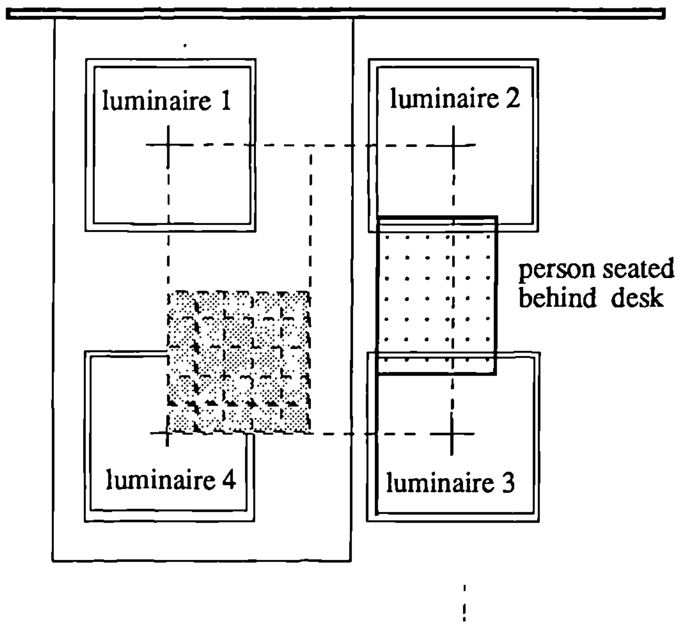

Figure 3.6: The CIBSE task area compared to a desk in a room with an SHR of 0.50

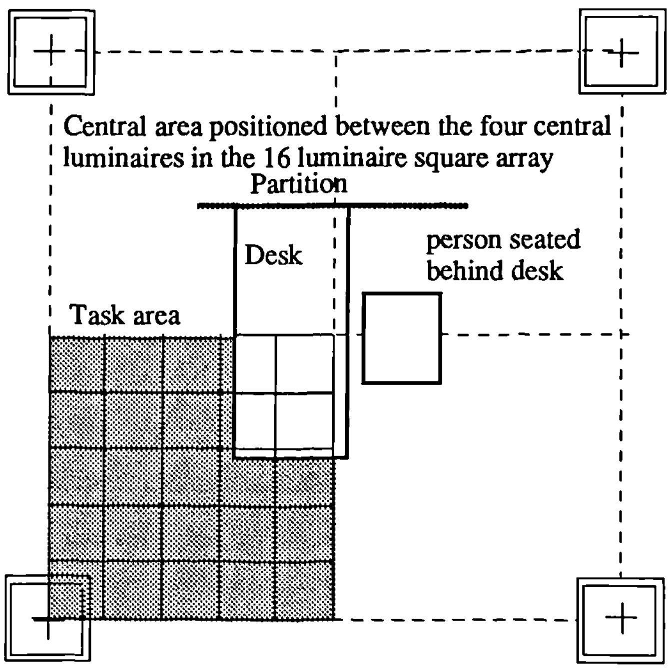

Figure 3.7: The same task area as in figure 3.6 but at an SHR of 2.00

different sizes and densities of furniture and equipment found in commercial interiors.

McEwan conducted a number of tests on the effect of individual obstructions on illuminance uniformity conditions on the task area and concluded that the obstruction which has the major effect was the human form due to its position adjacent to the task area. When considering the new task area, the human body has a very important effect in that it casts shadow on the central part of the task area. The human form in the original work was represented by a square of 0.5 *m* a side and due to its dominant effect a more refined method of representation was sought. The CIE Standard for "body shadow" used for Contrast Rendering Factor computation was suitable since this is capable of acknowledging the separate contributions of both body and head to the obstruction (4).

3.2.3.4 Illuminance calculation routines

Some of the routines in the procedure of calculating the illuminance contain a number of geometrical ambiguities. These mainly concern the determination of the angles in elevation subtended by the top of the obstruction and the luminaire at each point of the grid over the task area. The following two cases occur in both Linear and Point Source programs:-

a) When a point source is used, the angle in elevation subtended by the source at the calculation point is taken as the angle between any point at the source height in a vertical plane passing through the source in the Y-direction, which is taken arbitrarily and a corresponding point at the working plane height but not necessarily the calculation point, in a parallel plane passing through the calculation point. This definition leads to the conclusion that for instance points A, B and C in Figure 3.8 have the same angle of elevation with the source *S*. In practice however, each of the three points has a different angle which is the angle opposite the height of the triangle given by the source *S*, the point *s'* directly beneath it and the calculation point considered. The illuminance at any point is a function of the cosine of the angle of incidence at that point therefore using the wrong angle yields results which could lead to some misleading conclusions.

b) In the case of a linear luminaire, when comparing the angle in elevation subtended at the calculation point by any point along the axis of the luminaire, with that subtended at the same point by the top of the obstruction a mistake has occurred in calculating the second angle. Instead of using the obstruction height, the mounting height of the luminaire is considered as if the obstruction reaches all the way up to the luminaire (see Figure 3.9). This affects the decision on whether or not the luminaire is blocked in elevation and consequently the illuminance assessment at that particular point is affected. At lower SHR values where the luminaires are close together and their contribution to the illuminance at a point is considerable, a misjudgment of the effect of the obstruction could be very costly. One final criticism is that the program has limited facilities for input data. For instance, the Point Source program requires the input data file of the intensity distribution to have intensity values for all 8 planes. In practise, however, some manufacturers only provide the mean vertical intensity at 5° interval of elevation angles.

In the obstructed SHR concept, the empty space model of the CIBSE method for calculating spacing to height ratio was adopted with all the assumptions laid down. Although building on such a known and accepted model does not discredit the newly developed concept, some of the assumptions taken at face value need to be developed and modified to better suit the new concept. The following modifications are suggested:

(a) Redefinition of what constitutes "standard obstructions" in order to cover a wider range of office furniture items and the way they are used in the space.

(b) Redefinition of the task area and the grid size, since the space is no longer empty, the assumption that the quarter of the central area is representative of the whole area does no longer hold because there is no symmetry.

(c) Refinement of some of the illuminance calculation routines.

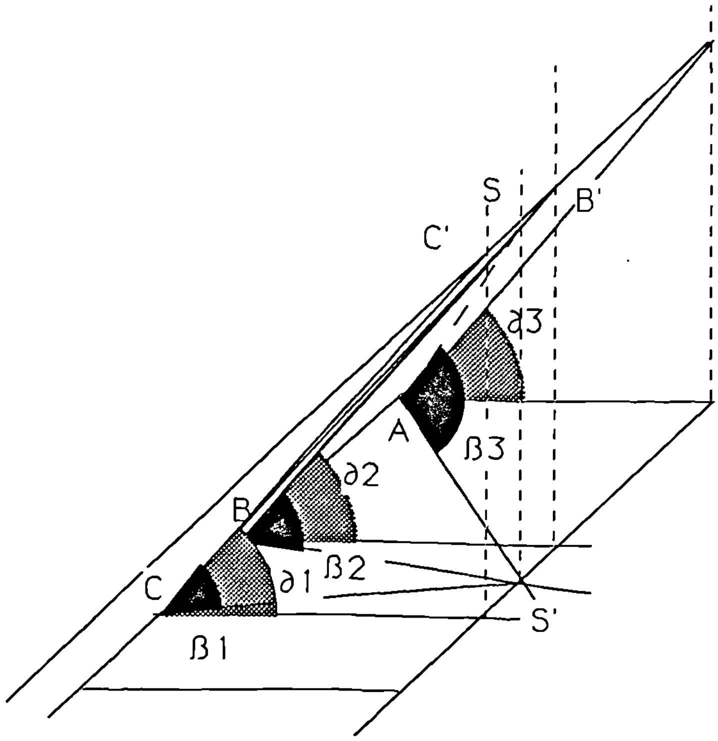

Figure 3.8: Angles subtended by the calculation point and the point source (S). Contrary to the previous model's assumption, angles ß1, ß2 and ß3 are different from ∂1, ∂2 and ∂3.

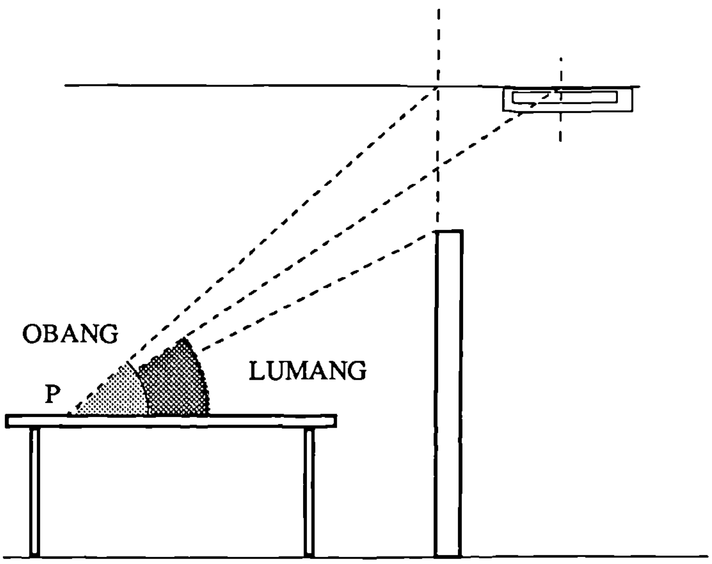

Figure 3.9: Elevation angles subtended by the luminaire and the obstruction at the calculation point.

3.3 The analysis approach to the lighting of obstructed interiors

In the previous sections, the need for general design guidance for obstructed spaces at the initial stage of the design process was identified and discussed. If the designer, however, wants to test quantitatively the consequences of earlier design decisions, he may still need tools to investigate illuminance conditions within an obstructed interior. Most of the analysis methods available in the mid nineteen eighties (5) were applicable only to the solution of the particular problem they address. Although collectively they contained many useful techniques they were not general enough to model a range of obstructed interiors.

To address these questions, McEwan developed an analysis program to investigate the lighting conditions within obstructed spaces lit by a defined range of artificial lighting equipment.This section describes the techniques used in the program and their implementation. The computer predicted resulted were validated by comparison with field measurements.

3.3.1 The purpose of the analysis program

The program was developed using some of the established techniques described in the literature together combined with a number of new ideas put forward by McEwan. It enabled planar and surface illuminance within an obstructed space to be calculated if the physical parameters of both the installation and the room and its contents were known. Starting with an initial luminaire layout based on a Lumen Method calculation, the luminaire layout was adjusted until the installed spacing to height ratio was equal to, or lower than, the appropriate spacing to height ratio for the particular case. The designer, by manipulating the input data, used the analytical capability of the program to make informed decisions about changes to the original layout to rectify any illuminance deficiencies caused by obstructions. This feature enabled the designer to quantify the effects of the modifications and to identify areas where illuminance is lower than an acceptable limit.

3.3.2 Program description

The program contains three main blocks. The input section is where the physical and photometric data is read from external files. The core of the program contains all the calculation procedures starting from the number of luminaires and their position and finishing with the output section showing graphical and tabulated results of working plane illuminance. The main features of the program are shown in the flow chart diagram in Figure 3.10. The following sections describe the various calculation techniques used in the program.

3.3.2.1 Luminaire positioning

The lumen method is used to produce the initial layout of luminaires which maintain the required average illuminance over the working plane. After the program has calculated working plane illuminance conditions, the layout could be altered either manually by the user or automatically by the program. In the latter case, the luminaires are distributed evenly around the room. The luminaires are positioned parallel to one direction at the time and illuminance calculations are performed. The solution which gives the most acceptable working plane illuminance is then adopted.

3.3.2.2 Representation of linear luminaires

Linear luminaires were represented by dividing them into sections and each section was treated as a point source. The size of each section was chosen depending on the ratio of the distance between the luminaire and the calculation point to the largest dimension of the the luminaire as one of the following:

(a) one fifth of the mounting height of luminaires above working plane

(b) half the length of the luminaire

(c) the whole luminaire.

If the luminaire is split into n sections each individual 'equivalent luminaire' has an intensity of 1/n of that of the total intensity of the luminaire.

3.3.2.3 Conventional representation of surfaces

Each one of the room and obstruction surfaces are designated a number according to their direction of facing (see Figure 3.11). This numbering allowed all surfaces facing in a particular direction to be considered together when the direct illuminance over them was being calculated or when the effect of an obstruction was being considered.

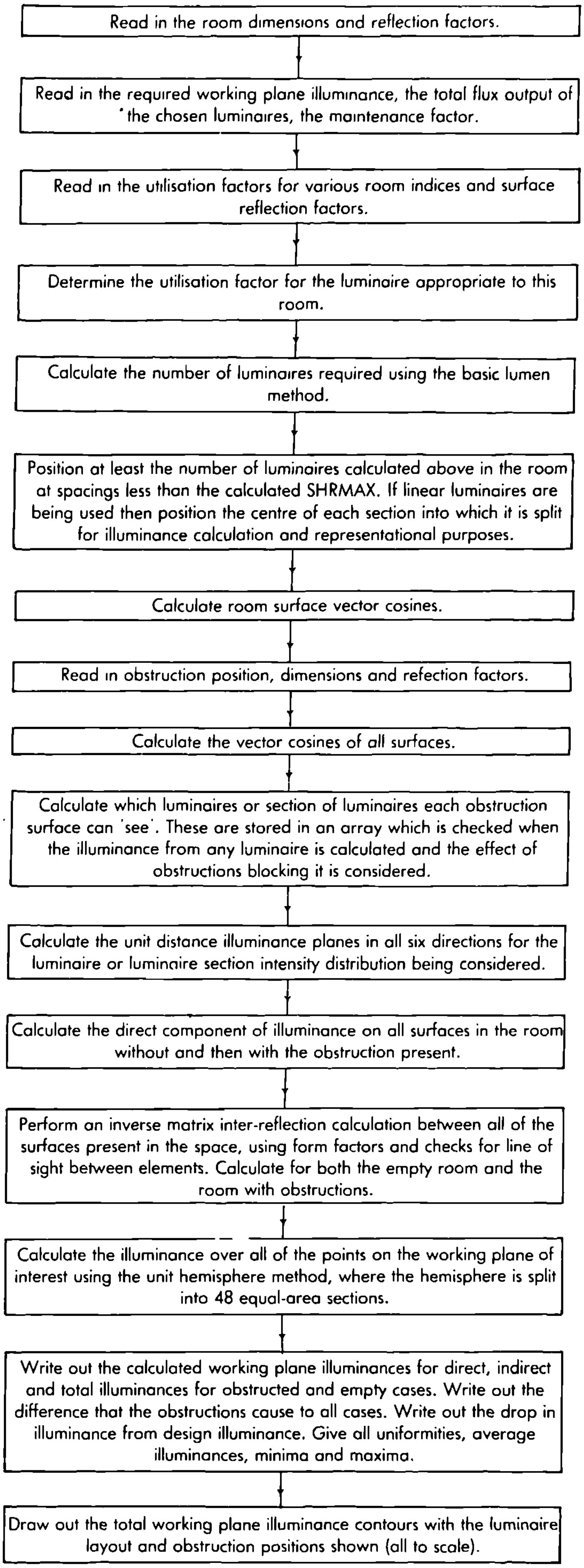

Figure 3.10: Flow chart diagram for the computer analysis program

3.3.2.4 Vector cosines

The vector cosine technique (6,7) was used to define all the surfaces in the model; the size and direction of the normal of each surface are defined uniquely in relation to a consistent origin in an axis system. The location of the origin and the orientation of the axis were arbitrarily chosen as one of the lowest corners. This illustrated if Figure 3.12.

The use of this axis system allowed all surfaces to be defined by the direction cosines of their normals and by the perpendicular distance P from the origin to the surface. When considering the planes or surfaces used in modelling an orthogonal room, the vector cosines are fixed and only the room dimensions are required as input data. The use of vector cosine technique when representing surfaces allowed determination of the point of intersection between a line of sight; between either a luminaire and a plane (i.e. direct illuminance) or two points on separate planes (i.e. inter-reflection), and a given obstruction. Each line of sight of flux interchange could therefore be tested for the presence, or otherwise, of an obstruction. To determine the intersection of a line with a plane the direction cosines of both the plane and the line were checked as follows. When a particle is travelling away from a point in a straight line its direction cosines are c_1, c_2, c_3 . If the cosines of the plane are d_1, d_2, d_3 the distance from the given point (x_0, y_0, z_0) to the point of interception (x_1, y_1, z_1) is:

$$r = \frac{P - d_1x_0 + d_2y_0 + d_3z_0}{c_1d_1 + c_2d_2 + c_3d_3} \qquad (3.1)$$

If r is negative, the particle is travelling away from the plane. If the divisor is zero, the line and the plane are parallel. The co-ordinates of the point of intersection can also be found.

Each obstruction was represented by six panels representing the surfaces and each panel was checked for any line of sight interception. The surfaces were then stored in arrays, according to their orientations expressed in terms of vector cosines.

For each line of sight between two points of consideration, the vector cosines are obtained and the points of its intersection with a particular plane is found using

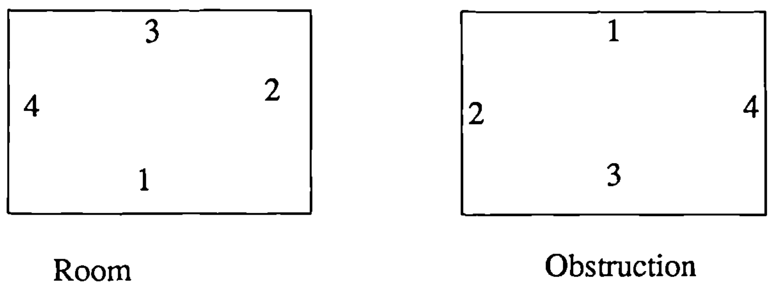

Figure 3.11: Convention used in numbering the various surfaces

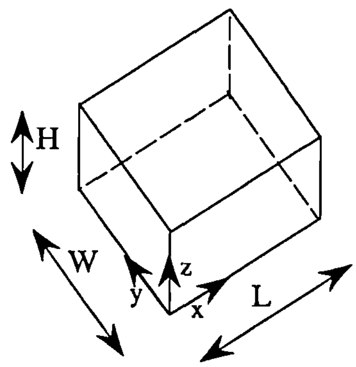

Figure 3.12: Representation of the surfaces of a rectangular room

Equation 3.1.

3.3.2.5 Direct illuminance calculation

The direct illuminance received over every surface in the room is of great importance since it determines both the inter-reflected flux and the final illuminance obtained over the working plane. The unit distance illuminance plane (UDIP) technique was used to calculate all direct illuminance over all internal surfaces. Using this technique, which was put forward by Bracket *et al* [8], allowed direct illuminance at any particular point to be obtained by interpolating amongst precalculated illuminance values on a plane situated 1 unit from the luminaire and allowing for the distance of the actual plane. The UDIP s were calculated as follows:

(a) The luminaire, if is not a point source, is split into sections and each section is to be treated as a point source.

(b) The luminaire is to be located at unit distance from the plane to be considered and illuminance is calculated at strategically located points using the inversesquare law. The points at which the illuminance is calculated are shown in Figure 3.13. These points are chosen so that any two adjacent points are displaced roughly 10^o from each other allowing the use of all the intensity distribution data.

The direct illuminance at a particular point on the floor or any vertical surface below a luminaire may be calculated by interpolating among the floor plane UDIP s using hyperbolic interpolation and taking into account the real distance between the luminaire and the point.

3.3.2.6 Indirect illuminance calculation

The program used a Finite Element method to calculate the indirect illuminance component. By approximating the actual light receiving and emitting surfaces by a set of discrete area elements, the photometric behaviour of each element was analysed and the overall contribution of elements were added up. A Gauss matrix inversion technique was then used to solve the resulting set of simultaneous equations. The luminance distribution of room surfaces is required to calculate the illuminance at any

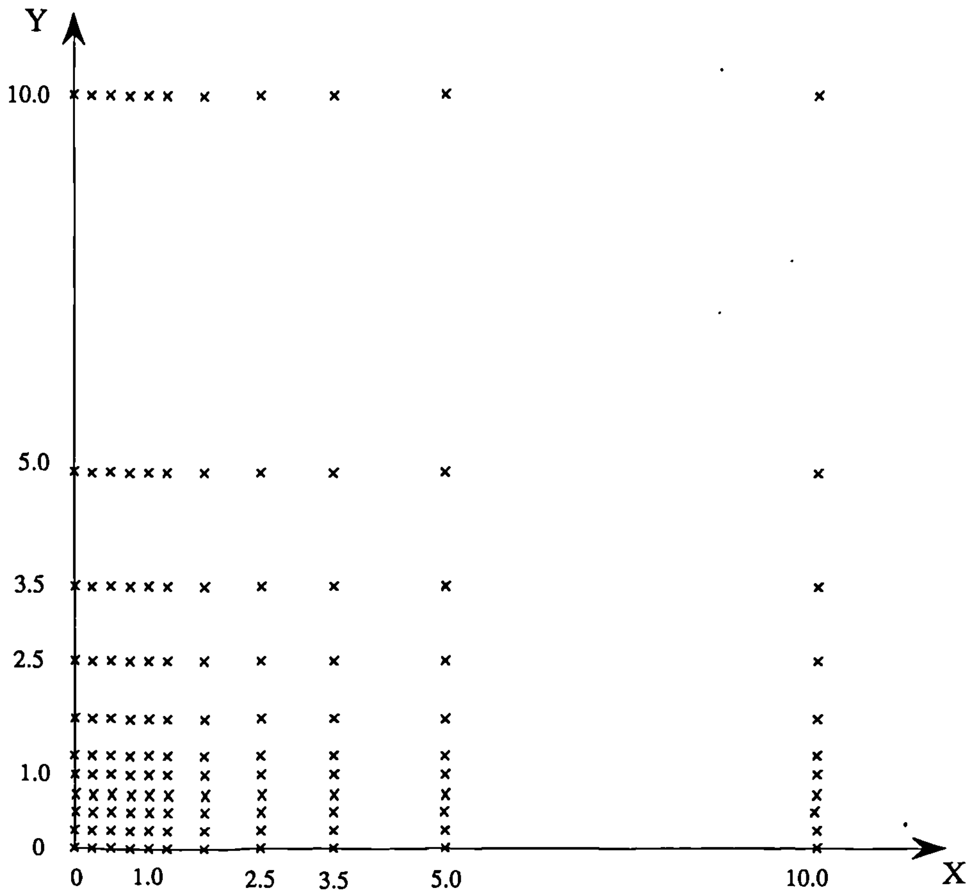

Figure 3.13: Tabulated calculation points for 1/4 of the Unit Distance Illuminance Planes (UDIP). The luminmaire is mounted a unit distance above the point (0, 0).

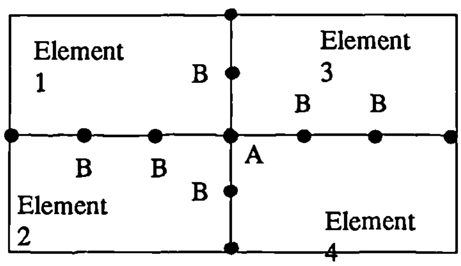

Figure 3.14: Overlap of surface elements

point.This luminance pattern is due to both the direct flux from the luminaires received at the element and the indirect component received from all surfaces by inter-reflection. An element may be a room or obstruction surface, or some subdivision of the surface so that the luminance and reflection factor over the surface may be considered constant. The size of element was varied to suit particular applications and to maintain an adequate balance between the representation of the photometric behaviour of the surface and computational efficiency, particularly since the matrix inversion solving time involved in the inter-reflection process increases with the square of the number of element considered.

When luminaires, with substantial proportions of light emitted upward, are used in the installation, the luminance pattern on the ceiling requires additional calculation techniques. In such a case the steep luminance gradients are dealt with by dividing the ceiling into small elements. The luminous existence of each element due to the luminaire is then calculated and the element is treated as a point source so that its contribution to working plane illuminance is calculated using a point-by-point method. Illuminance on room surfaces due to ceiling luminance not caused by direct exposure to luminaires was calculated as part of the general illuminance exchange process using the general Finite Element Equation 2.3 and a simplified form factor given by the Equation 2.4 (both in the previous chapter).

Introducing obstructions into a space has increased the number of elements to be considered in the inter-reflection process. The other effect of obstructions was that they block some of the line of sight between some elements and hence the form factor of such elements needed to be recalculated. This effect was accounted for by introducing the "view factor" which is determined by the ability of the centre of some part of an element to see the centre of an other element. When the view factor was considered in the radiant exchange process, the Finite Element equation of inter-reflection became:

$$M_i = M_{0i} + P_i \sum_{j=1}^{n} M_j F_{ij} V_{ij} \qquad (i=1....n) \qquad (3.2)$$

where V_{ij} is the view factor which is equal to unity if the two elements considered see each other and equal to zero otherwise.

When this technique of centre-of-element to centre-of element line of sight check for obstruction effect was used, it lead to considerable variations in existence between adjacent element when one of them is obstructed . To overcome this McEwan [1] introduced a slight overlap between element perimeters. All points which adjoin other elements had their illuminance calculated in proportion to illuminance received on all the adjoining elements. For instance the final illuminance at point A in figure 3.14 was calculated as follows:

$$E_{Af} = E_d \frac{\sum_{n=1}^{4}}{4} \qquad (3.3)$$

where:

E_d = the direct illuminance,

E_{in} = the indirect illuminance received by element n.

In a similar way all points B were found to have the same final illuminance value.

3.3.2.7 Calculation of indirect illuminance on the working plane

In this process the indirect illuminance on the working plane is calculated. The process takes into account the illuminance received from all surfaces in the room (obstructions included) except the high emittence area around the luminaires on the ceiling. A unit hemisphere was created above each calculation point and using the vector cosine technique the surfaces which intersect with the lines passing through each equal area section of the hemisphere were determined. The exitance of the point intersected, which is obtained by interpolating amongst the stored exitances calculated over every surface, was then used in determining the exitance received on the calculation point. In Figure 3.15 the horizontal illuminance at a point illuminated by a portion of a hemisphere was expressed as follows:

$$E = \int_{\theta_1}^{\theta_2}\int_{\phi_1}^{\phi_2} \frac{L(\phi,\theta)}{\pi} \sin\theta \cos\theta \, d\phi \, d\theta \qquad (3.4)$$

where: ϕ_1, ϕ_2 are the azimuth limits of the hemispherical section,

θ_1, θ_2 are the elevation limits of the section of hemisphere ($\theta = 90^o$ at the zenith).

$L(\phi,\theta)$ is the luminance at point (ϕ,θ) on the hemisphere.

Since the luminance was considered to be uniform over the section of hemisphere [7], then the illuminance would be :

$$E = \frac{-1}{4\pi} (\phi_2 - \phi_1) (\cos 2\theta_2 - \cos 2\theta_1) L \qquad (3.5)$$

(ϕ_1 and ϕ_2 are in radians).

The principle of equivalence [1] was used in the indirect illuminance calculation process. It states that two uniform diffuse sources will produce the same illuminance at a point P if their luminance is the same and they have the same boundary when viewed from P. In Figure 3.16 the two elements da and da' which have the same boundary when viewed from P would both have the same illuminance at P if their luminance is the same. This may be written as:

$$dE_p = \frac{L d\acute{a} \cos\theta}{I^2} \qquad (3.6)$$

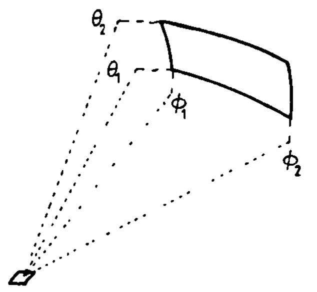

Figure 3.15: A target point illuminated by a section of a hemisphere

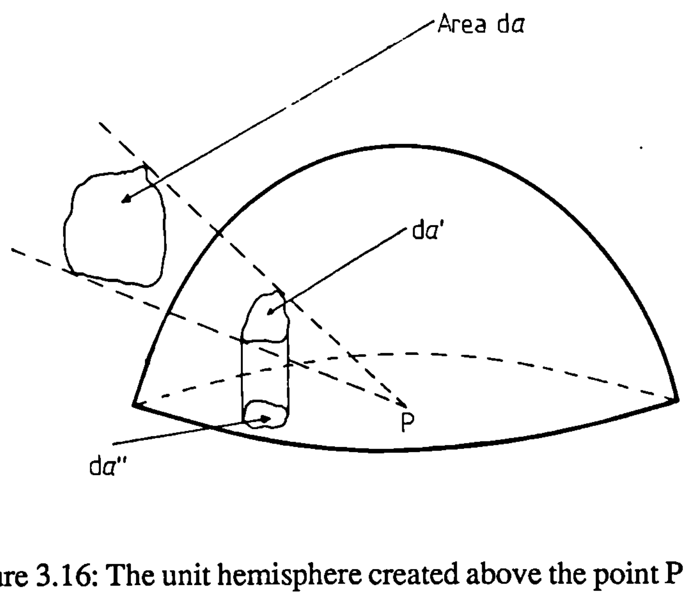

Figure 3.16: The unit hemisphere created above the point P to calculate the illuminance received at the point from a uniform diffuse source

Since da" is the projection of da' on the base of the hemisphere, it is therefore appropriate to equate da" to da' cos θ and as a result of that Equation 3.6 becomes:

$$dE_p = Lda'' \tag{3.7}$$

This argument was applied to each element of area of the source and the total illuminance at point P was found to be equal to the product of the source luminance L and the area *a*" which is the area of intersection on the sphere projected onto the base of the unit hemisphere. This was expressed as:

$$E_p = L\sum da'' = La'' \tag{3.8}$$

Each section of the hemisphere was assigned a uniform luminance. McEwan's model has used a hemisphere split into 48 separate sections. The q and f limits were chosen in the range 0, 30, 45, 60, 90°, and 0, 30, 60.....360°, respectively.

3.3.2.8 The program output

The output of the program consists of the input data, working plane illuminance grids for both empty and obstructed cases for direct, indirect and total illuminance, and contour plots of working plane illuminance showing the positions of luminaires and obstructions.

3.3.3 A lighting design example

McEwan demonstrated the use of the analysis program by means of a design example. In this design the working plane illuminance distribution is calculated for a medium sized office lit by two alternative luminaire types and using partitions and furniture items of known size and nature. The office is 14 *m* by 12 *m* with ceiling height of 2.6 *m* and a working plane height of 0.75 *m* . It is partitioned into cubicles, desk areas and a conference area using half-height partitions. Figures 3.17 and 3.18 show the layout and main furniture items projecting above the working plane.

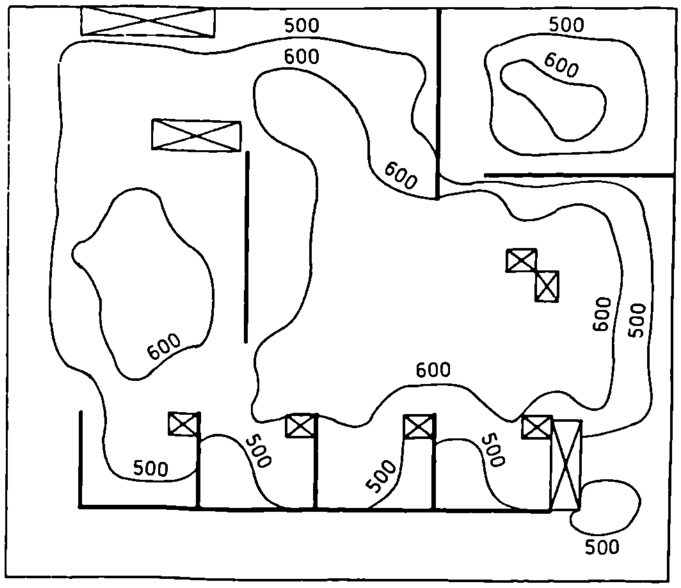

Figure 3.17:Calculated working plane illuminance for an office 14 by 12 m by 2.6 m, lit by Broadspread type luminaires with their axis parallel to the room length.

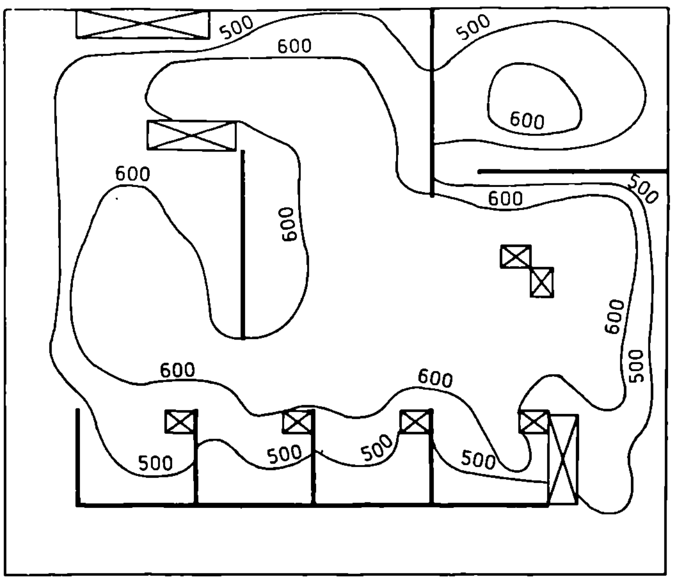

Figure 3.18: Calculated working plane illuminance for the same office as above but with lower partitions.

Initially, the program performed a lumen method calculation which produced an initial luminaire layout which satisfied the criterion of a standard service illuminance of 500 lx [9]. Using Broadspread luminaires whose axes were parallel to the long dimension of the room the working plane illuminance pattern shown in Figure 3.17 was obtained. Aligning the luminaires along the short axis of the room has produced a different pattern of illuminance. Using such a layout resulted in a reduction in illuminance in some areas where it fell to below 30 % of the standard service illuminance. Using the information in the output the designer could change the various design parameters to come out with a better solution. For instance, Figure 3.18 illustrates the effect of redesigning the installation using lower partitions. Among the program features is the possibility for the designer to override the luminaires positioning procedure and vary their position as well as the obstruction positions and their reflection properties.

3.3.4 Discussion of the analysis program

The analysis program was designed to investigate the effects of obstructions and other design related parameters on the illuminance conditions across the working plane. Considering the relatively short computer time involved in the calculation; compared to the large number of design parameters taken into account, the program was a useful tool to investigate lighting conditions in obstructed spaces. The program output in both tabulated and graphical forms provides the designer with means to assess the consequences of earlier design decisions and take informed measures to rectify any deficiencies when necessary.

The program was intended to handle a comprehensive range of furnished room sizes. Under its present form, however, the program contains restrictions on both the size of the space to be modelled and its contents. Although the physical dimensions of the space and the obstructions present in it together with their sizes were part of the input data, the user of the program did not have much choice in manipulating that data since the arrays where the input data is handled in the program were already pre-defined. For instance, the maximum room size allowed to be modelled could not exceed 14 *m* by 12 *m*. Similarly the number of obstructions to be considered was restricted to 24 items or less. If a different size and contents room is to be considered, it was necessary for the user , not only to manipulate the input data, but also to redefine the various arrays concerned with the data. Finding and amending the relevant arrays in the large declaration section of the program was a tedious job which was prone to error.

The second deficiency associated with the use of the program is the lack of an interactive input output facility. Such a facility gives the program more flexibility and enables the user to alter some of the input data as and when required. For instance the interactive input would allow the user to override the program in changing some of the luminaire positions.

The third problem are in the program concerned the luminaire positioning. The routine only checked to satisfy the SHR requirements but did not check the physical possibility of fitting all luminaires in the room which depend on the luminaire size in relation to the room dimensions.

3.4 Measured effects of obstructions

In order to assess light loss in actual obstructed interiors McEwan conducted a number of photometric surveys in offices before and after they were filled with furniture. These surveys had a twofold purpose; comparison of measured illuminance values with computed ones, obtained using the analysis program to simulate the same spaces surveyed and an investigation into factors affecting obstruction light loss.

3.4.1 Illuminance surveys

A number of surveys was carried out in a number of modern buildings [(10)]. Data was collected for a number of office interiors which varied in size, luminaire type, and obstruction type and layout. Illuminance measurements at the working plane level were carried out on a 1 *m* square grid throughout the room. These measurements were carried out both before and after the introduction of furniture into the rooms, after dark to eliminate the effect of daylight.

All measurements were carried out in accordance with the guidelines and recommendations of the CIBSE Code for Interior Lighting [(9)]. In the case of occupied offices the measurements included the size and position of obstructions present.

3.4.2 Comparison of measured and calculated illuminance

The data concerning physical and photometric properties of the offices surveyed was used to simulate these offices and calculate sets of illuminance values for each of the offices both empty and occupied. Then the calculated illuminance values were compared to the measured ones using only a visual inspection and isolux plots.

For the various cases the difference between calculated and measured values was computed and found that only a small number of individual points were outside the 10 % acceptable level of accuracy for measurements. The points outside this limit were due to identifiable circumstances. These were sources of error in the assumptions made about the following:

(a) Accuracy of measuring the reflection factors of surfaces which later were used in the program.

(b) The actual positioning of the obstructions present in the space being accurate compared to that input to the program.

(c) Differences between the intensity distribution of the actual luminaires and that given by the manufacturer. Added to this the actual output of the tubes compared to that given in the photometric data.

(d) The maintenance factor of the luminaires of installations if they are not properly maintained.

3.4.3 Factors affecting obstruction light loss

In order to establish a link between the various obstructions present in the space and the light loss over the working plane four surveys were carried out as described in the previous section. The offices were different in size, number and nature of furniture items and reflection factors of room surfaces and obstructions. Table 3.1 summarises details of room and obstructions properties, maximum and average illuminance over the working plane, and the area of the working plane within which the average illuminance falls below an acceptable uniformity ratio (0.8 of average illuminance).

Office details					Luminaire type	Average room reflection factor	Average obstruction reflection factor	Vertical obstruction surface area to floor area above working plane	Average height of obstruction to mounting height ratio	Reduction in illuminance %			Obstruction reduction area of working plane with illuminance below 0.8 of av. illuminance
Name	Mount. height (m)	Length (m)	Width (m)	Area (sqr. m)						Max	Av.	Max. task area	
Bedford House	2.00	10.40	12.50	130.00	OSRAM GEC speedpack prismatic	0.54	0.20	0.28	0.31	47	10	30	0.11
Norton House	1.58	10.90	4.70	51.20	THorn FTP236 recessed	0.57	0.39	0.23	0.48	35	10	27	0.09
Sunlight House	1.74	27.20	6.35	172.70	Moorlite Broadspread	0.55	0.72	0.35	0.39	36	9	25	0.05
Wythen-shaw office	1.95	17.84	27.36	488.00	Recessed 4 tubes 600x1200 mm	0.55	0.64	0.17	0.25	46	8	18	0.09

Table 3.1: Comparison of the offices surveyed

The results show that reductions in working plane illuminance can vary from an average of around 10 % which was common for all cases to a maximum reduction of 50 % in some cases. The results suggested that the obstruction height and reflection factors may be the main parameters affecting maximum and average reductions in illuminance respectively. They also showed that the differences in terms of light loss between the various installations were linked to the photometric properties of luminaires and room size but only tentative conclusions were drawn as to the relationship between the parameters of the installation and obstructed light loss.

3.5 Discussion

The obstructed interior work has covered three areas; the obstructed spacing to height ratio concept, analysis of illuminance conditions in obstructed interiors using a computer model and the measured effect of obstructions.

Obstructed SHR concept was shown to be more appropriate in addressing the problem of luminaire spacing since it acknowledged the effect of obstructions in terms of light loss across the task area. The points raised in the discussion of this work, however, indicate the need for development of the concept and modification of the present tentative methods of implementation.

The analysis program was designed to investigate the light loss due to obstructions in terms of illuminance drop across the working plane. It showed how the acknowledgment of the problems of obstructions could be incorporated within the design process.

In order to compare the results obtained using the analysis program with measured results, a number of surveys was carried out. A simple visual comparison of the results showed that the analysis program was capable of modelling illuminance conditions in obstructed spaces within an acceptable level of accuracy of the measurements. The need for a reliable statistical validation of the results obtained using the program is paramount if their robustness is to be established.

Survey work on the effect of obstructions on light loss has pointed the way towards the existence of some relationship between the physical and photometric properties of spaces, and the light loss across the working plane. This work however fell short of drawing any firm conclusions about this relationship and the individual effect of the various design parameters. In order to define quantitatively that relationship a large number of cases need to be investigated. Since survey work is too time consuming and difficult to undertake, computer simulation seems to be the alternative means which could be used in undertaking such work. If the validation of the analysis program were established it could be used to carry out this investigation.

3.6 Conclusion

All the published work on the lighting of obstructed interiors acknowledge the effect of obstructions. Despite this, conventional design techniques do not provide practical design guidance to deal with the problem. The techniques described in this review form the basis for future development of design tools which address the problem of obstructions in interiors. The first area where work is needed is the development of design guidance taking account of obstructions. The extension of the existing method of calculation of the spacing to height ratio is an area where such design guidance is needed. Such guidance would be based on representative cases of obstructed interiors. The second area of work is the need for a better understanding of the relationship between photometric and physical properties of obstructed spaces and the light loss. This would lead to the provision of some general guidance about light loss which could be used together with the spacing to height ratio of the obstructed space.

3.7 References

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Chapter 4

Modified Method for Calculating SHR in Obstructed Spaces

4.1 Introduction

It appears from the published work on the design of interior lighting installations that there is a consensus of opinion on the effects of illuminance conditions in terms of light loss caused by internal obstructions. Despite this fact however, conventional design methods do not allow for those effects. They assume an empty volume between the luminaire plane and the working plane.

The University of Liverpool has been undertaking a research work into the design of lighting installations in obstructed interiors. This work is intended to provide some design guidance for lighting designers on the effect on the effect of introducing obstructions in a space. This research has resulted in a computer method developed by McEwan (1) to calculate maximum and nominal spacing to height ratios for interiors which contain pre-defined "standard obstructions".

The model is based on the standard CIBSE method for calculating spacing to height ratio for empty spaces (2), to which obstructions have been introduced and their effect assessed. When the model was discussed in the previous chapter it was shown that some of its aspects needed development. In the present chapter a series of modifications are presented and the improved computer based method to calculate SHR in obstructed spaces is discussed.

4.2 Modifications to the obstruction configurations

In general lighting terms an obstruction is defined as an object which lies between the luminaire plane and the working plane. In an office for instance, this can be taken as:

a) Visual display units and word processing screens.

b) Filing and storage cabinets and paper racks.

c) Panels and screens used for dividing a large open plan office into work stations.

d) Users of the office when they are seated at the desks and their bodies cast shadow on top of the desk.

These obstructions are very common in modern offices. They are found in different combinations and positions according to the space usage. The obstruction configurations used in the programs when the model was first developed were arbitrary in size and shape. As part of developing the model it was felt necessary to introduce some modifications to both the human form and the office equipment which form the standard obstructions.

4.2.1 The human form

When a person is seated behind a desk their shadow cast on top of the desk in an area which is the most likely to be used at all times that is the central area of the desk. Also it was shown by McEwan (1) that the human form was an important obstruction as far as light loss is concerned. The importance of its shape and size in affecting the illuminance conditions over the task area has dictated the need for refining it. The square shape used in the original model has been refined to give a more faithful representation of the human form. The CIE body shadow used in Contrast Rendering Factor computation (3) has been adopted in the modified model as a standard representation of the human body. Figure 4.1 shows the new human form which consists of a torso and a head.

4.2.2 Other obstruction configurations

In the original model a variable size task area was adopted. Its size changes with the change in the spacing to height ratio as it was already shown in section 3.2.3.1. Introducing standard obstructions into the empty space has dictated the need for information on the size, shape and density of objects present in the central area of a typical office interior.

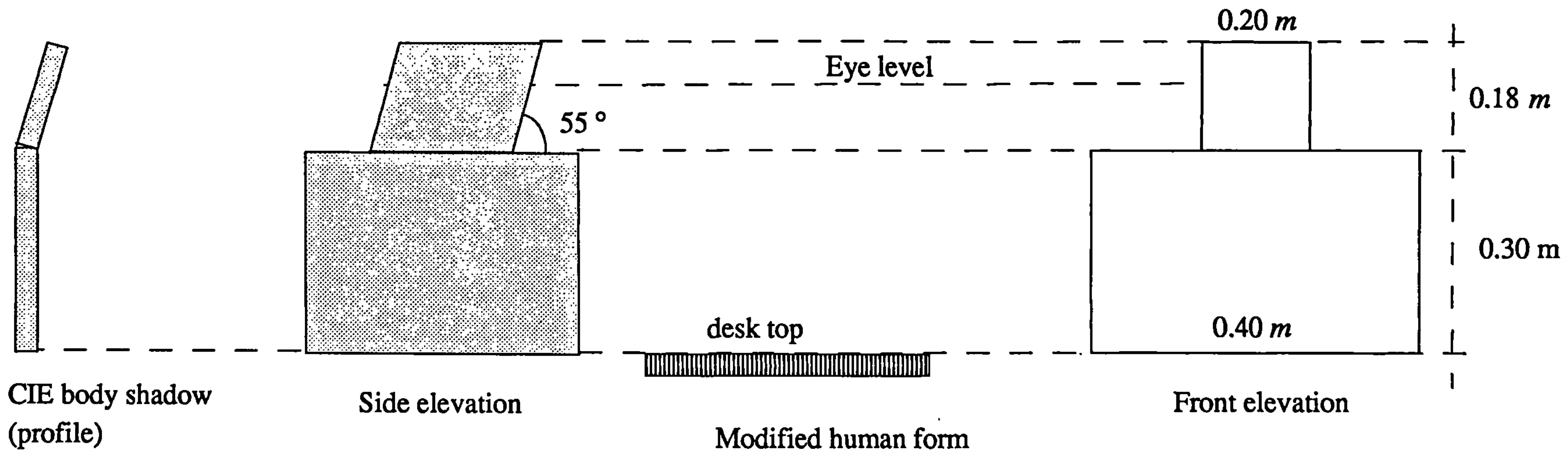


Figure 4.1: The modified human form used in the new SHROBS program

4.2.2.1 Survey work

McEwan conducted a survey of office equipment and contents in an open plan office in the University of Liverpool. The information sought was intended to provide what was needed to define "standard obstructions" in an office interior. The two obstruction configurations put forward were supposedly based on the results of that survey [1]. The author however did not present any convincing evidence which suggests that the obstructions were related to these survey findings. Contrary to the adopted obstruction configurations, the survey results for instance did not show the presence of any workstations with partitions. Since those obstruction configurations were intended to be standard the results of such a limited work do not provide the necessary information needed to define obstructions which are as close to reality as possible. This clearly shows the need for more work in order to define "standard obstructions".

4.2.2.2 Analysis of furniture manufacturers's data

In the obstructed SHR method the size of the task area is fixed and the direct illuminance calculation which determines the SHR for room installations is restricted to that defined area. Adopting such a different concept made it necessary to seek information on representative size and contents of work stations independently of the size and shape of the office. This information could be obtained either by surveying a large number of different existing office interiors or by analysis of data on office furniture provided by manufacturers. The first method is too time consuming and difficult to carry out. This is because its undertaking is dependent on some uncontrollable factors such as the willingness of office users to cooperate. Furthermore in such surveys the results obtained will depend on the shape, size and the way the office surveyed is used. The second method is more appropriate and easy to carry out. It provides information on the work stations used in offices independently from the office usage.

4.2.2.2.1 Steel Case data

Steel Case are an office furniture manufacturers based in the U.S.A and sell their products in North America and Europe. The data they provided cover office equipment such as desks and filing and storage units [4]. These office furniture elements are provided within defined workstation sizes and arrangements. As far as defining standard obstructions in an office environments this data is useful in two respects:

a) The sizes of desks and storage units are standardised and combined in different ways providing the office user with more options of layout.

b) Workstations are given in basic modules which are then arranged in different combinations to generate various layouts according to the shape and size of the office.

The sizes of the basic components for each module are given in Table 4.1. The height of the desk top above the floor is 0.75 *m*, but this could be lowered to 0.65 *m* for special purposes. The basic modules are shown in Figures 4.2 to 4.55. workstations are provided with task lights because panel wrapped work stations were used as shown in Figure 4.6. The use of local lighting substitutes for the drop in illuminance from the general installation. Nevertheless the data reviewed in this short analysis provide a useful guidance on the size and configuration of work stations.

4.2.2.2.2 Herman Miller data

The data presented in this section was provided by Herman Miller, a company specialised in furniture systems for office, health care, laboratory and industrial environments. The company is one of the world market leaders in office furniture. It has manufacturing facilities in 7 countries in North America and Europe and represented in 33 countries throughout the world. In fact it would not be surprising if, in the future, the standards established by this firm for office furniture would be adopted by office planners as references in designing layouts. Not surprisingly as well the Steel Case data contain some modules which bear similarities in layout and component sizes with some of the work stations in this data. Three layouts of existing furnished offices were provided along with product handbook for the various components of the work stations [5].

Work stations are almost identical in configuration except for the presence of dividing panels, their number and sizes. Usually work stations are L shaped with two desks; a pedestal one and a return one (see Figure 4.7). The dividing panels provide

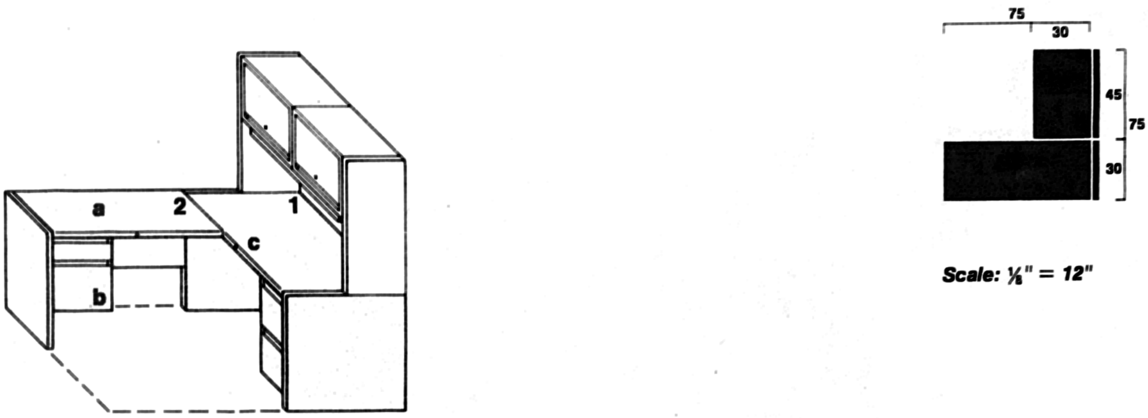


Figure 4.2: Steel Case basic module type 1 with two desks and a storage unit. The sizes are imperial units as given in the Product Handbook (1 " = 2.5 cm).

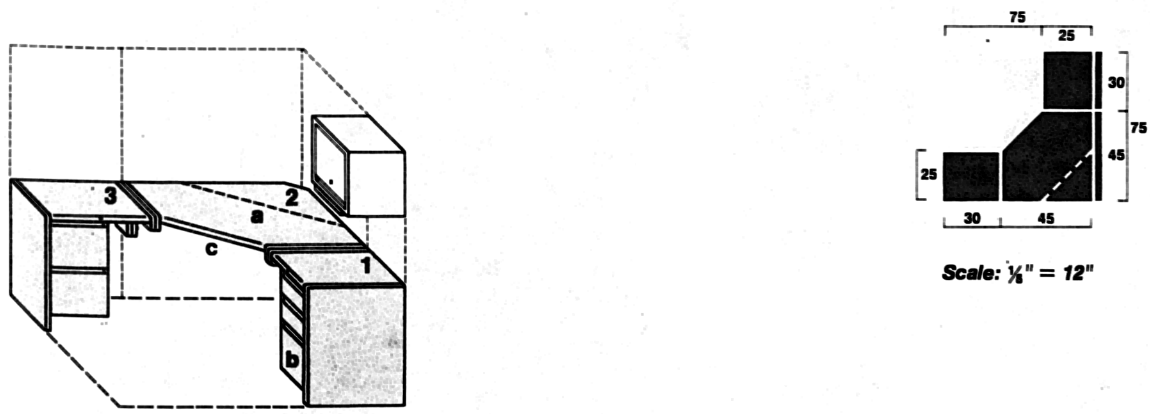


Figure 4.3: Basic module type 2, with three desks and storage facilities.

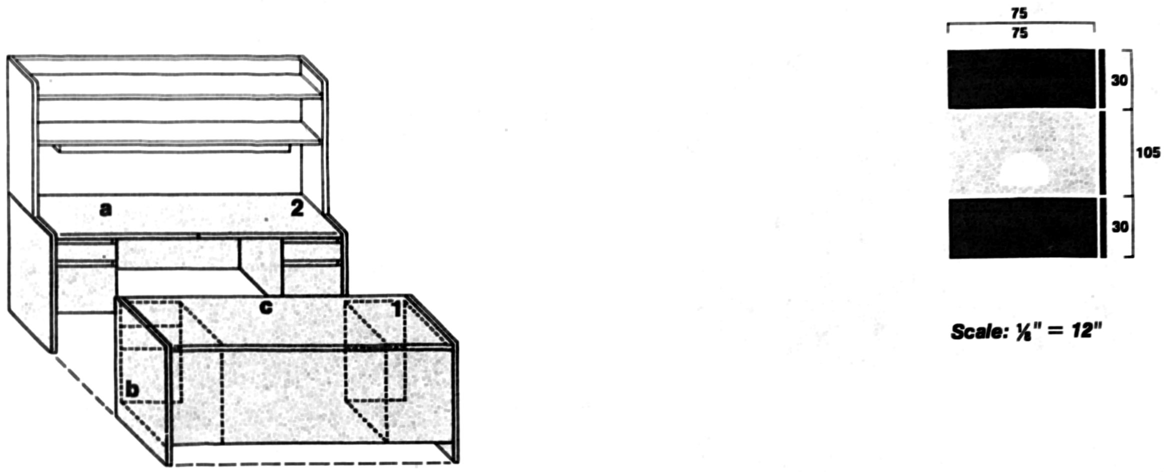


Figure 4.4: Plan and elevation of basic module type 3. It has two parallel desks and upper storage shelves.

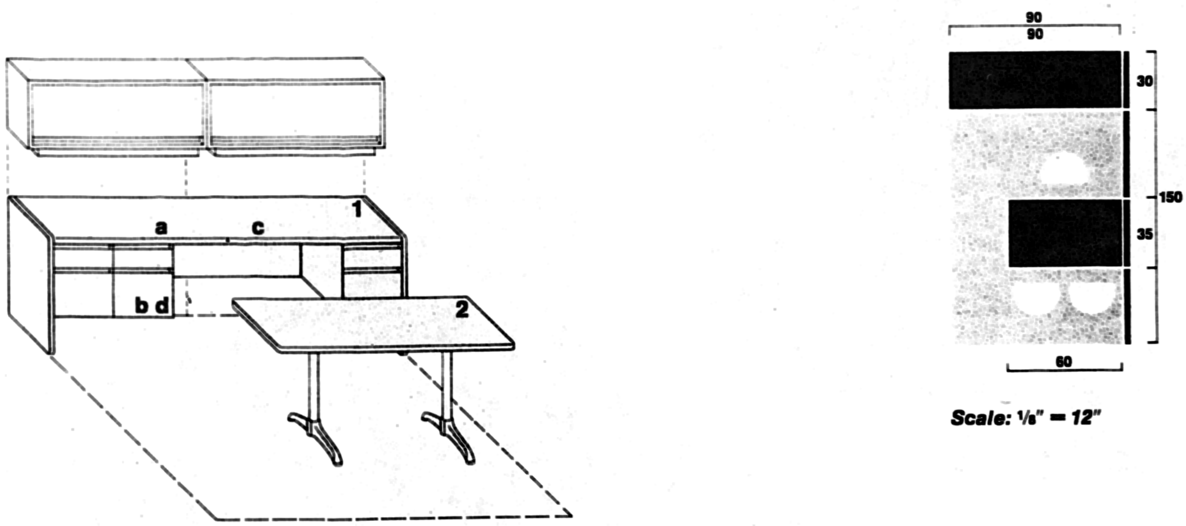
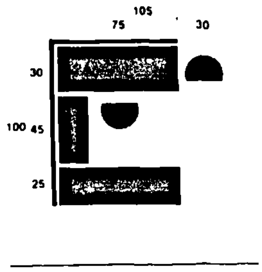
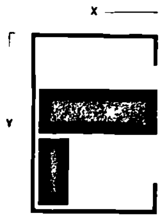


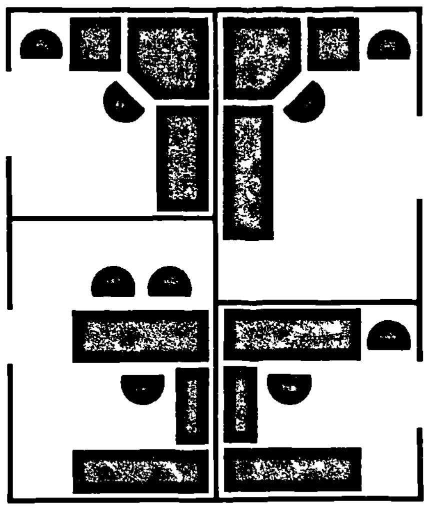
Figure 4.5: Basic module type 4 is similar to type 3 but with one table instead of a second desk.



a: Work station with panels on two sides



b:Work station with panels on three sides



c: Combination of different "closed" work stations

Figure 4.6: Different configurations of panel wrapped work stations in office interiors furnished according to Steel Case standard data

Module type	Work station size (m)		Number of desks	Size of desk (m)		Upper storage size (m)		Presence of lower storage
	width	length		width	length	width	height	
1	1.87	1.87	2	0.75 0.75	1.87 1.87	1.87 1.87	0.57 or 0.87	Yes
2	1.87	1.87	3	0.62 0.62 0.62	0.75 1.12 0.75	1.87 1.87 1.87	0.57 or 0.87	Yes
3	1.87	2.62	2	0.75 0.75	1.87 1.87	1.87 1.87	0.57 or 0.87	Yes
4	2.25	3.75	1 desk + 1 table	0.75 0.75	2.25 1.50	2.25	0.57 or 0.87	Only with desk

Table 4.1: Sizes of work stations and their components for the four modules provided by Steel Case

shelving and storage facilities. Additional storage and filing facilities are provided by units positioned away from the work stations. These work stations have been classified into different types according to the number of panels surrounding them. Table 4.2 gives the number of work stations of each type for each office and Table 4.3 shows the number of work stations for each combination of panels. The panels are of three types; P_1, P_2 and P_3 which are 1.07 *m*, 1.15 *m* and 1.57 *m* high above the floor level respectively.

The width of panels follow that of the desks. The combinations of panels given in table 3 are as follows:

a) $2P_3$: 2 type 3 panels

b) $1P_1+2P_3$: 1 type 1 and two type 3 panels

c) $2P_1+1P_3$: 2 type 1 and one type 3 panels

d) $3P_3$: 3 type 3 panels

Table 4.2 shows that out of 176 work stations from the three offices 140 are surrounded by three panels. This represent 79% of the total. Among those work stations 68 % are of the combination $2P_1$ and $1P_3$. At first glance these may seem highly obstructed work stations but one has to bear in mind the heights of panels which are only 0.32 *m*, 0.40 *m* and 0.82 *m* above the working plane.Task lights are provided for all work stations which were of medium obstruction density when compared to the heavily obstructed cases of Steel Case and the lightly obstructed ones in the office surveyed by McEwan [(1)].

4.2.3 Size of the new task area

In this improved method for calculating SHR for obstructed spaces the task area is defined as a physical horizontal surface in a work station where office work is performed. This surface is restricted to a desk top rather than the whole horizontal plane across the room at 0.75 *m* above the floor which is used as a notional working plane in the TM5 model [(1)]. In the data analysed in the previous section desks are of two sizes; 0.75 *m* by 1.87 *m* in the case of Steel Case [(4)] and 0.81 *m* by 1.80 *m* (or 1.20 *m* if needed) in that of Herman Miller [(5)]. These desk sizes were used in work stations which have task lights contributing to the illuminance of the task area and

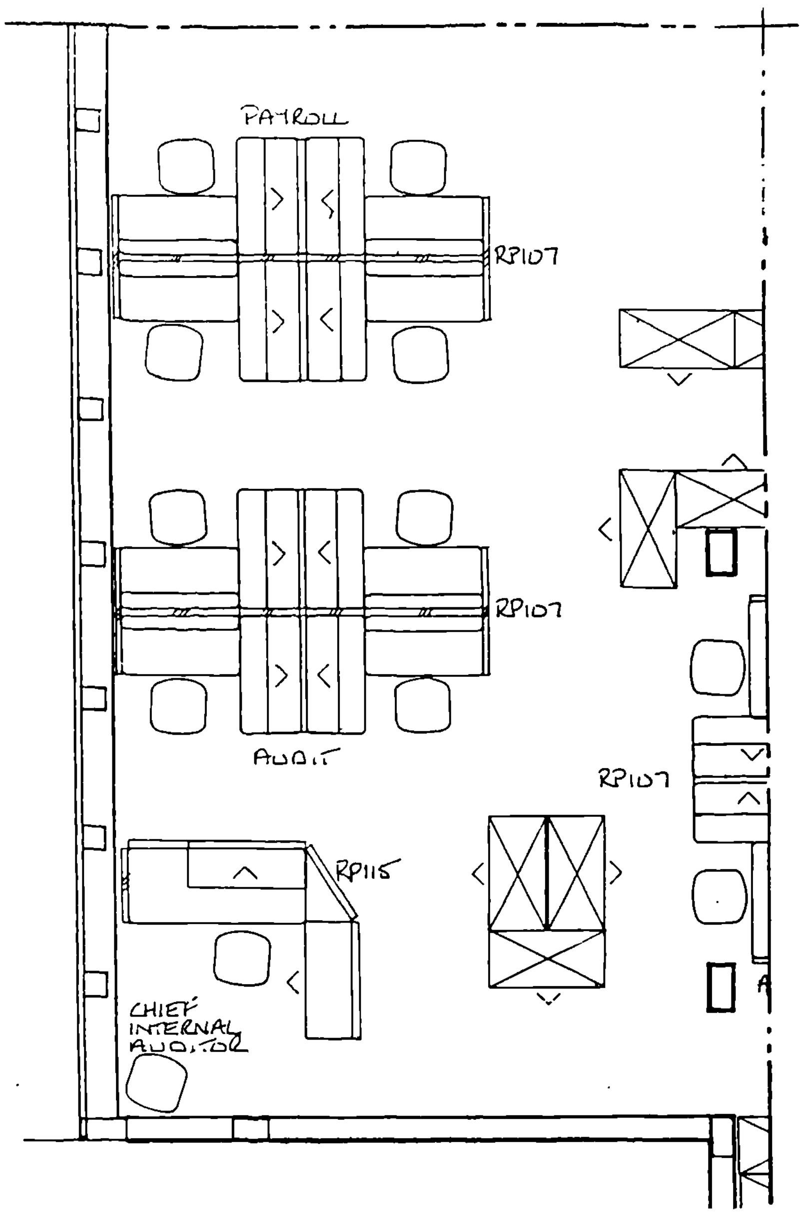


Figure 4.7: Layout of work stations along the wall in an office furnished using Herman office furniture items

Office No.	Workstations			
	with 1 panel	with 2 panels	with 3 panels	with 4 panels
1			37	2
2	3	8	52	14
3		9	51	
Total	3	17	140	16
Percentage out of total (3 offices)	2%	10%	79%	9%

Table 4.2: Workstations of each panel combination for every office. (data supplied by Herman Miller (5))

Nbre. of panels	combination	Nbre. of W.stations	Percent. out of total
2	2P3	12	7%
3	1P1 + 2P3	32	18%
	2P1 + 1P3	68	39%
	3P3	23	13%
others	Different combinations	41	23%

Table 4.3: The various combinations of panels used in dividing the workstations. (data from Herman Miller product Handbook (5))

illuminating any possible areas covered by distracting shadows. In this model if such a desk size is adopted, consideration ought to be given to those areas of shadow, in particular along the edge of the task where the angle of incidence of light is small and the shadow is very pronounced. The desk size used in this model was based on these considerations. Starting from a basic size of 0.80 *m* by 1.80 *m* as an area of a desk top, a strip of 0.10 *m* wide which represents areas of distracting shadows is then added on along the edge of the desk. This gives a desk size of 1.00 *m* by 2.00 *m*, these figures are then rounded up to 1.20 *m* X 2.10 *m* to give a size which is a multiple of 0.30 *m* in both directions and that represent a building module (see Figure 4.8). This size is used throughout in running the programs. If for special purposes, however, one would like to use a different size the program does provide the facility. Using a physically defined task area has two main advantages:

a) It provides a better representation of real conditions in an office rather than using one quarter of the central area assuming that it represents the whole central area by symmetry. This assumption is no longer valid since introducing obstructions breaks up the symmetry in the central area.

b) Defining the task area in the same way as the obstructions gives the model a more consistent criterion by which uniformity of illuminance is assessed. In the TM5 model for instance,having a variable size task area makes the assessment of uniformity not compatible with the reality where illuminance is measured at known points on a physically known working area.

4.2.4 New standard obstruction configurations

Two main features appear from the sets of data analysed in the previous sections, that is the identification of the different pieces of equipment used in offices and the different sizes of objects projecting above the working plane. The furniture used in those offices could fall into two main categories:

a) Filing, storage and partitioning facilities. In some cases they are combined in one element as in the case of panel mounted shelves. They can also be separated as in the case of a dividing panel on one side and a filing unit on the other side of the desk or even away from the work station. Two different

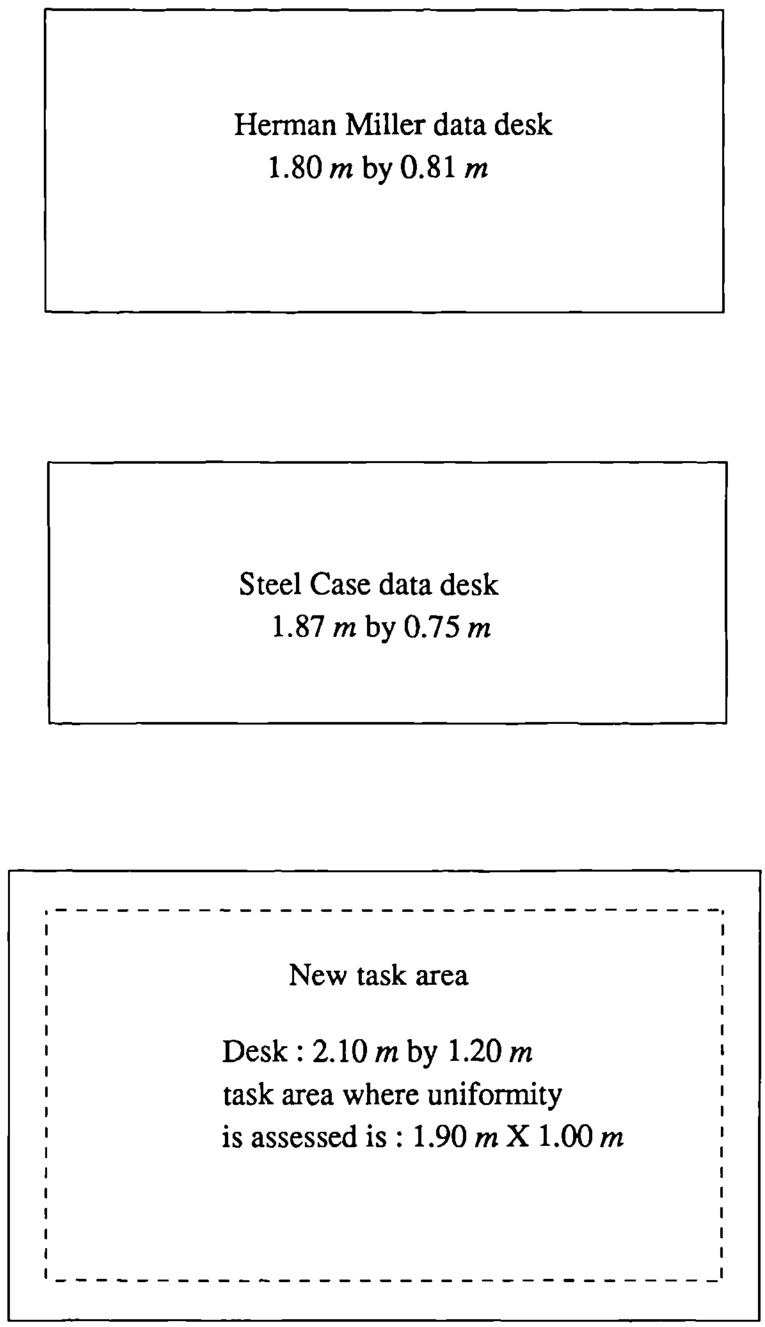


Figure 4.8: Derivation of the new task area from the existing sizes.

heights could be attributed to this category, 0.75 *m* and 0.50 *m* above the working plane. The first one is suitable for partitions or panel mounted shelves whereas the second one is more appropriate to a filing cabinet.

b) Typing and computer equipment where two heights could be attributed; 0.50 *m* and 0.25 *m* above the working plane. The first height could represent a high base visual display unit while the second one is suitable for representing a typing machine on a side table with a built in well or a paper rack on top of the desk.

Based on those findings new obstruction configurations have been put forward. In these configurations emphasis is put on the density of obstructions present and their heights rather than the nature of the obstruction as it was suggested in the original model [(1)]. The configurations cover typical office furniture such as filing and storage cabinets, visual display units, typewriter, partitions, paper racks and people seating at desks.

The three heights (0.75 *m*, 0.50 *m* and 0.25 *m*) identified earlier are used as standard heights for the different obstructions. The new configurations are classified according to the density of obstructions surrounding the desk. This classification is as follows:

a) Lightly obstructed interior where two obstructions are present. One is of a medium height (human form) and a second one of a lower height (0.25 *m*). This could represent whether a paper rack or a typewriter in well.

b) Medium obstructed case with two medium height obstructions, that is a human form and a filing cabinet or high base visual display unit (V.D.U.) and a third obstruction of a lower height which is a paper rack.

c) Heavily obstructed case with three obstructions, two of a medium height (0.50 *m*); a human form and a filing cabinet or a V.D.U on one side with a third obstruction of a larger height (partition 0.70 *m* high) on the other side.

The different obstruction configurations are shown in Figures 4.9 to 4.12.

4.3 Calculation of illuminance

In order to calculate the maximum SHR of the installation illuminance is

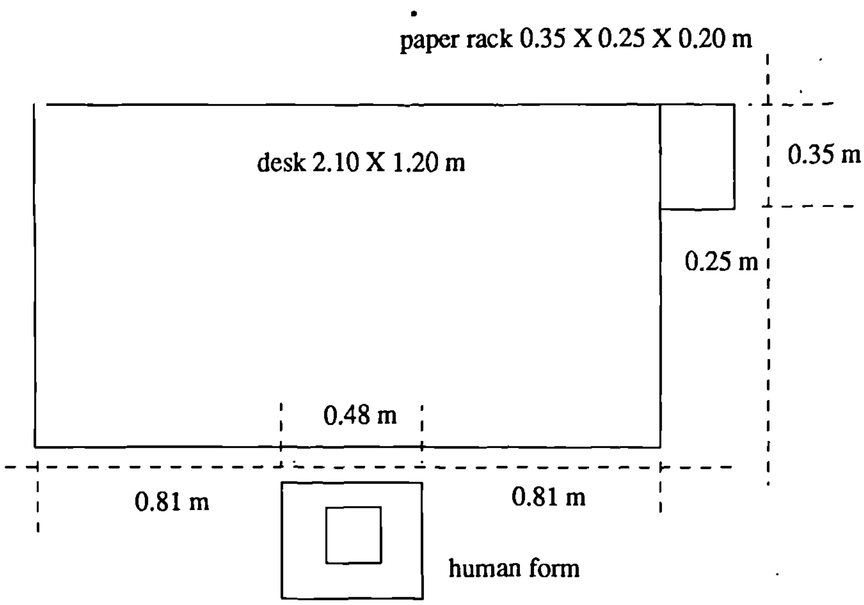


Figure 4.9 : lightly obstructed case with a human form and a paper rack

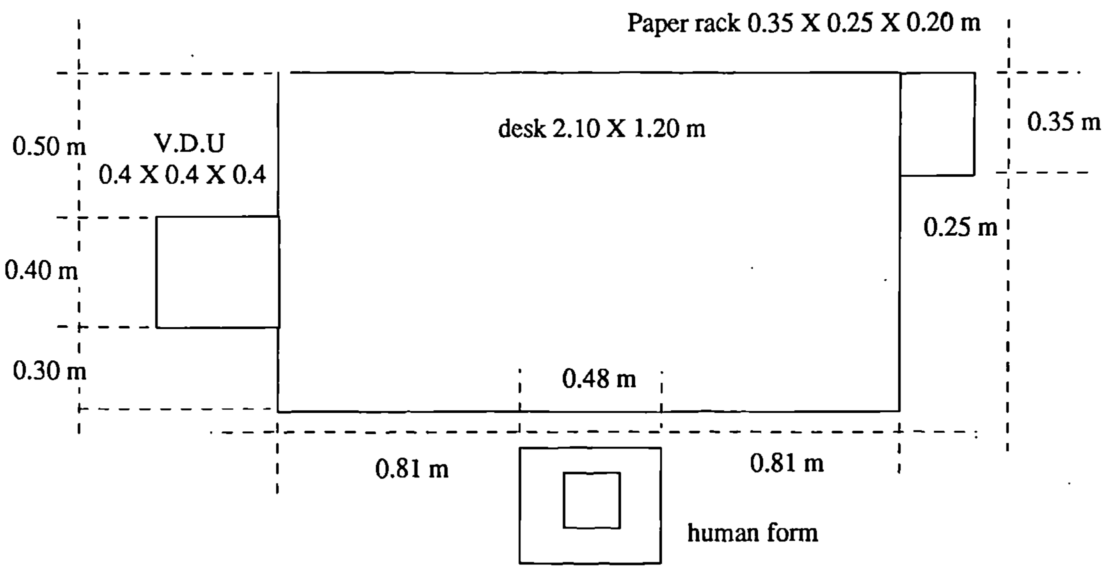


Figure 4.10 : Medium obstructed case (version 1) with a V.D.U , a human form and a paper rack

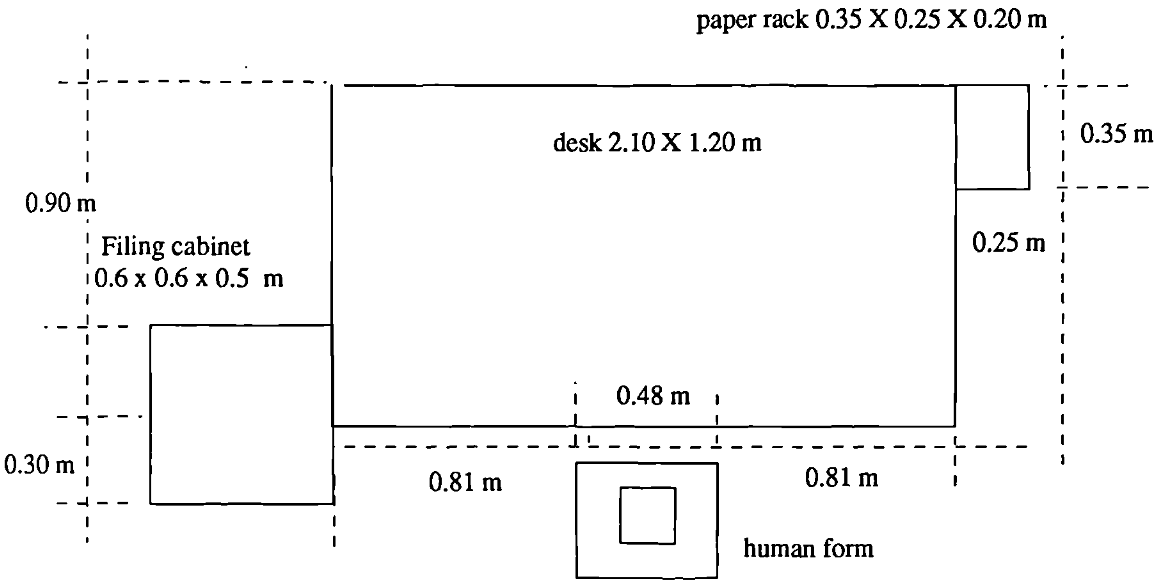


Figure 4.11 : Medium obstructed case (version 2) with a filing cabinet a human form and a paper rack

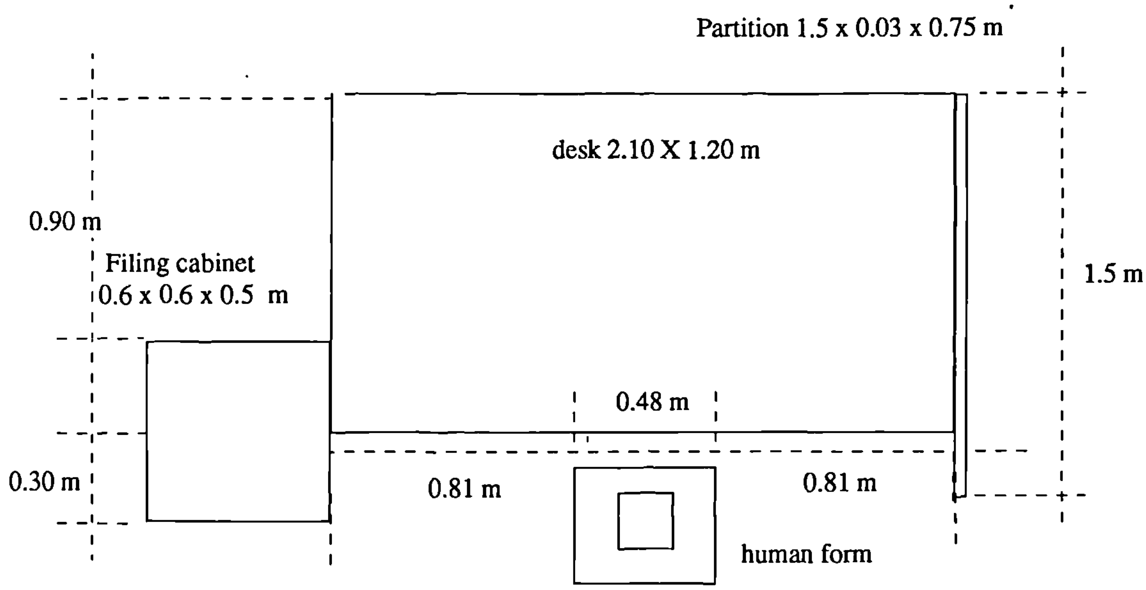


Figure 4.12 : Heavily obstructed case with a partition a human form and a filing cabinet

calculated over a grid of points on the task area and minimum, maximum and average values are found, from which uniformity can be derived and the SHR assessed whether acceptable or not.

4.3.1 Grid of calculation points

The grid of calculation points affects the uniformity, particularly in the obstructed case. In the CIBSE TM5 method (2) the size of the grid is not fixed and consequently the distance between two adjacent points varies with varying SHR. For example in the case of 36 point square grid, as it is the case of McEwan's model, that distance varies from 0.09 *m* at 0.5 SHR to 0.45 *m* at 2.5 SHR. These figures are based on a mounting height of luminaires of 1.80 *m*. If the same assumptions are applied to an obstructed case with defined task area that would mean the number of calculation points decrease with increasing SHR. This itself does not seem reasonable when assessing the uniformity of illuminance. For example if illuminance is measured at 0.10 *m* interval on top of a desk and then under the same lighting conditions readings are taken every 0.40 *m*. there would be some cases where both minimum and maximum or one of them will be missed out in the second reading. In this case the uniformity ratios for both sets of readings would considerably different. The same principle applies to the theoretical assessment of uniformity. For these reasons in this improved model the distance between two adjacent points is fixed at 0.10 *m* in both directions. A flow chart diagram of the calculation method is shown in Figure 3.4 in the previous chapter.

4.3.2 Assessment of obstruction effects

When assessing the contribution of a luminaire to the illuminance at a point checks are made to establish whether a linear luminaire is partly or fully blocked by the obstruction present. Those checks are made by comparing angles subtended at the considered point by the ends of the obstruction and those of the luminaire in plan and elevation. It has been shown in the third chapter that the original model compares two incompatible angles in elevation to determine if the point is not seen from the luminaire. In the present modified version of the method we suggest to check on the possibility of the luminaire (or part of it) being blocked by comparing the angles of elevation ∂ and ß shown in Figure 4.13.

4.3.3 Calculation of angle of incidence (point source)

The calculation of illuminance at any point illuminated by a point source is given by the inverse square and cosine law of illuminance (6). The definition used in the original model (1) suggests that the angle of incidence is equal to an angle between any point at the source level in a vertical plane passing through the source in the arbitrarily chosen Y-direction and a corresponding point at the working plane level in a parallel plane passing through the calculation point (see Figure 3.8 in Chapter 3). The angle of incidence in practice is independent from the direction of the point and is given as the angle opposite the breath of the triangle given by the source, the point on the task directly beneath it and the calculation point as shown in Figure 4.14. The new method makes use of this definition and calculates the direct illuminance at any point according to the inverse square law.

4.3.4 Aspect factor calculations

When using linear luminaires in an installation, the calculation of direct illuminance at any point due to the incident flux from any particular luminaire is performed using the Aspect Factor calculations. These calculations are based on five theoretical intensity distributions of luminaires which are given as functions of cosine the axial angle (7). For each of these classifications the ratio of axial intensity I_α / I_θ is given as follows:

a) $\cos\alpha$

b) $1/2\,(\cos\alpha + \cos^2\alpha)$

c) $\cos^2\alpha$

d) $\cos^3\alpha$

e) $\cos^4\alpha$

The angles α and θ are shown in Figure 4.15 .

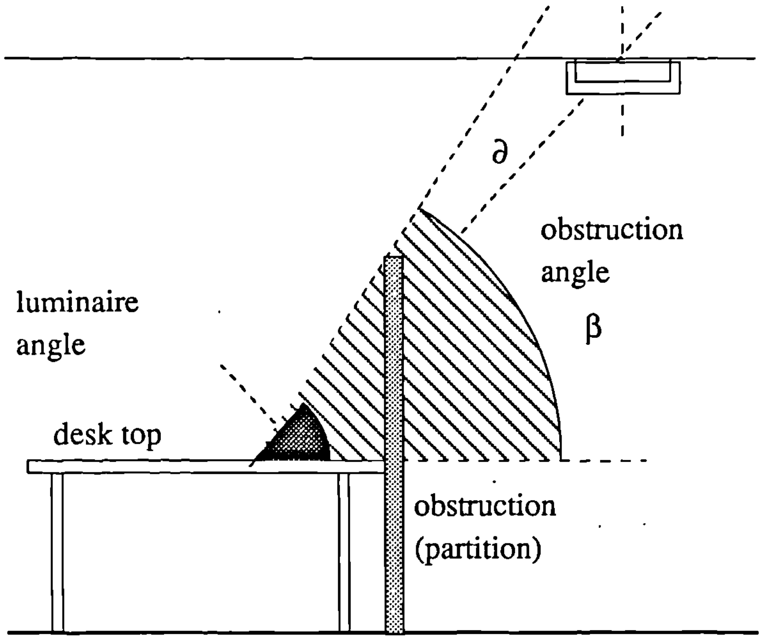


Figure 4.13 : Angles of elevation of obstruction and luminaire at a calculation point, on a cross section representing an obstructed case.

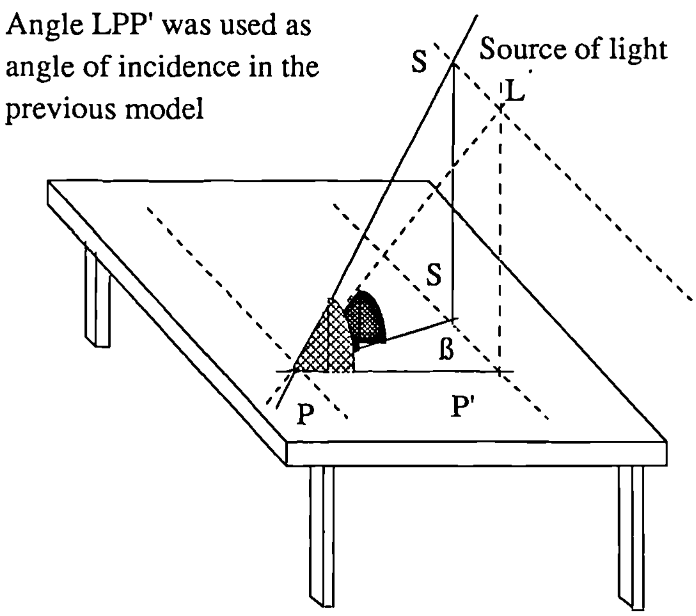


Figure 4.14 :The difference between the real angle of incidence and the assu

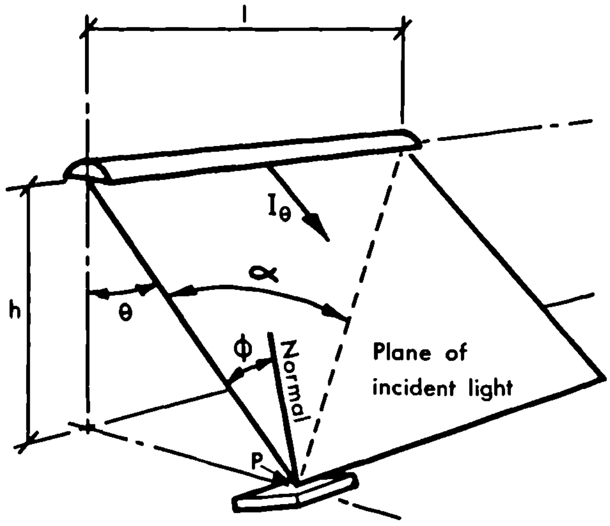


Figure 4.15: The different angles needed to calculate the aspect factors for a linear source with the plane of interest parallel to the source axis and the calculation point opposite end of source

For α and θ values of 45° and 0° the above expression have dividing limits of 0.65, 0.545, 0.46, 0.385 and 0.325 respectively. These values are used to check which of the above expressions is used to evaluate the aspect factor (7). This method is rather convenient and produces results which have a sound theoretical basis. In the obstructed SHR method some of these formulae have been replaced by other expressions for which neither method of derivation nor reference is given.

4.3.5 Improvement to the input / output of the program

The ability of the program to read in intensity distribution data has been improved to include any form of tabulated intensities as it is provided by luminaire manufacturers. This means that if the data contain only one single column of average intensities (in case of a point source) the program will be able to process it. The output of the program has been developed from a table of uniformity ratios for each SHR value to plots of direct illuminance grid over the task area along with uniformity ratios for each SHR value. This facility is important in assessing local light loss over the task area.

4.3.6 Uniformity ratio

The calculation points are evenly spread over the task area at 0.10 m interval in both directions. When illuminance is calculated, a strip 0.10 *m* wide around the desk is excluded from the task area when uniformity is assessed using either *minimum/maximum* or *minimum/average* illuminance. Excluding a 0.10 *m* strip around the desk , where in most cases the sudden drop in illuminance occur has the advantage of not condemning the uniformity of the task area when a minimum point occurs on the edge of the desk . Besides in practice nobody would use the whole area of the desk right up to the edge.

4.4 Results of Obstructed SHR computer calculations

Two separate computer programs were developed, one for each type of luminaires (linear or point source) using a Pascal programming language. The main difference between the two programs is in the way the effect of obstructions is checked upon and the direct illuminance is calculated at each point of the calculation grid. In the case of a point source the checking on the contribution of any luminaire in the installation to the illuminance at the point considered resulted in either a "see" or a "no see " situation based on the comparison of angles subtended by the ends of the obstruction and the luminaire at that point. If a " see " decision is reached then the illuminance from that luminaire to the point is calculated using the inverse square and cosine law. When the checking on the obstruction results in a " no see " case the illuminance from the luminaire to the calculation point is nil.

When a linear luminaire is used the program first determines the unobstructed section (or sections) which then is treated as a luminaire and the contributing illuminance is calculated using the aspect factor calculations.

4.4.1 Linear luminaires

The linear luminaires program was run using four different types of luminaires for which the intensity distributions along with the results are shown in Table 4.4. For each luminaire the program was run first with the unobstructed case and then the different cases of obstruction configurations were introduced one at the time. For each obstructed case first the desk was positioned perpendicular to the luminaire axis. At a second stage the desk was positioned parallel to the luminaire axis.

4.4.1.1 Twin lamp Broadspread reflector

In the case of a desk perpendicular to the luminaire axis the maximum spacing to height ratio (SHRMAX) has dropped from 1.88 for the empty case to 1.35 for the lightly and medium obstructed case (version 1 using a V.D.U) to 1.28 in the case of a medium case (version 2 using a filing cabinet) to reach a final value of 1.26 for a heavily obstructed case.

When the desk is parallel to the luminaire axis SHRMAX dropped from 1.88 for the unobstructed case to 1.50 for the lightly obstructed case. When the medium and heavily obstructed cases are introduced the 0.7 *min./max.* uniformity ratio threshold was not reached and consequently the uniformity test failed. The failure is usually caused by a side obstruction (V.D.U, filing cabinet or partition) but not the human form.

The uniformity ratio based on *minimum/average* illuminance gives SHRMAX

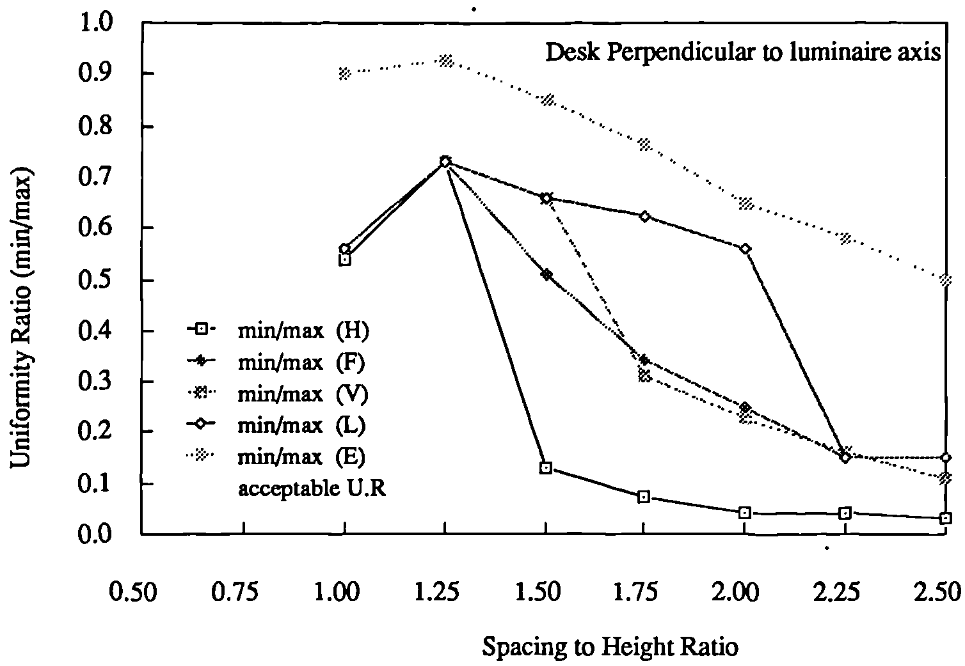


Figure 4.16: Variation in uniformity ratio as a function of SHR for empty and obstructed interiors lit by a luminaire 1 type installation.

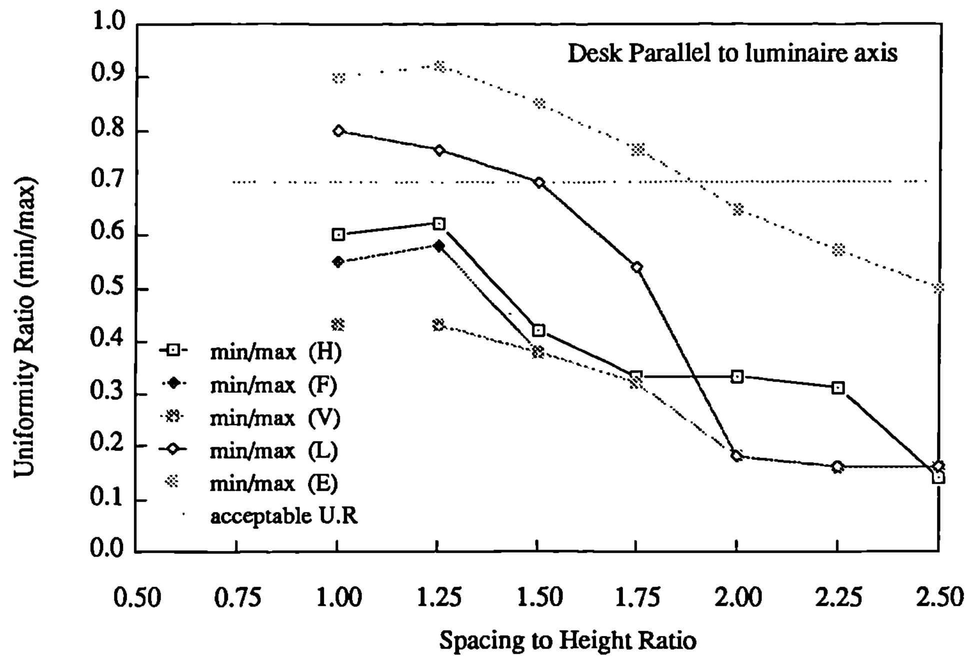


Figure 4.17: Variation in uniformity ratio as a function of SHR for empty and obstructed interiors lit by a luminaire 1 type installation.

results which follow the same pattern of that of the minimum to maximum based SHRMAX. This is mainly due to the effect of the minimum illuminance. In fact in some cases only one point right on the edge of the notional task area has a very low illuminance and therefore condemn the uniformity of the whole area. Figures 4.16 and 4.17 show the variation in uniformity ratio as a function of the spacing to height ratio for the empty case and the different obstructed cases. The SHRMAX values for each of the cases are given in Table 4.4.

4.4.1.2 Twin lamp recessed modular diffuser

When the desk was positioned perpendicular to the luminaire axis all the obstructed cases have reached the 0.7 *min./max.* uniformity ratio threshold. The SHRMAX has dropped from 1.63 for an empty case to 1.34 for a lightly and a medium obstructed case (version 1). When the V.D.U was replaced by a filing cabinet (medium obstruction version 2) the SHRMAX has dropped again to 1.30 and to finally reach 1.25 when a heavily obstructed case was considered.

When the desk was positioned parallel to the luminaire axis more cases fail the 0.7 uniformity ratio criterion compared to those of the perpendicular case. This is mainly due to the drop in illuminance which occurred not only on the edge of the task (within the 0.10 *m* safety strip) but also in the middle. The plots of illuminance in Figures 4.18 illustrate this situation. The SHRMAX has dropped from 1.63 for an empty space to 1.36 for a lightly obstructed one and then fails the 0.7 limit for the remaining cases.

The *minimum/average* illuminance uniformity ratio based SHRMAX follow the same pattern of that of the *minimum/maximum* and the number of cases satisfying the uniformity criterion is the same. The variation in uniformity ratio as a function of SHR for the empty and obstructed cases is illustrated in Figures 4.19 and 4.20. The SHRMAX values for the same cases are shown in Table 4.4.

4.4.1.3 Twin lamp prismatic reflector

In the case of a desk perpendicular to the luminaire axis , at medium SHR values the drop in illuminance occur within the 0.10 *m* strip around the edge of the task and therefore all cases have passed the 0.7 *min./max.* uniformity ratio. The SHRMAX has dropped from 1.70 for an unobstructed case to 1.40 for both the lightly and medium

1047	1029	1001	975	943	907	868	827	787	733	703	663	625	1049	1054	1061	677	750	804	868	917	295
1151	1142	1110	1130	1100	1107	1095	1072	1064	1071	1067	1067	1071	1078	1011	1098	1110	1112	1112	1119	1102	1151
1151	1146	1106	1107	1029	1023	1008	997	989	987	962	940	920	903	889	1098	1110	1112	1113	1117	1146	1151
1142	1021	1065	1094	1084	1073	1067	1057	1048	1053	1049	1047	1046	1079	1087	1098	1108	1120	863	1122	1113	1149
1140	970	1054	1090	1081	1074	1065	1055	1047	1053	1049	1047	1046	1051	1056	1062	1107	1119	867	939	1115	1146
935	945	1043	1084	1081	1082	1072	1067	1061	1070	1069	1069	1070	1079	1087	1094	1106	1117	1112	1119	1114	1142
1138	922	1091	1091	1086	1079	1070	1086	1078	1069	1069	1069	1069	1078	845	1093	1105	1102	1122	1131	1126	1138
1133	1131	1126	1120	1110	1102	1092	1082	1078	1068	1068	881	865	859	849	1092	1091	1110	1120	1126	1131	1133
1132	1118	960	1056	1065	1061	1054	1048	909	892	874	861	871	863	857	1090	1101	1110	1118	1125	1130	1132
1097	560	580	1063	1061	974	956	936	918	903	884	873	868	862	861	1096	1107	1115	1124	1130	1134	1136
1133	1116	559	994	983	970	963	943	924	909	891	881	879	875	878	1085	1094	1105	1112	1128	1132	1133
1086	1053	1056	1047	984	994	997	984	931	836	873	865	806	884	897	1085	1074	1099	1113	1116	1119	1125
1084	1058	1051	1048	1027	1015	1015	938	959	800	848	835	751	902	866	1075	1090	1095	1110	1113	1119	1122

Figure 4.18: Plot of illuminance across the working plane for an obstructed interior lit by a linear luminaire type 2.

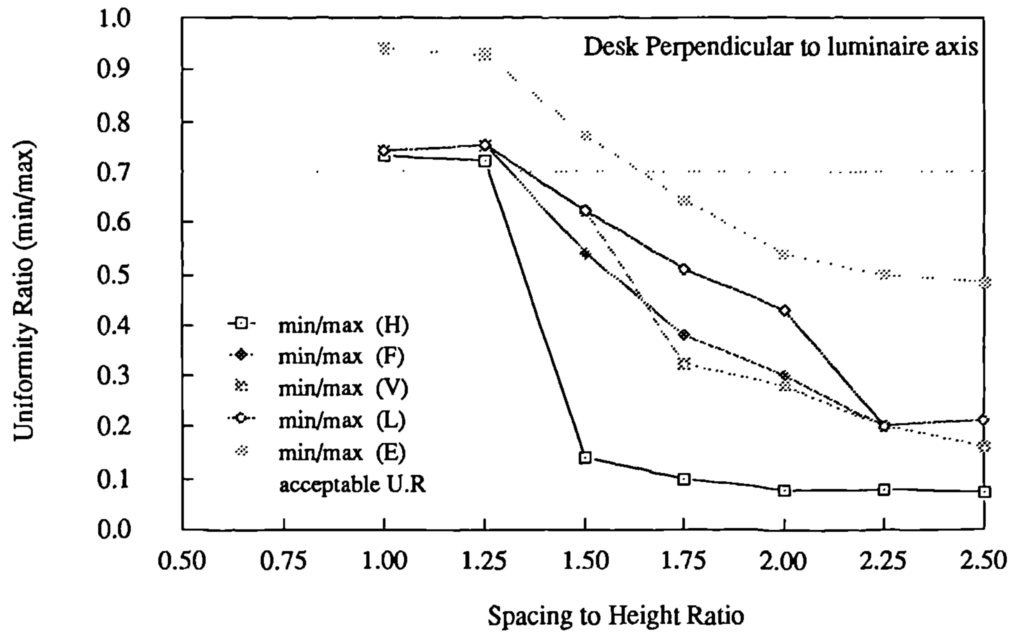


Figure 4.19: Variation in uniformity ratio as a function of SHR for empty and obstructed interiors lit by a luminaire 2 type installation.

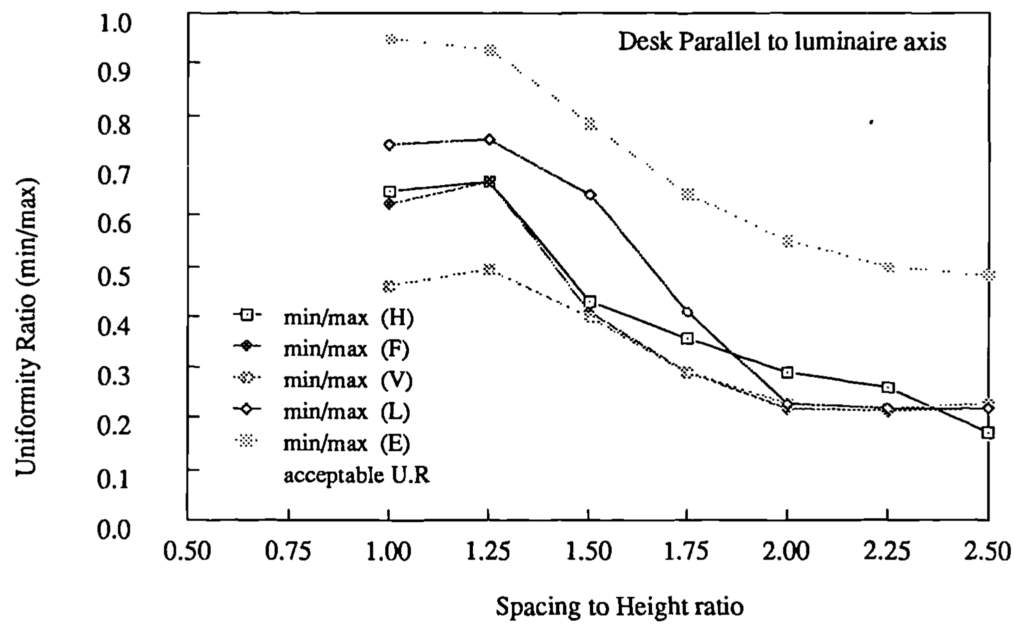


Figure 4.20: Variation in uniformity ratio as a function of SHR for empty and obstructed interiors lit by a luminaire 2 type installation.

obstructed case (version 1). When the filing cabinet was introduced in the medium obstructed case (version 2) the SHRMAX reached 1.33 and and dropped again in the case of heavy obstruction to reach 1.27.

When the position of the desk was changed to be parallel to the luminaire axis both the medium (version 1 with V.D.U) and the heavily obstructed cases failed the 0.7 threshold. For the remaining cases the SHRMAX has dropped from 1.7 for the empty case to 1.00 for the lightly obstructed case and picked up again to reach 1.25 in the case of a medium obstructed case (version 2 with a filing cabinet).

The *minimum/average* illuminance based SHRMAX has about the same cases failing the 0.8 test. In this case as well, there was a sharp drop in SHRMAX from that of the empty case to that of the lightly obstructed case. In the remaining cases the same pattern as that of the *mini/max.* is found. Figures 4.21 and 4.22 illustrate the variation in *min./max.* uniformity ratio as a function of SHR.

4.4.1.4 Twin lamp linear bat-wing luminaire

When this luminaire was used all cases have satisfied the min./max. uniformity ratio criterion in the case of a desk perpendicular to the luminaire axis. As shown in Table 4.4 the drop in the SHRMAX from one case to an other is quite steady. From 1.90 for the empty case it came down to 1.52 when a lightly obstructed case was considered. In the case of V.D.U version of a medium obstructed interior SHRMAX was 1.50 and then dropped again to reach 1.25 when a filing cabinet was used. The introduction of a partition in a heavily obstructed case has not made any changes to the SHRMAX which was the same as that of the medium obstructed case (version 2).

When the desk was parallel to the luminaire axis only the lightly obstructed case has satisfied the uniformity criterion to have an SHRMAX of 1.00 while the remaining obstructed cases failed the uniformity criterion at all SHR values.

The main features of these results could summarised in the following points:

1) In the case of workstations with desks perpendicular to the luminaire axis all obstructed cases have satisfied the 0.7 *min./max.* uniformity ratio for all luminaires. When the desk was positioned parallel to the luminaire axis only the lightly obstructed case has satisfied this criterion, except for one medium case.

2) When the desk was perpendicular to the luminaire axis there were some similarities between the different cases in terms of SHRMAX. for instance the lightly

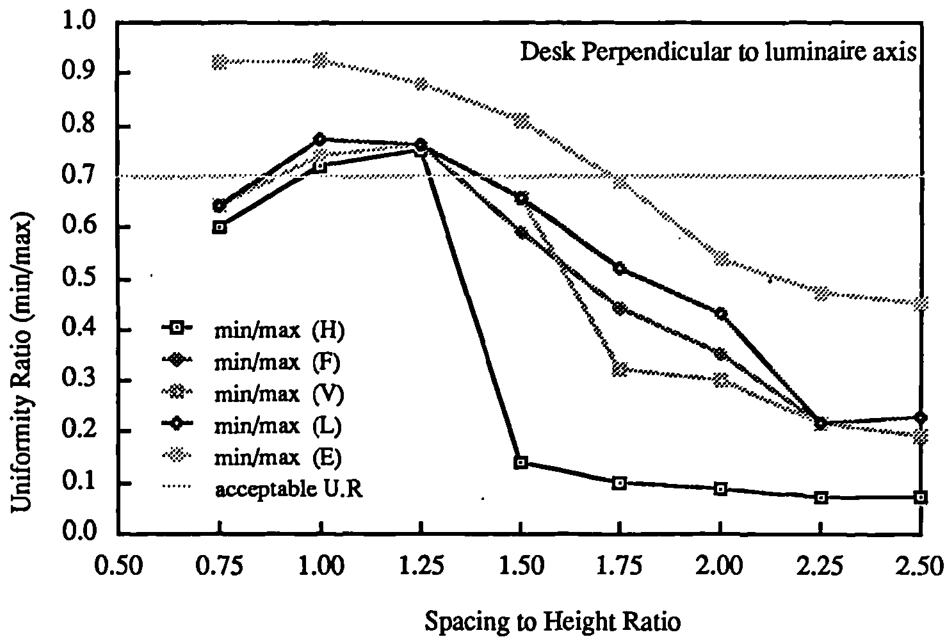


Figure 4.21: Variation in uniformity ratio as a function of SHR for empty and obstructed interiors lit by a luminaire 3 type installation.

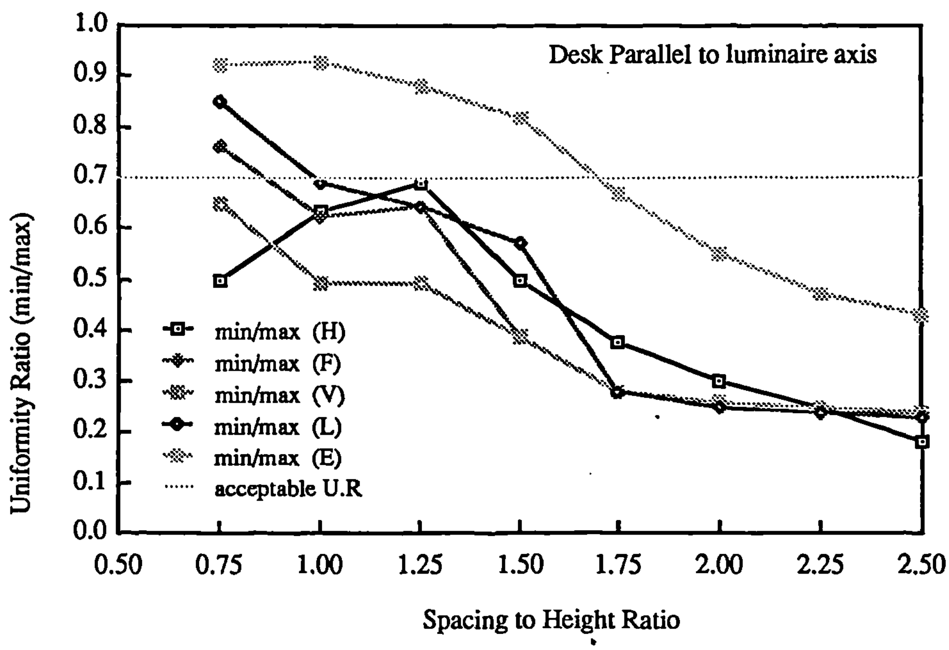


Figure 4.22: Variation in uniformity ratio as a function of SHR for empty and obstructed interiors lit by a luminaire 3 type installation.

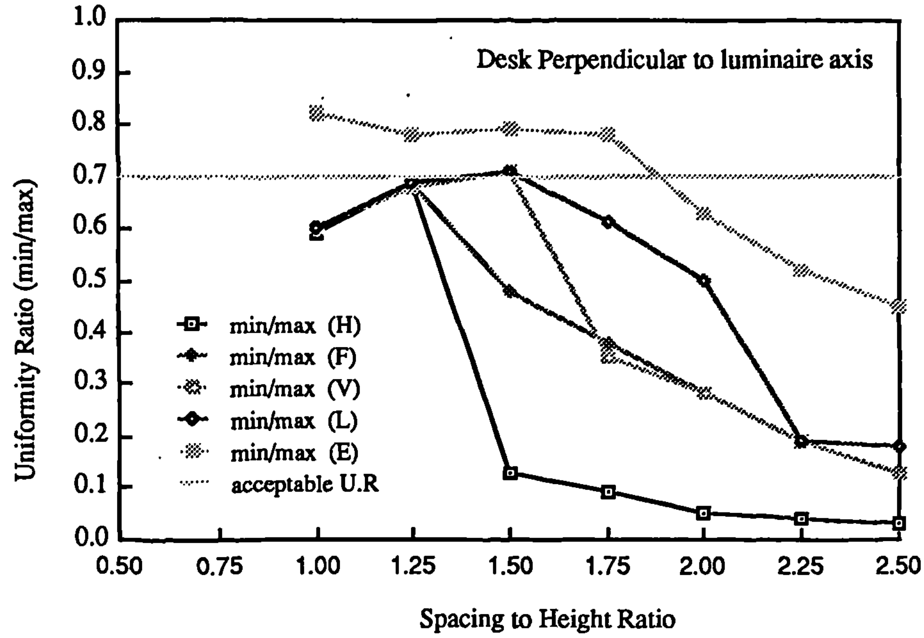


Figure 4.23: Variation in uniformity ratio as a function of SHR for empty and obstructed interiors lit by a luminaire 4 type installation.

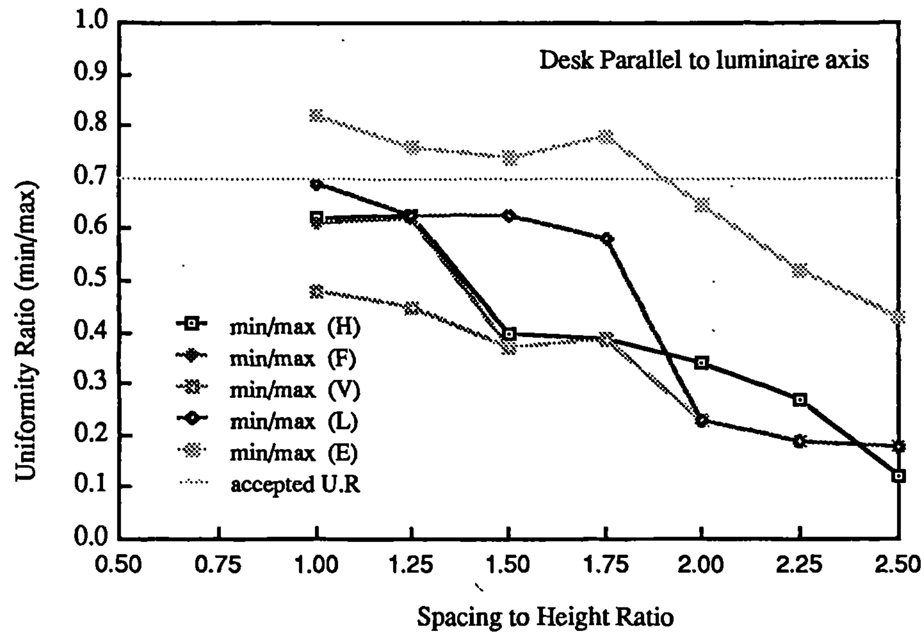


Figure 4.24: Variation in uniformity ratio as a function of SHR for empty and obstructed interiors lit by a luminaire 4 type installation.

obstructed case was similar to the medium obstructed case (version 1 with V.D.U), whereas the medium case (version 2 with a filing cabinet) is close to the heavily obstructed case.

3) In the case of luminaires positioned perpendicular to the desk, most of the sharp drop in illuminance occurred within the "safety zone" along the 0.10 *m* strip. Rotating the luminaires at 90° resulted in the drop occurring at isolated points (sometimes one or two) inside the notional task area and therefore more cases failed the *minimum/maximum* uniformity criterion. This phenomenon highlights the problem of relying on single points to assess the uniformity of illuminance.

4) When the desk was parallel to the luminaire axis the sharp drop in illuminance which causes the uniformity to be condemned is usually caused by the side obstructions such as V.D.U, filing cabinet or partition.

5) The human form has more effect in the case of a perpendicular desk than that of a parallel one.

4.4.1.5 Effect of individual obstructions

In order to establish the effect of the individual elements which make up the different obstruction configurations the program was run with one element at the time using the twin lamp Broadspread reflector. The results were as follows:

a) : When the desk was perpendicular to the luminaire axis the human form has an important effect particularly at lower and medium SHRNOM values (up to 1.75). For higher SHRNOM values it does not determine the minimum and consequently its effect is not very relevant.In the case of a desk parallel to the luminaire axis and for all cases the human form did not cause the occurrence of the minimum illuminance but it has contributed to the drop.

b) : In the perpendicular position of the desk the effect of the V.D.U was very important at higher SHRNOM values (1.75 and upwards) where it determines the minimum illuminance and consequently the uniformity ratio. For the parallel position of the desk, the effect of the V.D.U. was more noticeable at lower spacing to height ratios. This was due to its positioning being perpendicular to the luminaire axis which resulted in more flux in the axial plane being blocked, particularly at lower angles of incidence where the higher intensities occur.

c) : In the case of a perpendicular desk the individual effect of the filing cabinet

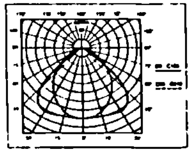
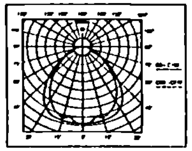
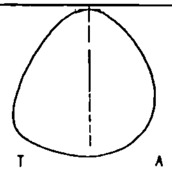
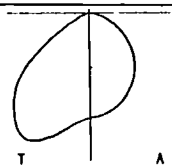
luminaire type	polar curve	position of work station	empty case	lightly obstructed case	medium obstructed case		heavily obstructed case
					V.D.U	F. cabinet	
Twin lamp Broadspread reflector (1)		desk perpend. to luminaire axis	1.88	1.35	1.35	1.28	1.26
		desk parallel to luminaire axis	1.88	1.50	—	—	—
Twin lamp recessed diffuser (2)		desk perpend to luminaire axis	1.63	1.34	1.34	1.30	1.25
		desk parallel to luminaire axis	1.63	1.36	—	—	—
Twin lamp recessed prismatic panel reflector (3)		desk perpend. to luminaire axis	1.70	1.40	1.40	1.33	1.27
		desk parallel to luminaire axis	1.70	1.00	—	0.85	—
Twin lamp surface mounted broadspread reflector (4)		desk perpend. to luminaire axis	1.90	1.52	1.50	1.25	1.25
		desk parallel to luminaire axis	1.90	1.00	—	—	—

Table 4.4: The SHR values for each luminaire and the effect on them of the various obstructions..

The luminaires used are of the type linear.

was less marked than that of the V.D.U. This was due to the position of the V.D.U. being away from the halfway between the two inner rows of luminaires. As a consequence, the bulk of the shadow area was beyond the safety zone into the task. Nevertheless it was responsible for the minimum illuminance in the medium obstructed case for SHRNOM values of 1.50, 1.75 and 2.00. When the parallel desk was considered, the effect of the filing cabinet caused the minimum illuminance to occur for SHRNOM values up to 1.75. At higher SHRNOM values its effect was still present but not very important.

d) : When the desk was perpendicular to the luminaire axis the effect of the partition was very considerable at medium and higher SHRNOM values. Apart from causing the minimum illuminance point, the drop in illuminance due to its presence was spread over a large area for which the size changes with the change in SHR value. In the case of a parallel desk (therefore partition perpendicular to luminaire axis) its effect at lower SHRNOM values was on the opposite side of the desk combined with that of the other perpendicular obstructions. At higher SHRNOM the minimum illuminance point started to shift towards the partition.

4.4.2 Point source luminaires

The point source program was ran using two luminaires for which the intensity distributions along with the SHRMAX results obtained are shown in Table 4.5. The variations in uniformity ratio as a function of SHR for the empty and various obstructed cases are shown in Figures 4.25 and 4.26.

4.4.2.1 Compact source

The drop in maximum SHR from the empty case to the heavily obstructed one is smooth. From 1.75 for the unobstructed case the SHRMAX has dropped to 1.40 in the case of a lightly obstructed case (human form and a paper rack). For both versions of medium obstructed case the SHRMAX was 1.27. This suggests that for this particular luminaire both the visual display unit and the filing cabinet behaved in the same way. The heavily obstructed case (human form, partition and a filing cabinet) experienced a slightly larger drop in SHRMAX to reach 1.25. Figure 4.25 illustrates these results.

4.4.2.2 Square downlight

When this point source was used in running the program all the cases satisfied the uniformity ratio criterion. The drop in SHRMAX value was smooth as in the case of the downlight source. From 1.32 for the unobstructed case it dropped to 1.17 for both the lightly and medium obstructed case (V.D.U version) and dropped again to reach 1.15 for both the medium (filing cabinet version) and the heavily obstructed case. Table 4.5 shows the values of SHRMAX for the various cases. The variation in uniformity ratio as a function of SHR is illustrated in Figure 4.26.

4.5 Discussion

To study the effects of the various standard obstructions the uniformity ratio for each of the preferred series of SHR set out in CIBSE TM5 was calculated for a number of examples. The results are summarised in a tabulated form in Tables 4.4 and 4.5 and as graphs in Figures 4.16 to 4.26 for both linear and symmetric point luminaires and include examples for standard obstructions positioned such that their axes are parallel or perpendicular to those of the linear luminaires. To provide a reference to the obstructed case the uniformity ratio for the empty case is also shown.

The reduction in SHR for the symmetric luminaires is shown in Figures 4.25 and 4.26. there are large differences in SHRMAX between empty and obstructed cases and smaller but significant differences between the obstructed cases. In terms of SHRNOM, which is a major concern to designers, the difference become even more marked. For the Compact source, for example, the value for the heavy obstructed case falls two preferred increments from empty. The major contributing factor to the large reduction in uniformity ratio when considering point sources is when the point of minimum illuminance on the task area moves from "seeing" to "not seeing" the luminaires with major illuminance contribution and under these circumstances shadow may be a problem.

Marked differences between empty and obstructed cases for linear luminaires are apparent from Figures 4.16 to 4.24, in some cases this being up to two increments of SHRNOM. Cases with workstations perpendicular to luminaires gave acceptable uniformity ratios for all obstruction configurations but with relatively little difference between the obstructed cases in terms of SHRMAX. For workstations parallel to luminaires only the light and some medium cases have acceptable results but at

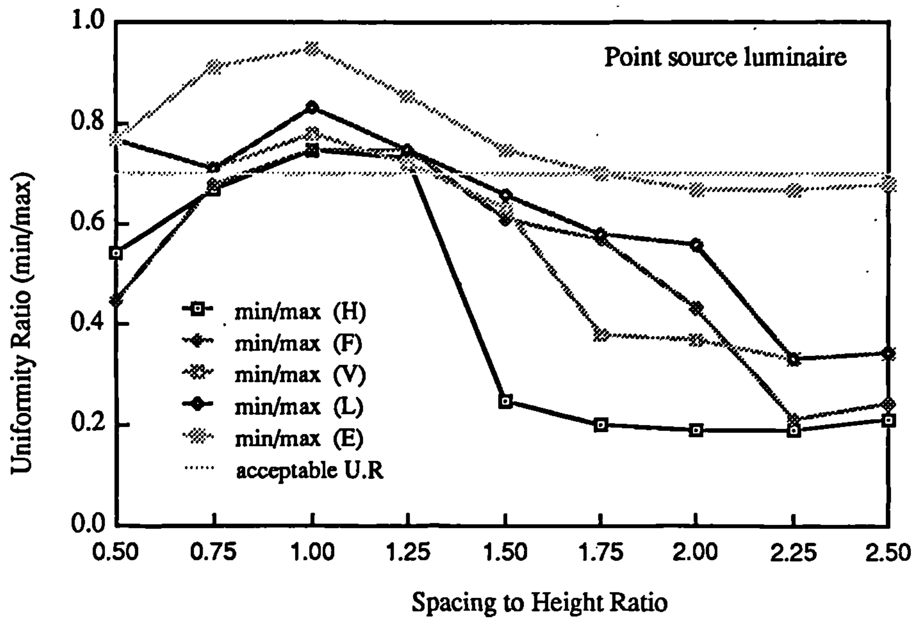


Figure 4.25: Variation in uniformity ratio as a function of SHR for empty and obstructed interiors lit by a luminaire 1 type installation.

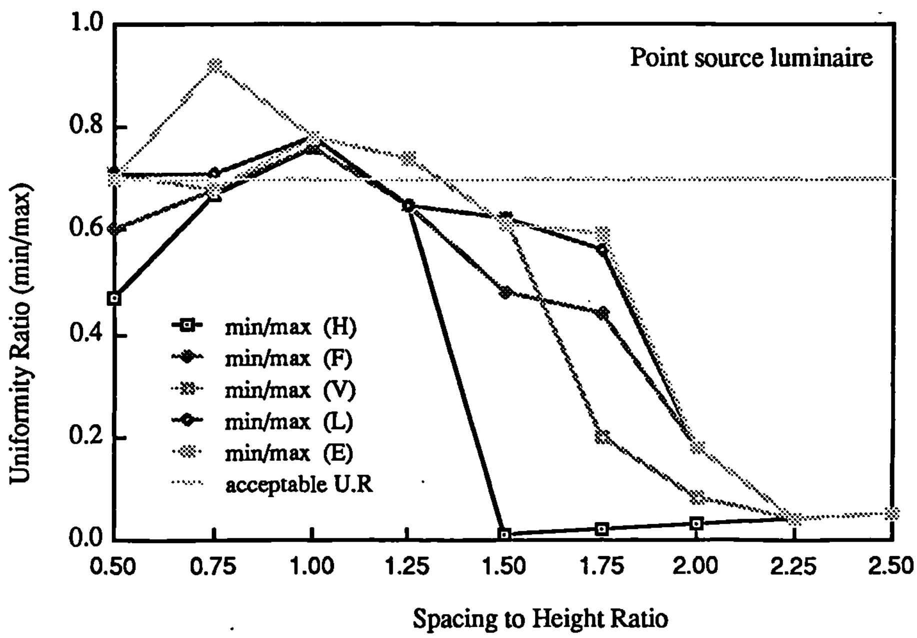


Figure 4.26: Variation in uniformity ratio as a function of SHR for empty and obstructed interiors lit by a luminaire 2 type installation.

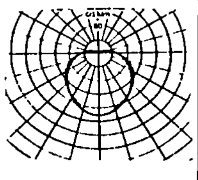
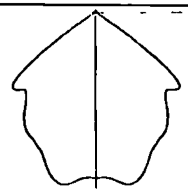
luminaire type	polar curve	position of work station	empty case	lightly obstructed case	medium obstructed case		heavily obstructed case
					V.D.U	filing cabinet	
surface mounted compact source diffuser (1)		desk perpend. or parallel to luminaire axis	1.75	1.40	1.27	1.27	1.25
square downlight recessed diffuser (2)		desk perpend. or parallel to luminaire axis	1.32	1.17	1.17	1.15	1.15

Table 4.5: The SHR values for each luminaire and the effect on them of the various obstructions..

The luminaires used are of the type linear.

SHRNOM value three increments lower than empty. This appears to lead to the general conclusion that the effect of an individual obstruction component is greater when perpendicular than parallel to a linear luminaire.

4.6 Conclusions

It is clear that obstructions have a major effect on illuminance conditions within an interior and that designers ignore that at their peril. The difference between the empty and various obstructed cases indicates that not only the presence of obstructions is important but also their size and disposition.

The modified SHR method described in this work may be used by designers in two ways: Either to indicate the design SHR at which acceptable task uniformities will be obtained or to give a warning of the need for local lighting. A proposed method of use of obstructed SHR in design is given in Chapter 7.

4.7 References

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Chapter 5

Representation of uniformity of illuminance

5.1 Introduction

The illuminance obtained in any lighting installation in practice will never be completely uniform over the entire working plane. In naturally lit rooms illuminance levels are primarily determined by the distance from the windows but in artificially lit spaces the illuminance varies with the change in location with respect to the luminaire array with the superimposed variation due to the discrete nature of luminaires. Additionally room contents may obstruct the passage of light from the source to the task area and cause areas of local illuminance diversity. The desire to limit the magnitude of change in illuminance across a working plane is usually regarded as a major quality concern of the lighting designer. Design methods enshrine this notion in the concept of the provision of average standard service illuminance over the working plane within some prescribed limit of uniformity.

Uniformity standards evolved in the early days of artificial lighting development and probably were due to the desire for uniform illuminance as a reaction to the diversity of daylight schemes [(1)]. At that time acceptable average working plane illuminance levels were as low as 50 lux and the calculation process was developed to maintain an acceptable level of minimum task illuminance and this, despite general illuminance levels having increased in the meantime, still forms the basis of the common representations of uniformity in use today. There is evidence that in addition to ensuring minimum working plane illuminance, uniformity is a factor in producing desirable performance levels of the visual task and providing user satisfaction with installation appearance [(2,3)].

There are a large number of ways to be found in the literature by which the uniformity of illuminance is represented . The most common one is the ratio of minimum to maximum illuminance used in the CIBSE TM5 method for calculating spacing to height ratio for luminaires [4]. This criterion is also used by designers when specifying illuminance levels.

The purpose of the present work is to derive and test alternative representations of uniformity which will be applied to both empty and obstructed SHR calculations. This chapter reviews the various representations of uniformity that have been promulgated, describes how some may be incorporated into SHR calculations and presents results for a range of luminaires.

5.2 Uniformity and the SHR calculation

The lumen method is the most popular design technique for general lighting schemes and has as its principal aim the provision of uniform illuminance over a working plane [5]. The core of the method is the spacing to height ratio (SHR) which determines the layout of the luminaires. The standard U.K. method for calculation of SHR in empty rooms is described in the CIBSE Technical Memoranda No.5 [4] and defines SHR as the ratio of the spacing in a stated direction between photometric centres of adjacent luminaires to the mounting height of the luminaires above the horizontal reference plane. Using a standard array of sixteen identical luminaires in a square grid the luminaires are positioned, at first, very close together and then moved apart in ordered steps so that the SHR is increased until the uniformity ratio defined by the minimum to maximum illuminance falls below the 0.7 threshold value. In order to calculate uniformity, the direct illuminance is calculated over a grid of points in the central area of the standard array of luminaires. Two SHR's are defined in the calculation: SHRMAX is the value of SHR which gives the widest spacing at which a ratio of minimum to maximum illuminance greater or equal to 0.7 is achieved over the central area and SHRNOM is the greatest value of SHR in the preferred series of steps to achieve the 0.7 minimum/maximum uniformity ratio.

A modification to the TM5 method of SHR calculation has been developed that allows for the effect of obstruction loss caused by the contents of non-empty rooms This is fully described in Chapter 4 and elsewhere [6,7,8]. The modified method takes account of light loss caused by defined obstructions positioned within the central area of the standard square array and is implemented by means of a computer program. In both the empty and obstructed SHR calculations the method of representation and threshold value of uniformity ratio are critical factors. When using the uniformity ratio defined by the ratio of minimum to maximum illuminance the result depends on two point illuminance values. The illuminance grids for typical SHR calculations of the type described in TM5 for empty rooms are characterised by smooth gradients of illuminance from point to point and the minimum and maximum values used to define the uniformity ratio will usually be representative of conditions over relatively large areas of the working plane. This is shown in a typical illuminance grid in Figure 5.1. Adding obstructions to the calculations, on the other hand, causes sharp decreases in local illuminance due to the shadowing of the notional room contents. The resulting uniformity ratio could thus be adversely influenced by a large single isolated value of minimum or maximum illuminance that is unrepresentative of adjacent areas. The example shown in Figure 5.2 is typical of the sharp variation in illuminance between adjacent areas in the case of obstructed interiors. Furthermore, introducing obstructions into a space divides the wall - to - wall working plane area, used in conventional design methods, into smaller task areas separated by circulation areas. These areas do not necessarily require the same illuminance uniformity of 0.7 minimum to maximum as in the case of task areas. This shows that the presence of obstructions affects not only the levels of illuminance on the working plane but also the definition of the working plane itself in the space.

5.3 Measures of uniformity

The most commonly used measures are the maximum, minimum and average illuminance, or ratios of these items over some prescribed area of a plane. Statistical measures of spread or distribution of illuminance, usually based on a series of point values across a plane have also been put forward, as have gradient techniques based on a rate of change of illuminance between near points. The minimum / maximum / average methods and statistical approaches may be regarded as being "global" in application since their use implies the assessment of uniformity over an area. This area may be the whole working plane within a room or some more localised area on which the visual task is performed. The gradient technique is essentially a method of

744	718	689	659	629	600	573	549	528	511	499	491	489
709	685	659	632	605	579	554	532	513	498	487	480	477
667	645	622	598	574	551	529	509	493	479	469	463	461
630	611	590	569	548	528	508	491	476	464	455	449	448
610	593	575	556	537	519	502	486	473	462	454	449	448
597	581	565	548	531	515	500	486	474	464	457	453	451
593	580	565	549	534	519	505	493	482	473	466	462	461
599	586	572	558	543	530	517	505	495	487	481	477	476
594	582	569	555	542	529	517	506	496	489	483	480	478
592	580	568	555	543	530	519	508	499	492	486	483	482
598	586	574	562	549	537	525	515	506	499	494	490	489
598	586	574	562	549	537	525	515	506	499	494	490	489
592	580	568	555	543	530	519	508	499	492	486	483	482
594	582	569	555	542	529	517	506	496	489	483	480	478
599	586	572	558	543	530	517	505	495	487	481	477	476
593	580	565	549	534	519	505	493	482	473	466	462	461
597	581	565	548	531	515	500	486	474	464	457	453	451
610	593	575	556	537	519	502	486	473	462	454	449	448
630	611	590	569	548	528	508	491	476	464	455	449	448
667	645	622	598	574	551	529	509	493	479	469	463	461
709	685	659	632	605	579	554	532	513	498	487	480	477
744	718	689	659	629	600	573	549	528	511	499	491	489

Figure 5.1 Plot of illuminance across the working plane for an empty interior.

549	31	24	23	25	26	26	27	28	27	29	29	29
524	203	47	37	35	34	31	30	32	34	38	38	44
494	319	184	99	42	40	44	44	45	49	62	92	144
471	354	252	174	119	69	48	53	71	89	115	159	219
462	377	298	234	185	131	109	99	99	135	167	209	264
461	396	336	284	243	186	163	153	153	162	209	249	233
592	578	563	548	532	517	503	449	435	425	414	406	401
597	584	570	556	541	527	514	502	436	423	412	406	399
594	582	567	553	540	527	514	503	493	417	405	395	387
592	580	566	555	540	528	516	505	496	411	399	388	379
598	586	574	562	549	534	523	512	503	495	490	383	356
598	586	574	562	549	534	523	512	503	495	490	383	356
592	580	566	555	540	528	516	505	496	411	399	388	379
594	582	567	553	540	527	514	503	493	417	405	395	387
597	584	570	556	541	527	514	502	436	423	412	406	399
592	578	563	548	532	517	503	449	435	425	414	406	401
596	580	564	547	531	488	469	454	440	427	444	440	405
609	593	575	556	537	498	480	462	447	457	446	441	448
630	611	590	569	548	513	493	475	468	458	450	449	448
665	644	619	590	543	497	440	388	358	341	333	349	329
709	685	658	621	593	570	540	485	374	343	315	169	98
744	718	682	651	624	596	570	546	526	509	29	29	29

Figure 5.2 Plot of illuminance across the working plane for an obstructed interior.

assessing "local" uniformity between adjacent points.

5.3.1 Ratios of Minimum/Maximum/Average Illuminance

This system forms the basis of the specification of uniformity in most of the major national and international lighting codes. The CIBSE Code(9) uses a uniformity ratio defined as the minimum to average illuminance over the task area and recommends that its value should not fall below 0.8. To attempt to ensure that this is the case, luminaires are recommended to be installed at an SHR which limits to 0.7 the ratio of minimum to maximum direct illuminance values obtained beneath and between luminaires in a square array at the middle of an installation. This ratio is known as the mid-point ratio and provides a simplified worst case calculation as a basis for determining SHRMAX which normally gives a uniformity ratio of 0.8 over the central region of an installation (4). The SHRMAX calculation procedure attempts to ensure that the uniformity criterion would be acceptable at any spacing up to the maximum for the type of luminaire distribution. The limiting value of mid-point ratio of 0.7 appears to result from the work of McWhirter (10), and experimental work by Saunders (11) showed that people's assessment of uniformity worsened as minimum/maximum illuminance fell below 0.7 to a point at 0.5 where the majority was dissatisfied. Recent work on the subjective response of people carrying out visual tasks under various lighting systems showed that for tasks which occupy only the central part of the desk, illuminance uniformity of 0.5 was acceptable (12). As pointed out by Cuttle (13) the minimum/average and minimum/maximum limits have a mathematical relationship such that for an unbiased distribution a minimum/average ratio of 0.8 would be equivalent to a minimum/maximum ratio of 0.67, thus representing a slight relaxation of standards. By a similar argument the minimum/maximum limit of 0.7 is equivalent to that of 0.82 minimum/average . The CIE Code on Interior Lighting (14) and the DIN Standard 5035 (15) adopt a minimum/average criterion for specification of uniformity on the working plane with limiting values of 0.8 and 0.66 respectively although neither is explicitly linked to luminaire spacing.

5.3.2 Statistical representations of uniformity

Concern that minimum/maximum/average ratio methods of representing uniformity produced a result heavily influenced by a single point value - usually the minimum- lead to the development of statistical techniques for determining the distribution about the average of all points of illuminance calculation or measurement. Mahler and LeVere (16) put forward "Uniformity of illuminance" (UI) as a measure related to both average and the distribution of planar illuminance.

$$UI = \frac{1 - M_D}{E_{ave}} . 100 \qquad (5.1)$$

where M_D is the mean deviation and is calculated from the following expression:

$$M_D = \frac{\sum_{p=1}^{n} \left| E_{ave} - E_p \right|}{n} \qquad (5.2)$$

where:

E_{ave} = average planar illuminance

E_p = illuminance at a particular point

n = number of measurement points

The major omission in the UI method were that no indication of the number and position of points of calculation for working planes of different sizes was given, and that there was no guidance as to what constitutes desirable, or otherwise, limiting values of UI.

The use of the standard deviation (S) technique was proposed by Jones and Levin (after Mahler and LeVere (16)) as means of giving some indication of the distribution of the points measurement and at the same time more heavily weights extreme values.

$$S = \frac{\sum_{p=1}^{n} (E_p - E_{ave})^2}{n} \qquad (5.3)$$

This approach has the advantage that the lighting designer would be able to tell for example, that about two-thirds of the measurement points would be found within plus or minus one standard deviation of the average, and by dividing standard deviation by average, an index (S/E_{ave}) could be defined which express uniformity in terms of percentage of illuminance variation from average, related to the number of measurement points. Mathieu (17) incorporated the standard deviation approach into the measure of "Statistical Uniformity" (SU)

$$SU = \frac{(E_{ave} + S)}{(E_{ave} - S)} \qquad (5.4)$$

A test for convergence is required to establish the number of calculation points required to give acceptable results for E_{ave} and S. Mathieu (17) suggested that the appropriate number of points could be obtained by varying the size of the calculation grid subject to a minimum of 100. A generalised relationship between SU and uniformity ratio (in terms of minimum and average) exists, SU being effectively a measure of "maximum/minimum" ratio. This means that a uniformity expressed as an SU could be interpreted in a similar manner to the maximum/minimum planar illuminance ratio if, for example, a design specification was in terms of illuminance of adjacent areas.

5.3.3 Gradient techniques

Fink [18] and Ewing [2] developed measures of uniformity based on gradient of illuminance between adjacent points on a plane and calculated as percentage change in illuminance over a finite distance, usually for most applications 0.1 of the mounting height of luminaire. Fink also reported the results of some experiments which attempted to determine the size of gradients that observers found noticeable, and also to relate gradient measures to minimum/maximum/average ratios. Although the results should be treated with caution due to the small number of observers tested, the experiments indicated that a uniformity ratio of 0.8 minimum/average was equivalent to about 10 % gradient, this being valid if no large gradients existed. It was also demonstrated that the gradient techniques could be used, in place of minimum/average uniformity ratio, in calculation of SHR in empty rooms.

5.4 Application of uniformity measures

For each value of the preferred series the SHR calculation was performed using different uniformity criteria and was then assessed against limits appropriate to each measure. Details of the SHR calculation procedure are given in the previous chapter. The method of representation of the criteria and derivation of the limits is described below.

5.4.1 Minimum / Maximum / Average Illuminance

The task area was divided into a grid of points at 0.1m centres at which direct illuminance was calculated. Maximum and minimum points were selected, average illuminance calculated for the whole grid area and the appropriate ratios calculated. An additional 16 point minimum/maximum ratio was derived this being the lowest and highest illuminance averaged over areas on the task of size of approximately an A4 piece of paper. This produced, it was hoped, a measure that was not unduly influenced by single points values. and was calculated by dividing the illuminance grid into sub-areas of 16 points over which an average was calculated. The limit of this measure was taken as 0.8 since it was expressed in terms of averages.

5.4.2 Statistical measures

The standard deviation approach was used to develop two measures of uniformity together with appropriate limits. The first is the ratio of standard deviation to average illuminance with an associated limiting value derived from the familiar ratio of minimum to maximum illuminance of 0.7. Assuming a normal distribution in which 95 % of the points (i.e. two standard deviations) satisfy the criterion of normality, then:

$$E_{min} = E_{ave} - 2S \qquad (5.5)$$

and

$$E_{max} = E_{ave} + 2S \qquad (5.6)$$

If the ratio Minimum to Maximum is expressed in terms of Equations (5.5) and (5.6) we then get:

$$\frac{(E_{ave} - 2S)}{(E_{ave} + 2S)} = 0.7 \qquad (5.7)$$

hence:

$$S = 0.1\ E_{ave} \qquad (5.8)$$

Illuminance values at all points on the grid, standard deviations, and the uniformity measure $(S/E_{ave}) \times 100$ were calculated for comparison with the limiting value of 10 %.

The second statistical measure considered is Statistical Uniformity (SU) which uses one standard deviation as the basis of its calculation process. Based on a minimum/maximum ratio of 0.7 and substituting for S by the expression in Equation 5.8, SU can be written as:

$$SU = \frac{(E_{ave} + 0.1\,E_{ave})}{(E_{ave} - 0.1\,E_{ave})} \tag{5.9}$$

Solving the equation will result in a limiting value for SU of 1.22.

5.4.3 Gradient measures

Gradients were calculated between all individual points having a separation of 0.3 *m* in both directions over the whole illuminance grid. The spacing of 0.3 *m* was selected for the calculation since it represented the size of the "area" of task already used in the 16 point minimum/maximum measure and was similar to the size of the grid of points used for gradient calculations by Fink [18]. For each point on the 0.3 *m* grid the gradient was calculated in both X and Y directions as follows:

$$Gr_{ab} = \frac{2\,(E_a - E_b)}{(E_a + E_b)} \tag{5.10}$$

where $Gr_{a\,b}$ is the gradient between points a and b which are adjacent on the grid. All gradient values were calculated and the maximum value is selected as the uniformity measure. Fink suggests an acceptable maximum gradient of 10 % although this was determined for empty spaces lit by luminaires with smooth intensity distributions.

5.5 Results of the calculations

To study the effect of the various uniformity measures, SHR calculations were performed for both empty and obstructed spaces using a number of luminaire types and results for four luminaires (two linear and two point sources) are presented in Table 5.1 in terms of SHRMAX and in Table 5.2 in terms of SHRNOM. Inspection of Table 5.1 indicates that the relationship between the various measures and SHR follow similar general patterns for each luminaire. More detailed results for luminaires 1 and 3 in Table 5.1 are shown in Figures 5.3 to 5.6 and 5.7 to 5.13 respectively. These show in graphical form results using six uniformity measures applied to both empty and obstructed calculations and enable the relationships to be examined in terms of both SHRMAX and SHRNOM. Since a number of the measures rely on either the magnitude or location of the minimum point the SHR calculations were repeated with the minimum point value arbitrarily reduced by 20 %. The results are also shown in Table 5.1. The purpose of the test was to give a pointer to the robustness of the the measures when dealing with illuminance grids that may contain isolated local areas of low illuminance, this being a particular problem in obstructed spaces.

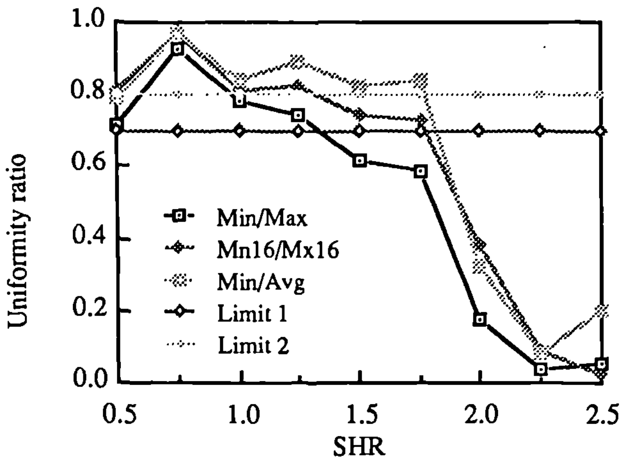
5.5.1 Point source luminaire

Results of the SHR calculation for an empty interior using the various uniformity measures for luminaire 1 in Tables 5.1 and 5.2 are shown in Figure 5.3. These were compared with those obtained for obstructed interiors which are shown in Figures 5.4 to 5.6. Those figures indicate that using all the various uniformity measures, the greater the degree of obstruction the smaller the maximum SHR permitted. The minimum/maximum measure using two illuminance points which has been used to date in all SHR calculations, gives very different SHRMAX values for the various obstructed cases, but the same SHRNOM, one increment lower than that of the empty case. SHRNOM calculations using the minimum/average measure with single point minimum were higher than the equivalent minimum/maximum calculation by two increments for the empty case and three increments for lightly obstructed case. Interestingly the SHRNOM values for the medium and heavy cases of obstruction were similar to those calculated using minimum/maximum. This is due to the obstructions causing a change in the statistical distribution of the illuminance grid from smoothly to rapidly varying which in turn causes average illuminance and maximum point illuminance to vary at different rates. The minimum/maximum values calculated using the 16 point sub- areas of the illuminance grid gave higher SHRMAX value than the single point minimum/maximum in all cases despite the higher limiting value of the 16 point measure. In terms of SHRNOM the empty case was the same as single point but the obstructed cases were all one SHR increment higher. This result is not unexpected since given the "averaging" effect, the use of the A4 sized sub-areas would tend to produce minimum/maximum ratio that approaches unity.

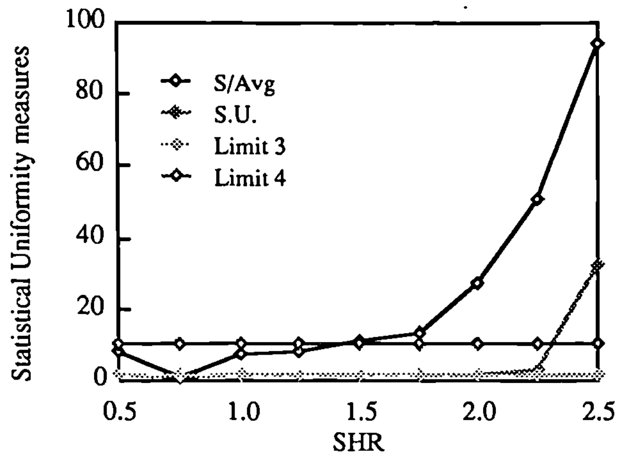
Both statistical measures give higher SHRMAX results than single point minimum/maximum but with a less steep fall in SHR from the light to the heavy obstructed cases. The effect on SHRNOM was to produce the same value for all obstructed cases, one increment higher than the equivalent minimum/maximum value. The major difference between the two measures was apparent only in the heavily obstructed cases where a substantial number of points on the illuminance grid, with low illuminance values, lay between one and two standard deviations and in this case the S/E_{ave} measure was better able to take account of the widely dispersed points at or near the minimum.

Interpretation of the gradient measures was difficult because of uncertainty about what constitutes a limiting value of maximum gradient. The application of Fink's suggested figure of 10% would mean that the empty case would have a maximum of 0.9 and light and medium obstructed cases 0.5 SHR. The results should be treated with caution since they are considerably at variance with the results produced by the other measures. Inspections of the curves in Figures 5.3 to 5.6 suggest that an alternative limit which gives result of a similar order to those of the other measures may be the point at which the graph of uniformity measure increases sharply. This would, for example, give a value of SHRNOM for the empty case of 1.75 compared with minimum/average of 1.75 and minimum/maximum of 1.25. It is likely that the point of sharp increase of maximum gradient is caused by large areas of low value illuminance on the grid at the particular SHR and that under these circumstances the maximum gradient may be through the point of minimum illuminance.

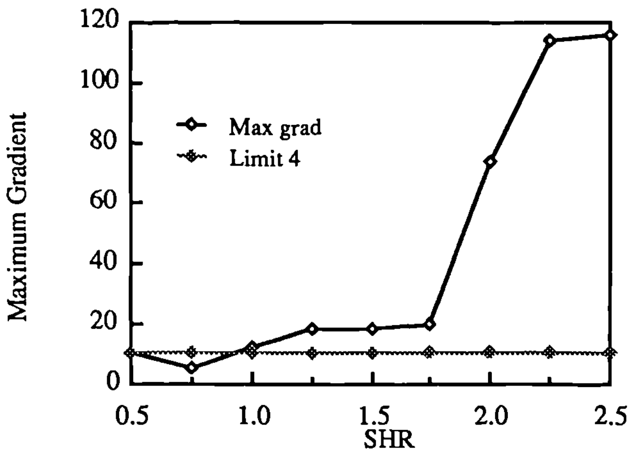
The effect of arbitrary reduction of the minimum point illuminance can be seen in column 4 in Table 5.1 (for luminaire 1). The effect on minimum/maximum and minimum/average is dramatic, as it may be expected, since the measures are highly dependent on the single value of minimum illuminance. In both cases neither uniformity measure attains the limiting value although all other points on the illuminance grid remain the same. The effect on 16 point minimum/maximum and on the statistical measures are negligible, all attaining the same SHRNOM as before. The effect on gradient measures is erratic. The difference between the results produced by original and modified measure suggest that this is due to the variations in geographic locations of the maximum gradient.



Case a: Variation in Min/Max/Avg uniformity ratio
as a function of Spacing to Height Ratio.

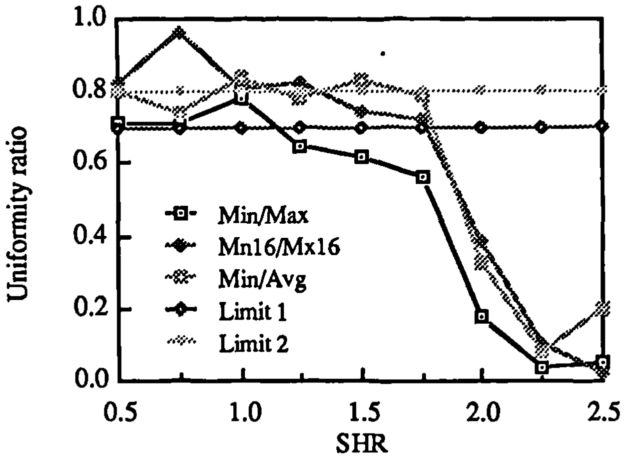


Case b: Variation in Statistical uniformity measures
as a function of Spacing to Height Ratio.

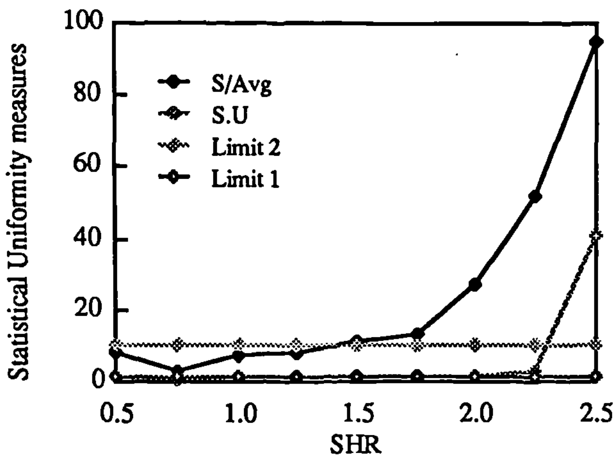


Case c: Variation in maximum gradient
as a function of Spacing to Height Ratio.

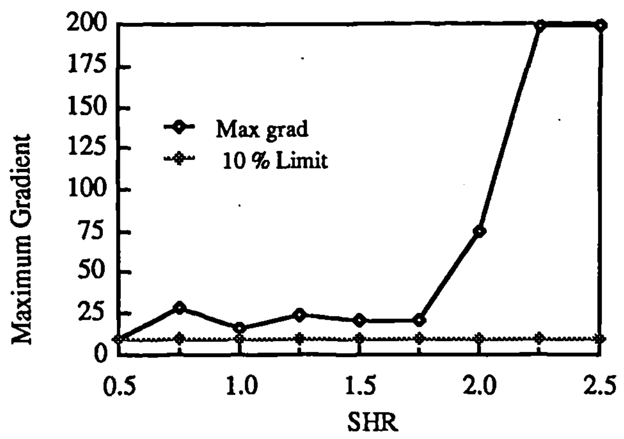
Figure 5.3: Uniformity measures for an empty space lit by a point soure (1)



Case a: Variation in Min/Max/Avg uniformity ratio
as a function of Spacing to Height Ratio.

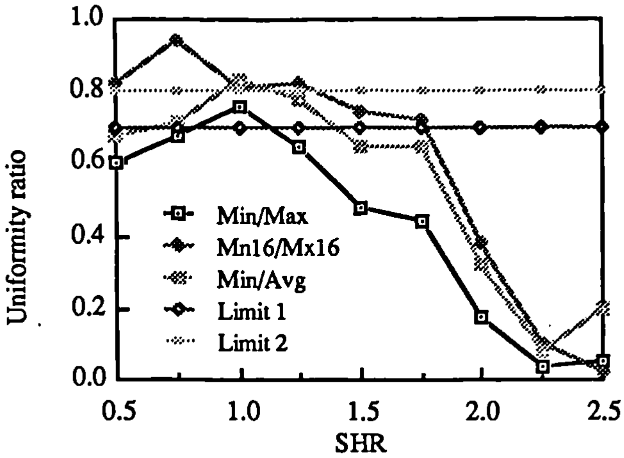


Case b: Variation in Statistical uniformity measures
as a function of Spacing to Height Ratio.

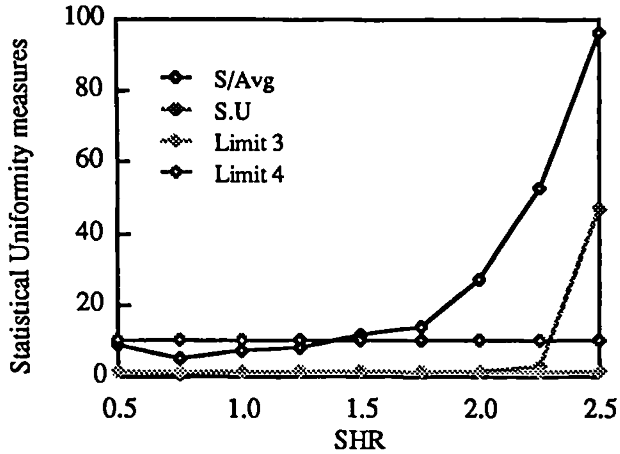


Case c: Variation in maximum gradient
as a function of Spacing to Height Ratio.

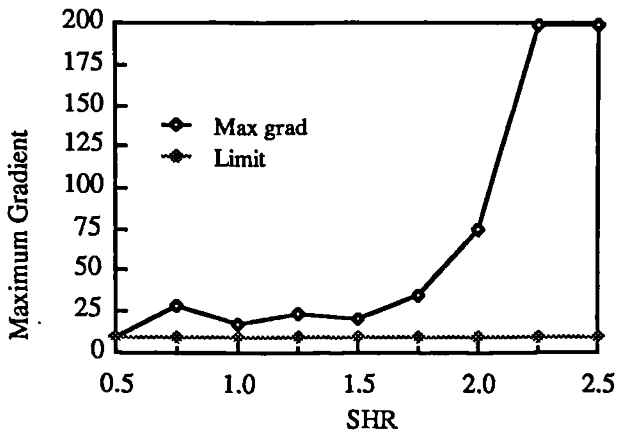
Figure 5.4: Uniformity measures for a light obstructed space lit by a point source (1)



Case a: Variation in Min/Max/Avg uniformity ratio
as a function of Spacing to Height Ratio.

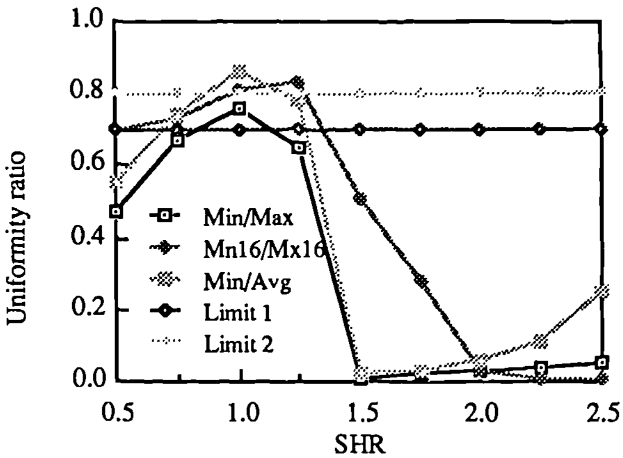


Case b: Variation in Statistical uniformity measures
as a function of Spacing to Height Ratio.

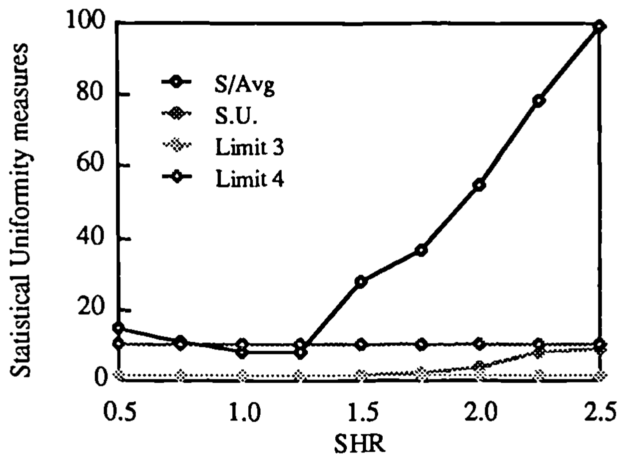


Case c: Variation in maximum gradient
as a function of Spacing to Height Ratio.

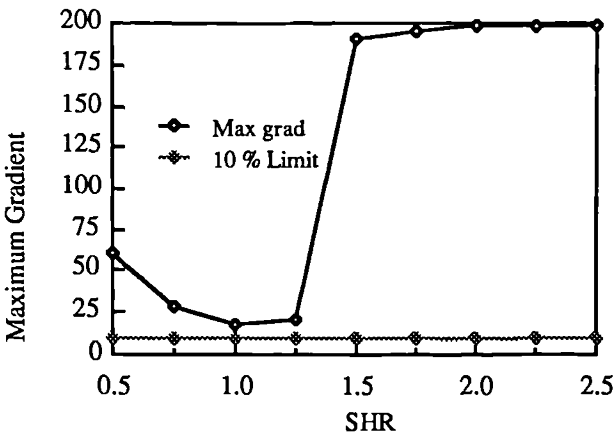
Figure 5.5: Uniformity measures for a medium obstructed space
(Filing cabinet version) lit by a point source (1)



Case a: Variation in Min/Max/Avg uniformity ratio
as a function of Spacing to Height Ratio.



Case b: Variation in Statistical uniformity measures
as a function of Spacing to Height Ratio.



Case c: Variation in maximum gradient
as a function of Spacing to Height Ratio.

Figure 5.6: Uniformity measures for a heavy obstructed space
lit by a point source (1)

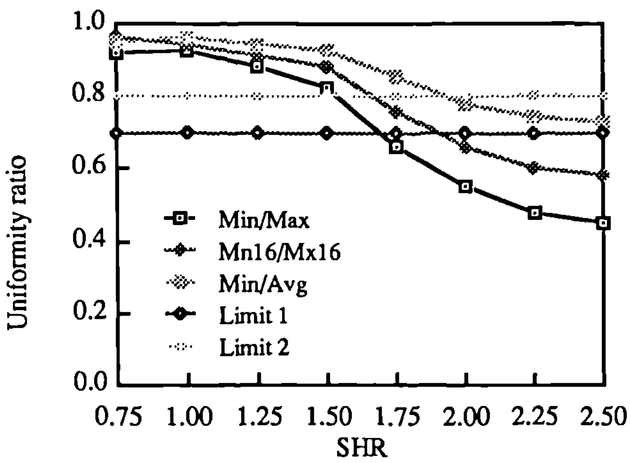
5.5.2 Linear luminaire

When linear luminaires were used, two possible orientations of luminaire were considered for the obstructed cases. In the case of an empty interior both perpendicular and parallel orientations yielded similar results. An example of the data produced is shown in Figure 5.7 for the empty case and Figures 5.8 to 5.13 for the various obstructed cases. these results were obtained using luminaire 3 in Tables 5.1 and 5.2. For each of these cases the various uniformity measures produced different SHR results. On the other hand all the results follow a similar pattern characterised by drop in SHR with increased obstruction density.

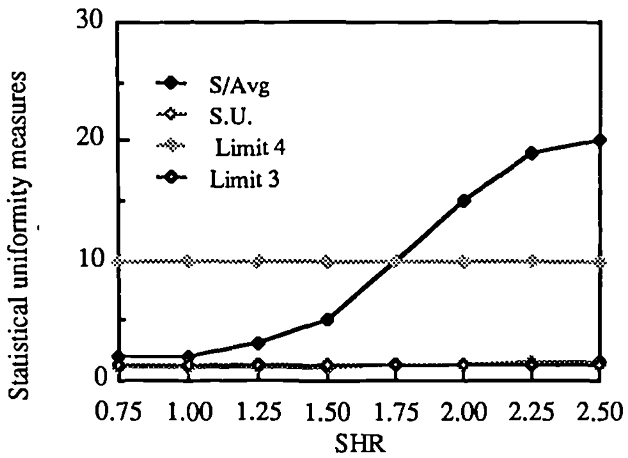
The two illuminance points minimum/maximum produced the same SHRNOM for all obstructed cases when the perpendicular orientation was considered. This was 1.25 as compared to 1.50 for the empty interior. The SHRMAX values were 1.70 for the empty case and, 1.40 for the lightly obstructed case, 1.33 for the medium and 1.27 for the heavy case. When the parallel orientation was considered, both nominal and maximum values of SHR dropped for the obstructed case. Both of them were 1.00 for the light case and dropped to 0.75 and 0.85 respectively for the medium case. The heavy case failed to have one. The 16 points minimum/maximum produced results which exceeded the two illuminance points measure by one increment for the SHRNOM for perpendicular orientation and 2 increments for the parallel one. This was the case in all interiors except the heavy one. The minimum/average results were similar to those of the minimum/maximum.

When the statistical measures were used, both empty and obstructed cases yielded results similar to those of 16 points minimum/maximum in terms of SHRNOM. The SHRMAX values for the various cases were about the same magnitude as those for the 16 points illuminance measure but with slight variations from one case to an other.

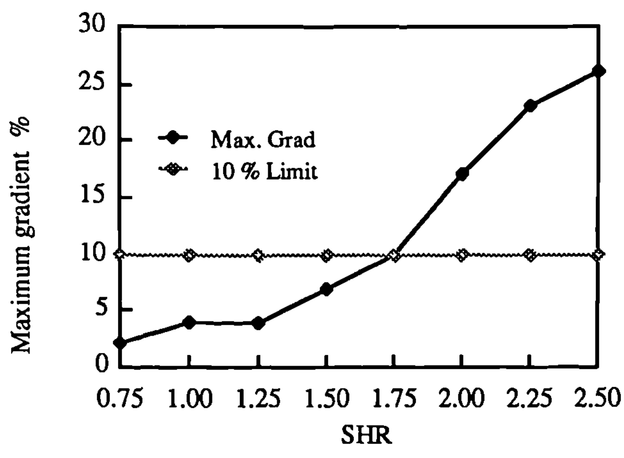
Using the gradient measures to calculate SHR produced results which both erratic and difficult to interpret. This was due to the lack of a recognised limit. Using the 10 % limit developed for the empty spaces has produced SHRMAX values in the order Of 1.75 for empty case, 0.80 for light case and 0.75 for medium case. The heavy case as well as all obstructed case for the perpendicular orientation failed to have an appropriate SHR.



Case a: Variation in Min/Max/Avg uniformity ratio as a function of Spacing to Height Ratio.

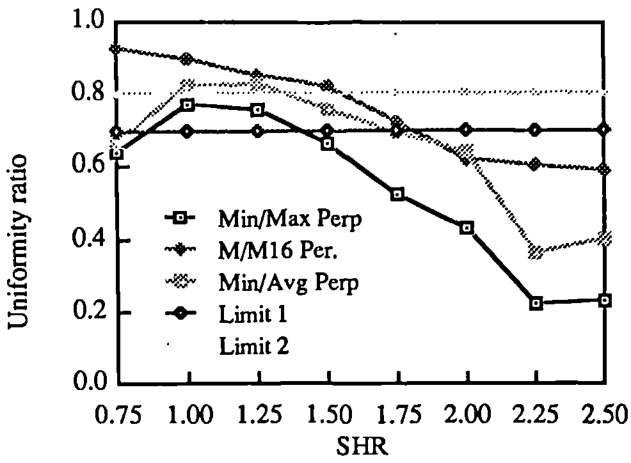


Case b: Variation in Statistical uniformity measures as a function of Spacing to Height Ratio.

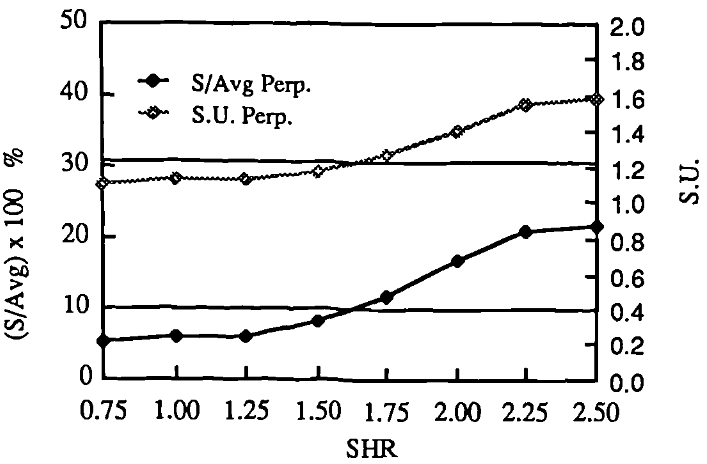


Case c: Variation in maximum gradient as a function of Spacing to Height Ratio.

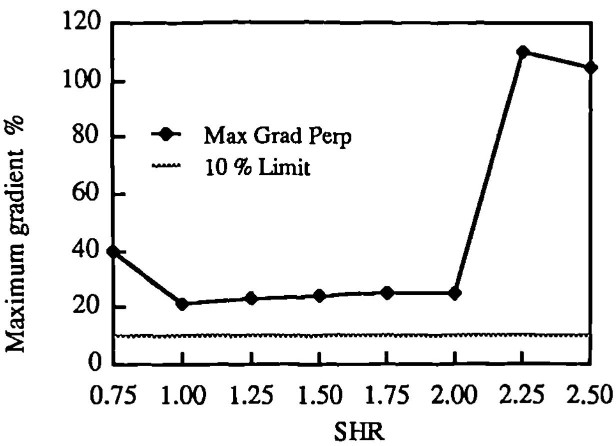
Figure 5.7: Uniformity measures for an empty space lit by a linear luminaire (3).



Case a: Variation in Min/Max/Avg uniformity ratio
as a function of Spacing to Height Ratio.

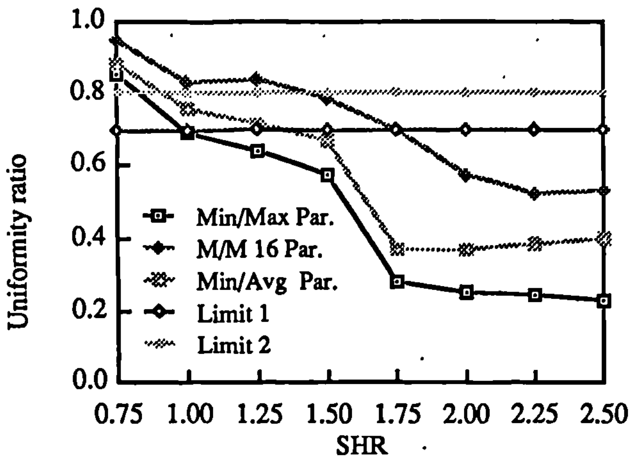


Case b: Variation in Statistical measures
as a function of Spacing to Height Ratio

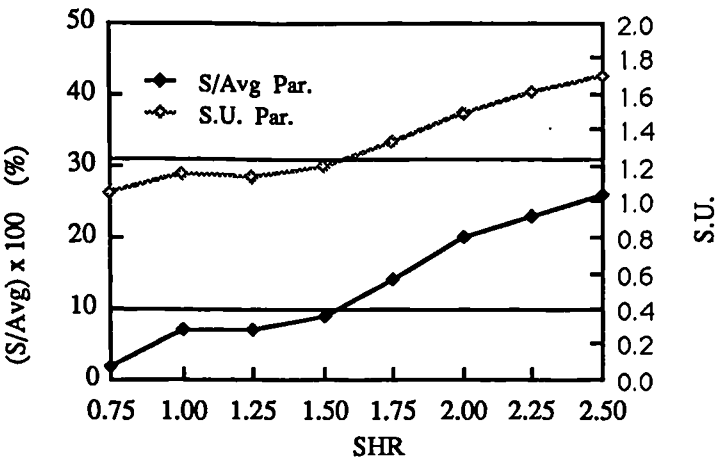


Case c: Variation in maximum gradient
as a function of Spacing to Height Ratio.

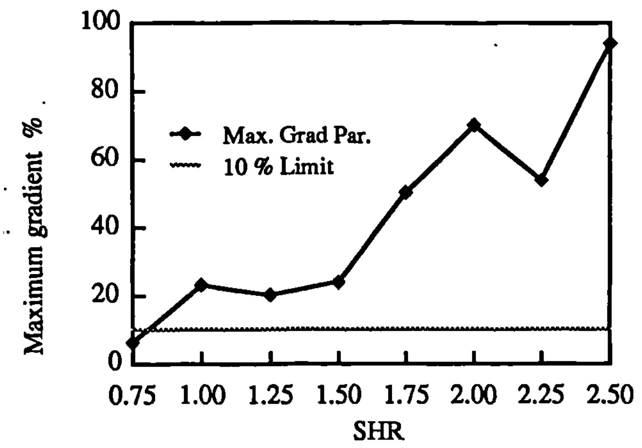
Figure 5.8: Uniformity measures for a light obstructed space lit by linear luminaire 3 perpendicular to desk.



Case a: Variation in Min/Max/Avg uniformity ratio as a function of Spacing to Height Ratio.

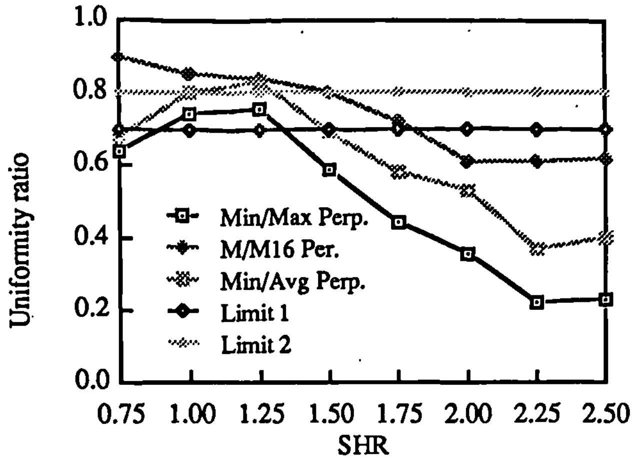


Case b: Variation in Statistical measures as a function of Spacing to Height Ratio

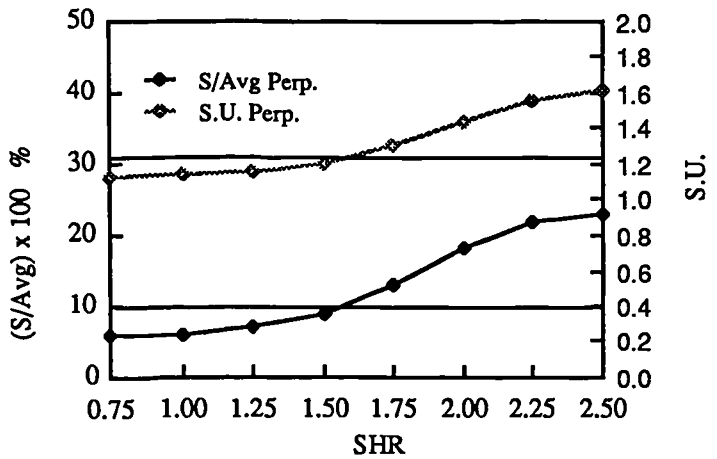


Case c: Variation in maximum gradient as a function of Spacing to Height Ratio.

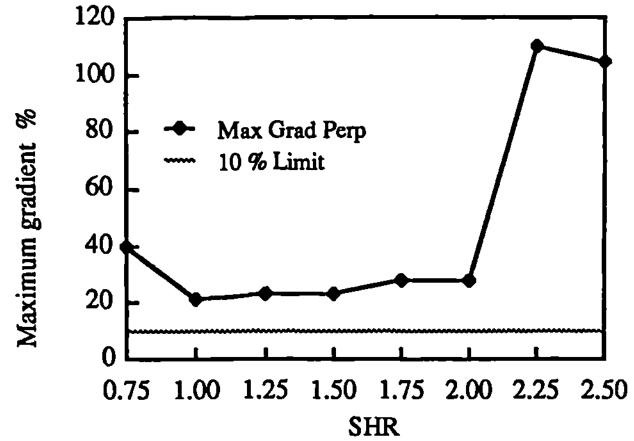
Figure 5.9: Uniformity measures for a light obstructed space lit by linear luminaire 3 parallel to desk.



Case a: Variation in Min/Max/Avg uniformity ratio as a function of Spacing to Height Ratio.

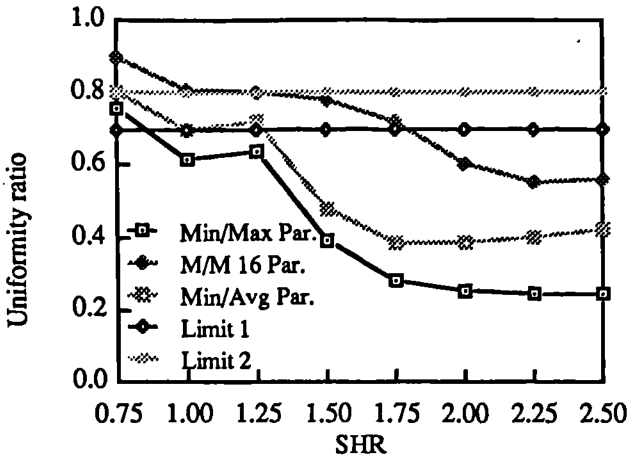


Case b: Variation in Statistical measures as a function of Spacing to Height Ratio

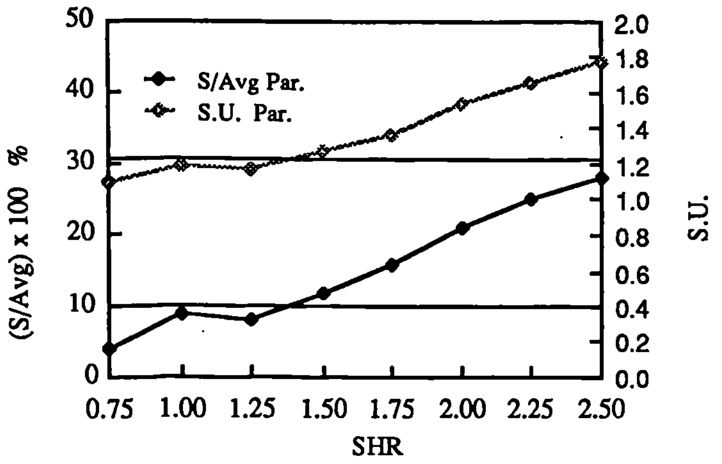


Case c: Variation in maximum gradient as a function of Spacing to Height Ratio.

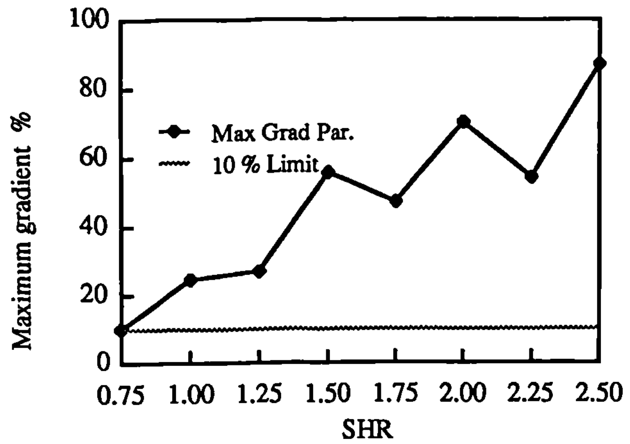
Figure 5.10: Uniformity measures for a medium obstructed space (F.C. version) lit by linear luminaire 3 perpendicular to desk.



Case a: Variation in Min/Max/Avg uniformity ratio
as a function of Spacing to Height Ratio.

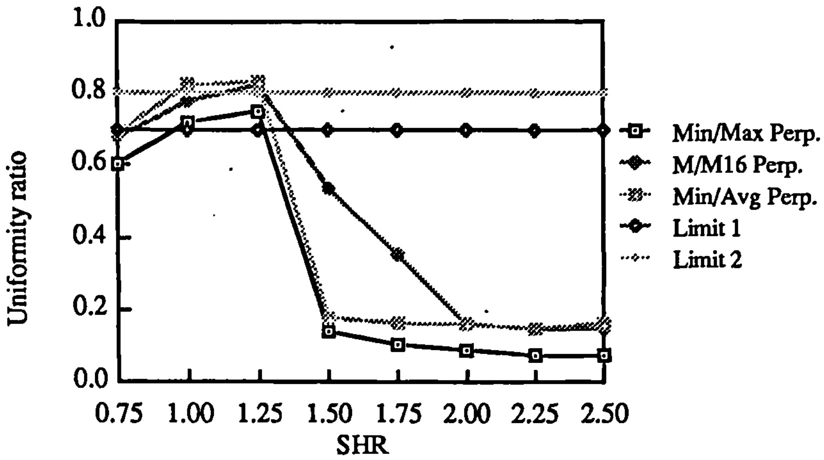


Case b: Variation in Statistical measures
as a function of Spacing to Height Ratio

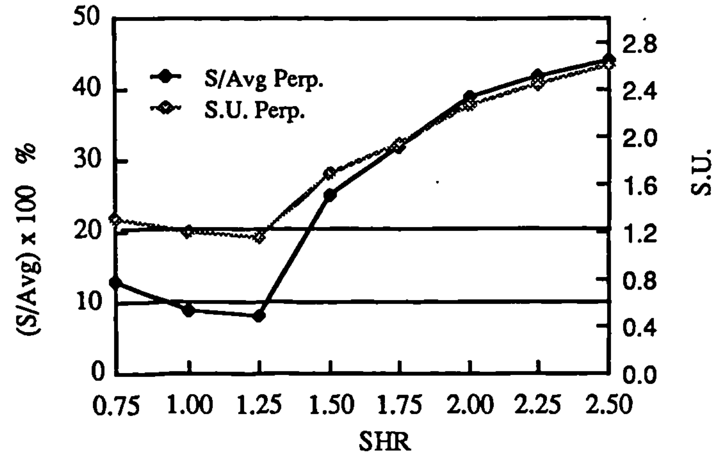


Case c: Variation in maximum gradient
as a function of Spacing to Height Ratio.

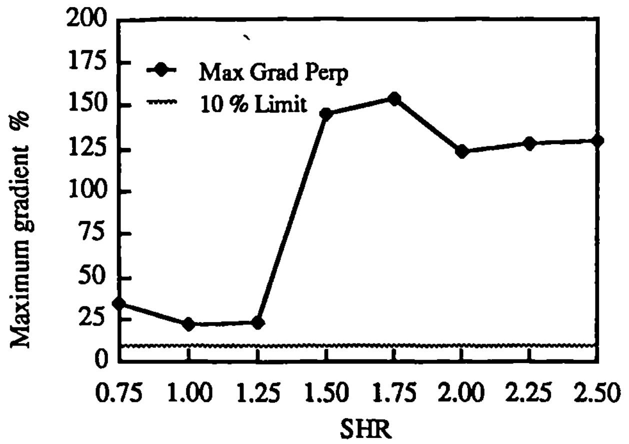
Figure 5.11: Uniformity measures for a medium obstructed space
(F.C. version) lit by linear luminaire 3 parallel to desk.



Case a: Variation in Min/Max/Avg uniformity ratio as a function of Spacing to Height Ratio.

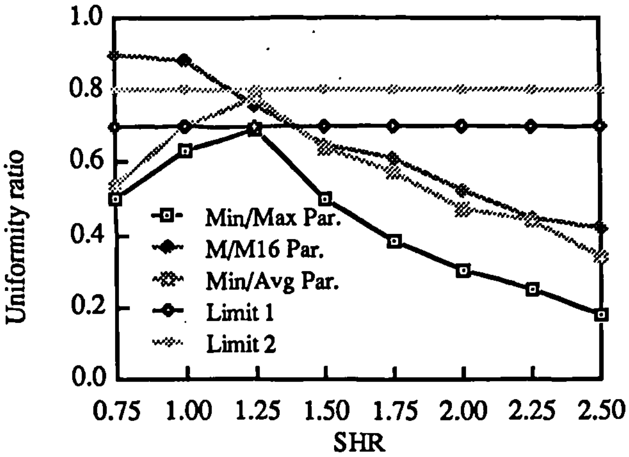


Case b: Variation in Statistical measures as a function of Spacing to Height Ratio

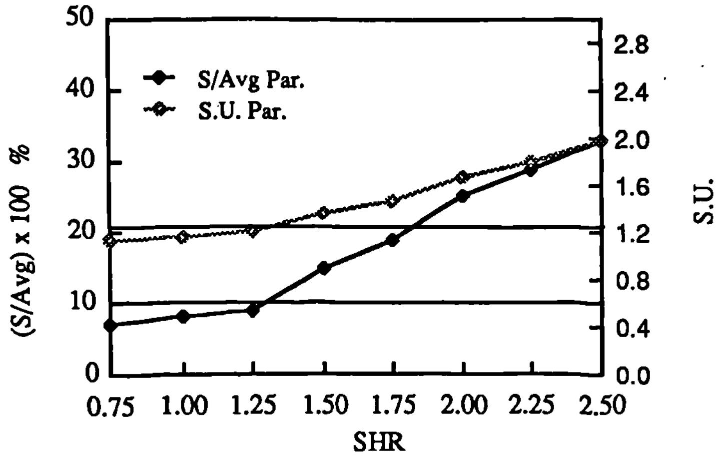


Case c: Variation in maximum gradient as a function of Spacing to Height Ratio.

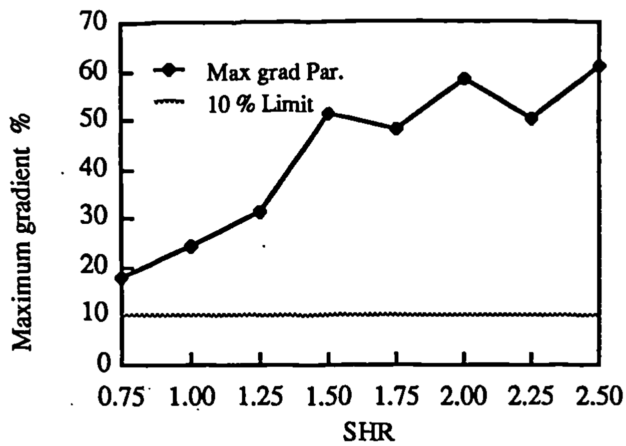
Figure 5.12: Uniformity measures for a heavy obstructed space lit by linear luminaire 3 perpendicular to desk.



Case a: Variation in Min/Max/Avg uniformity ratio
as a function of Spacing to Height Ratio.



Case b: Variation in Statistical measures
as a function of Spacing to Height Ratio



Case c: Variation in maximum gradient
as a function of Spacing to Height Ratio.

Figure 5.13: Uniformity measures for a heavy obstructed space
lit by linear luminaire 3 parallel to desk.

Luminaire type	Uniformity measure	Empty case	Lightly obstructed case	- 20 %	Medium obstructed case (Filing cabinet)		Heavily obstructed case	
Luminaire 1	Min. /Max.	1.32	1.17	___	1.15		1.15	
Point source	Min.16/Max.16	1.31	1.31	1.29	1.31		1.27	
	Min. /Avg.	1.76	1.75	___	1.15		1.18	
	S/Avg	1.41	1.41	1.38	1.38		1.27	
	S.U.	1.42	1.39	1.35	1.38		1.27	
	Max. Grad.	0.92	0.50	0.50	0.50		___	
Luminaire 2	Min. /Max.	1.75	1.40		1.25		1.25	
Point source	Min.16/Max.16	2.00	1.75		1.75		1.28	
	Min. /Avg.	2.50	1.55		1.37		1.25	
	S/Avg	2.50	2.12		1.87		1.31	
	S.U.	2.40	2.10		1.87		1.30	
	Max. Grad.	2.00	0.53		0.53		___	
Luminaire 3	Min. /Max.	1.70	**1.40**	1.00	**1.33**	0.85	**1.27**	___
Linear source	Min.16/Max.16	1.88	**1.55**	1.50	**1.50**	1.25	**1.27**	1.16
	Min. /Avg.	1.92	**1.35**	0.91	**1.30**	0.75	**1.26**	___
	S/Avg	1.75	**1.62**	1.55	**1.56**	1.37	**1.27**	1.29
	S.U.	1.75	**1.62**	1.53	**1.55**	1.36	**1.27**	1.29
	Max. Grad.	1.75		0.80		0.75		___
luminaire 4	Min. /Max.	1.90	**1.52**	1.00	**1.50**	___	**1.25**	___
Linear source	Min.16/Max.16	1.86	**1.62**	1.75	**1.62**	1.08	___	1.00
	Min. /Avg.	2.25	**1.50**	1.00	**1.25**	___	**1.25**	___
	S/Avg	1.95	**1.25**	1.25	**1.50**	1.12	___	1.00
	S.U.	1.92	**1.25**	1.78	**1.50**	1.08	___	1.00
	Max. Grad.	1.85	___	___		___		___

Key:

- 20 % : SHRMAX values obtained with a minimum illuminance reduced by 20 %

___ : For all SHR values the uniformity criterion does not reach the limit

Bold figures: The work station is perpendicular to the luminaire axis

Table 5.1: SHRMAX values for typical luminaires calculated using different uniformity measures for empty and obstructed interiors.

Luminaire type	Uniformity measure	Empty case	Lightly obstructed case	- 20 %	Medium obstructed case (Filing cabinet)		Heavily obstructed case	
Luminaire 1 Point source	Min. /Max.	1.25	1.00	___	1.00		1.00	
	Min.16/Max.16	1.25	1.25	1.25	1.25		1.25	
	Min. /Avg.	1.75	1.75	___	1.00		1.00	
	S/Avg	1.25	1.25	1.25	1.25		1.25	
	S.U.	1.25	1.25	1.25	1.25		1.25	
	Max. Grad.	0.75	0.50	0.50	0.50		___	
Luminaire 2 Point source	Min. /Max.	1.75	1.25		1.25		1.25	
	Min.16/Max.16	2.00	1.75		1.75		1.25	
	Min. /Avg.	2.50	1.50		1.25		1.25	
	S/Avg	2.50	2.00		1.75		1.25	
	S.U.	2.00	2.00		1.75		1.25	
	Max. Grad.	2.00	0.50		0.50		___	
Luminaire 3 Linear source	Min. /Max.	1.50	**1.25**	1.00	**1.25**	0.75	**1.25**	___
	Min.16/Max.16	1.75	**1.50**	1.50	**1.50**	1.25	**1.25**	1.00
	Min. /Avg.	1.75	**1.25**	0.75	**1.25**	0.75	**1.25**	___
	S/Avg	1.75	**1.50**	1.50	**1.50**	1.25	**1.25**	1.25
	S.U.	1.75	**1.50**	1.50	**1.50**	1.25	**1.25**	1.25
	Max. Grad.	1.75		0.75		0.75		___
luminaire 4 Linear source	Min. /Max.	1.75	**1.50**	1.00	**1.50**	___	**1.25**	___
	Min.16/Max.16	1.75	**1.50**	1.75	**1.50**	1.00	___	1.00
	Min. /Avg.	2.25	**1.50**	1.00	**1.25**	___	**1.25**	___
	S/Avg	1.75	**1.25**	1.25	**1.50**	1.00	___	1.00
	S.U.	1.75	**1.25**	1.75	**1.50**	1.00	___	1.00
	Max. Grad.	1.75	___	___		___	___	___

Key:

- 20 % : SHRNOM values obtained with a minimum illuminance reduced by 20 %

___ : For all SHR values the uniformity criterion does not reach the limit

Bold figures: The work station is perpendicular to the luminaire axis

Table 5.1: SHRNOM values for typical luminaires calculated using different uniformity measures for empty and obstructed interiors.

5.6 Conclusion

It is apparent that the use of the various measures of uniformity as the basis of SHR calculations gives results of the same general pattern but exhibiting some important variations. The most important of these in terms of current practice is the difference between the results obtained using minimum/maximum, the basis of calculàtions in CIBSE TM5, and minimum/average which is used for specification of uniformity in CIBSE Code for Interior Lighting. Minimum/maximum/average calculations have the advantages of simplicity, which make them easy to understand and suitable for hand calculations, and of association with limiting values which appear to have some experimental validation and which have been in use for a long time, albeit with limits that do not equate to each other. The problems with these measures are caused under the circumstances where isolated point minimum or maximum values adversely affect the results. This lack of robustness is to some extent overcome by the use of the 16 point minimum/maximum measure. The two statistical measures, appear from the the experimental evidence, to produce robust result and have limiting values developed from the tried and tested minimum/maximum/average values. It is clear however that for most illuminance grids which have wide spreads of points that the S/E_{ave} measure is superior to SU. Both were more complex than the other measures tested but since most SHR calculations are performed on computers this is not a major drawback in practice. The gradient measures produce results that deviate most from the general pattern. The use of maximum gradient as a measure makes both interpretation of results and definition of suitable limits very difficult. The measure suffers from the same disadvantage as minimum/maximum/average in that it critically depends on localised point values and there is a clear need for more subjective work to establish acceptable limiting maximum gradient of illuminance.

This work has tested a number of alternative uniformity measures for use in SHR calculations. Gradient measures have been shown to be unsuitable for this purpose whilst single point minimum/maximum/average measures exhibit inconsistency. Statistical and 16 point minimum/maximum measures on the other hand have been shown to have potential for the development as the basis of SHR calculations.

5.7 References

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Chapter 6

Effect of design parameters on light loss

6.1 Introduction

Despite the consensus of opinion on the effect of obstructions on the lighting conditions in interiors (1), the majority of general lighting installations are designed assuming that the space between the plane of luminaires and the working plane is empty. In practice, however, most building interiors contain furniture, office equipments and office users projecting above the working plane which affect the pattern of light distribution and may cause local reductions in working plane illuminance coupled with the formation of shadowed areas. Routine design methods for general lighting systems do not allow for light loss caused by obstructions. Both the CIBSE (2) and the North American IES (3), for instance, suggest that in order to overcome the problems caused by obstructions luminaires must be installed at closer spacings than those which are appropriate for empty spaces. Neither body however provides any quantitative guidance as to how much closer to move luminaires under particular circumstances or the visual conditions achieved. The scarcity of design guidance is due to the lack of quantitative understanding of the effect of obstruction, on the spacing of the luminaires which was discussed in Chapter 4 and will be implemented in a design method in Chapter 7, and light loss.

In order to obtain information on illuminance conditions in actual obstructed interiors a number of workers have used survey methods to assess light losses. Kajima et al (4) carried out measurements of working plane illuminances in a number of offices before and after installation of furniture but their results showed only the drop in average working plane illuminance, which was by up to 20 % for the obstructed cases. The relationship between installation parameters and the magnitude of obstruction light loss over the working plane has been investigated using photometric surveys in actual installations [5] . The results showed reduction in average working plane illuminance in obstructed interiors ranging from 8 % to 10 % and a series of tentative relationships were put forward between obstruction size, shape and number, and the light loss. The data obtained from the survey work, however was not enough to define those relationships. Nonetheless they pointed out the way forward to carry out a full investigation.

6.2 Computer simulation of obstruction effects

A lengthy investigation of parameters affecting light loss could not be undertaken using survey methods since these have the disadvantage of only being able to provide data corresponding to the limited range of variables of each survey site. Furthermore the methods would be too time consuming if the large number of combinations of installations and design parameters required for a full understanding of the subject had to be located and measured. An alternative method to carry out such work was the use of computer simulation. The following sections describe the work undertaken using a computer analysis program, which was already described in detail in Chapter 3. The program simulates illuminance conditions in rooms of different sizes and reflectances, initially empty and then filled with obstructions which varied in type, height and reflectance.The effect of the various design parameters on the drop in average working plane illuminance is discussed.

6.2.1 Validation of the analysis program

It was pointed out in Chapter 3 that the analysis program results needed validating. In order to formulate a statement on the validity of the results, these were compared with data obtained from surveys carried out in actual interiors. Both surveyed and simulated interiors were similar. A statistical analysis method was used to compare sets of measured and calculated illuminance data.

Since the prime objective of this analysis is the correlation between measured and calculated illuminance values, the null hypothesis H_0 was chosen so that these sets of data are not correlated. This hypothesis was formulated for the purpose of being rejected so that the alternative hypothesis H_1 may be accepted [6]. The

Spearman rank correlation test was chosen for the purpose of this work. Apart from being a correlation test, it is based on ranks and also on the difference in scores between two variables for each rank. In this analysis, the null hypothesis is rejected if the statistical test yields a value whose associated probability of occurrence under H_0 is equal to or less than the level of significance α. For the purpose of this analysis α was taken as 0.01 in order to have a confidence level of correlation of 99 %.

For each of the data sets a correlation coefficient together with a confidence limit was obtained. Measured and calculated values had correlation coefficients ranging from 0.665 to 0.941 with 99 % confidence level. A plot of measured against calculated illuminance values for a typical data set is shown in Figure 6.1. Table 6.1 shows the correlation results for all sets of data. These results demonstrated that the analysis program is capable of simulating the lighting conditions in interiors for which the photometric and physical characteristics are known.

6.2.2 Improvements to the program

When first developed, the program was intended to handle a comprehensive range of furnished room sizes. The user however did not have much choice in manipulating the input data since the arrays of input data were already pre-defined in the body of the program according to a constant number of elements. The maximum room size, for instance, allowed to be modelled could not exceed 14 *m* by 12 *m*. Similarly the number of obstructions to be considered was restricted to a maximum of 24 elements. Redefining these arrays for particular applications was a tedious job which was prone to errors. In order to give the user more flexibility the arrays which handle the input data were redefined as a function of variables which in their turn were declared as constants with given values to suit any particular application. A list summarising a range of input data is shown in Table 6.2.

Concerning the positioning of luminaires, the program only checked to satisfy the SHR requirement but not the physical possibility of fitting all luminaires in the room which depends on the luminaire size in relation to the room dimensions. A new routine was introduced to overcome this shortcoming.

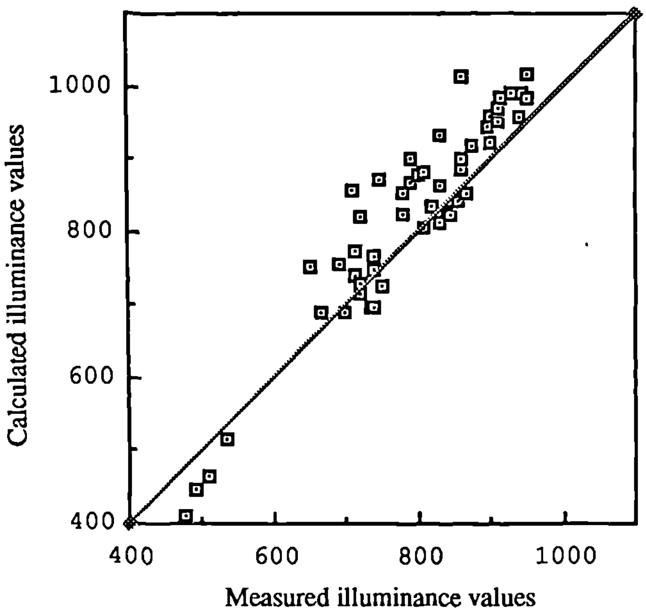

Figure 6.1: Comparison of measured and calculated illuminance values

Data set measured V calculated	Spearman coeff.		Decision about H0	Confidence level of correlation (if there is any)
	rs	t		
Room 1 empty case	0.665	12.44	H0 rejected at both 0.05 & 0.01 there is correlation	99 %
Room 1 obstruct. case	0.623	10.32	H0 rejected at both 0.05 & 0.01 there is correlation	99 %
Room 2 empty case	0.908	23.94	H0 rejected at both 0.05 & 0.01 there is correlation	99 %
Room 2 Obstr. case 1	0.917	15.07	H0 rejected at both 0.05 & 0.01 there is correlation	99 %
Room 2 Obstr. case 2	0.941	17.59	H0 rejected at both 0.05 & 0.01 there is correlation	99 %
Room 2 Obstr. case 3	0.774	9.49	H0 rejected at both 0.05 & 0.01 there is correlation	99 %
Room 2 Obstr. case 4	0.889	13.45	H0 rejected at both 0.05 & 0.01 there is correlation	99 %

Table 6.1: Results of the statistical analysis

Floor area XXLIMIT YYLIMIT (m X m)	Ceiling height m	mounting height m	Room index	Number of work stations	Number of Obstructions N	XMAX & XXMAX arrays	
						BBC, BBBC CAA	TTY, TYY
4 X 3	3.03	2.28	0.75	1	4	24	32
8 X 3	2.93	2.18	1.00	2	8	40	48
8 X 3	2.49	1.74	1.25	2	8	40	48
8 X 6	3.03	2.28	1.50	4	16	74	84
8 X 9	2.86	2.11	2.00	6	24	108	120
16 X 9	3.05	2.30	2.50	12	48	208	224
16 X 15	3.33	2.58	3.00	20	80	340	360
16 X 15	2.68	1.93	4.00	20	80	340	360
16 X 15	2.30	1.55	5.00	20	80	340	360

Table 6.2: Array sizes used to run the analysis program.

6.3 Description of simulated interiors

Using the revised version of the analysis program the simulation of working plane illuminance conditions was undertaken for rooms of different sizes and surface reflectances, initially empty and then filled with standard obstructions which varied in type, height and reflectance. The various interiors were lit by six installations consisting of point source or linear luminaires.

6.3.1 Characteristics of interiors

The sizes of the interiors used in this study were based on modular work stations which covered an area of 4 *m* by 3 *m* each including circulation space. Combinations of work stations and ceiling heights produced room sizes with Room Index ranging from 0.75 to 5.00. These combinations are shown in Table 6.2 together with a typical room furniture layout shown in Figure 6.2. For all interiors the working plane height was taken as 0.75 *m*. A number of room surfaces reflection factors similar to those of the Utilisation Factor calculations were used.

The standard obstructions described in the discussion of the obstructed SHR concept [7,8] were used as typical contents of the work stations. Each interior was made up of work stations with similar obstruction configurations. This lead to the room being either light, medium 1, medium 2 or heavy obstruction case with a partition of one of four heights; 1.25 *m* , 1.50 *m*, 1.75 *m* and 2.00 *m*. In the case of heavy obstruction configuration the partition was used with four different reflection factors; 30 %, 50 %, 60 % and 70 %.

6.3.2 Luminaire types

The various interiors were lit by six different types of general lighting installations which consisted of three linear and three point source luminaires which varied in size, intensity distribution and the way they were installed onto the ceiling. These were:

a) The first luminaire type was a twin lamps, 600 *mm* wide 1200 *mm* long recessed with a prismatic panel diffuser. It had a maximum luminous intensity of 214 *cd* / 1000 *lm* and a Downward Light output Ratio (DLOR) of 0.54. Its catalogue

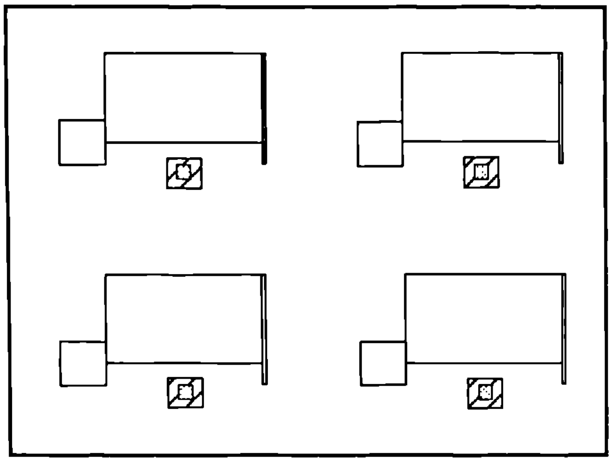

Figure 6.2: Room and furniture layout for one of the offices simulated.

number is FTP 236 + FTPP 612 [9]. The intensity distribution polar curves are shown in Figure 6.3.

b) The second luminaire was a 300 *mm* wide 1200 *mm* long twin lamps surface mounted reflector with a Batwing intensity distribution in the transverse plane. In the axial plane it had a cosine like distribution. The polar curves for these intensities are shown in Figure 6.4. Its DLOR is 0.67 and its catalogue number is CAS 3236 + CAS 1226 [9].

c) The third linear luminaire was a twin lamps, 300 *mm* wide 1500 *mm* long modular recessed reflector. As shown in Figure 6.5, it has an intensity distribution similar to the previous luminaire but with a reduced maximum luminous intensity of 226 *cd*/1000 *lm* and a DLOR of 0.66. This luminaire is to be found under the catalogue number CAS 2258 + CAS 1056 [9].

d) The first of the three point source luminaires was a 280 *mm* square shaped surface mounted diffuser with prismatic controllers. It was a compact source with a symmetrical intensity distribution and a DLOR of 0.51 (see Figure 6.6). The catalogue number of this luminaire is GY/2D/28 [10].

e) The second point source luminaire was a 2D 260 *mm* down light recessed diffuser with a symmetrical intensity distribution which had a sharp cut-off at around 60°, and a DLOR of 0.51. This is illustrated in Figure 6.7 and to be found under number 2D DSFR 16 [9].

f) The third point source luminaire was a 600 mm square shaped multi-cell low brightness recessed reflector with a Batwing intensity distribution and a cut-off at 60° (see Figure 6.8). Its DLOR was 0.66 and its catalogue number is 600/M9M/3218 [10].

6.4 Design parameters

The simulated interiors were made up of combinations of space characteristics, contents and luminaire types used in the installations. In order to investigate the effects of the various design parameters on the light loss it is necessary to define these parameters first, and then isolate one at the time and vary it over a fixed range when running the program while keeping the rest unchanged so that the effect of individual

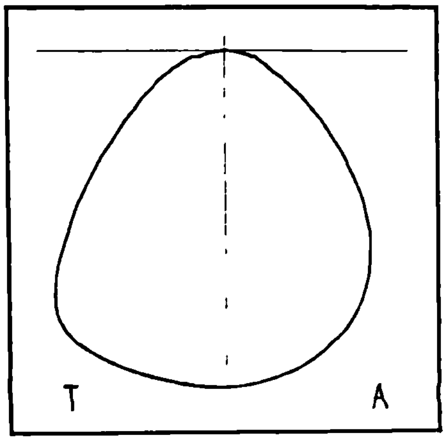

Figure 6.3: Intensity distribution for luminaire type 1

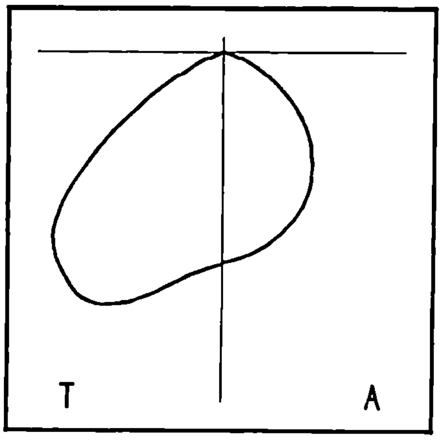

Figure 6.4: Intensity distribution for luminaire type 2

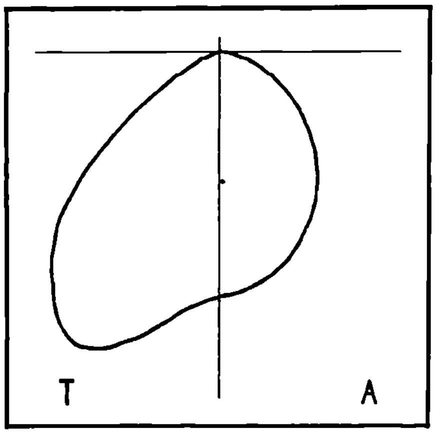

Figure 6.5: Intensity distribution for luminaire type 3

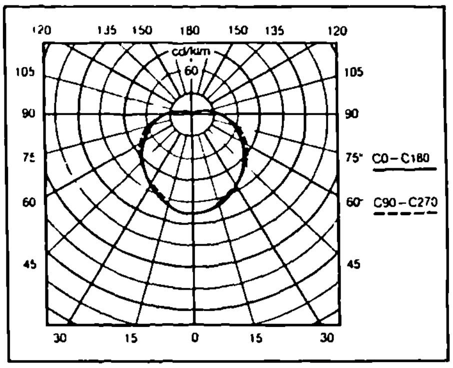

Figure 6.6: Intensity distribution for luminaire type 4

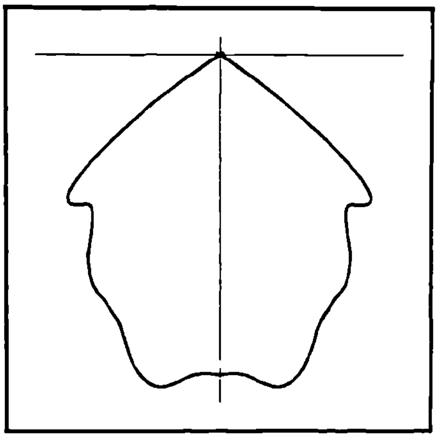

Figure 6.7: Intensity distribution for luminaire type 5

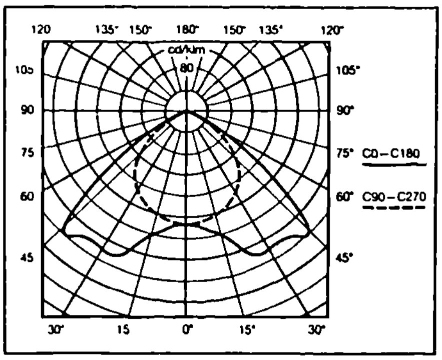

Figure 6.8: Intensity distribution for luminaire type 6

parameters could assessed.

6.4.1 Space parameters

When a space is considered (without any contents) the two characteristics which could affect light distribution are the proportions of wall areas to floor area and the surface colour. The former affects the proportion of flux falling on the wall, which determines a large part of the inter-reflected component. On the other hand, the latter influences the inter-reflection process between the various room surfaces. When referring to the design parameters, these two characteristics are represented by the Room Index R_i and the room surfaces reflection factors, α_c for the ceiling, α_w for the walls, and α_f for the floor. The range of room indices and room surface reflections factors used in the simulation are given above in section 6.3.1.

6.4.2 Obstruction parameters

The main obstruction parameter is the the obstruction configuration. This has already been shown in the discussion of the obstructed SHR concept. Since the various standard obstruction configurations produced different SHRMAX values, they are bound to have different effects on the light loss. In addition to obstruction density, the height and reflectance of the partition were considered as design parameters.

6.4.3 Installation parameters

Luminaire type and spacing to height ratio are the two design parameters, by which a general installation may be described. Both could influence illuminance distribution and light loss across the working plane. The effect of the intensity distribution attributed to each of the luminaire types will be examined. The spacing to height ratio may also have a significant effects on illuminance distribution. In this case however, since the spacing of luminaires is fixed before running the program (this point will be explained in detail at a later stage), the mounting height remains the other variable which may affect the light loss.

6.5 Running the program

Each simulated interior was a combination of a number of design parameters. In order to be able to assess the effect of the various parameters, only one was changed at any time while the rest were kept unchanged. When isolating the parameters, for each of the six luminaire types there were 42 different cases of interiors including four cases of obstruction density, four cases cases of partition height and an other four of partition reflectances.The room index range covered nine cases as well as the room surfaces reflection factor combinations for each of the light and heavy obstructed cases at one room index. Finally three cases of mounting height were used. The 42 various cases needed only 37 runs. This was because some of the data obtained were used to assess the effects of more than one parameter. For all six luminaires, 222 runs were performed.

Before each run was performed, several data files have to be prepared. These included a room data file, an obstruction data file and a general data file to store information on luminaire positioning.

First a series of test runs were performed. In these cases, the facility of automatic positioning of luminaires in the program was used. After their number was calculated using a lumen method calculation, the luminaires were then positioned in a layout which satisfied the requirements of the appropriate spacing to height ratio. In some cases this was achieved by modifying the number of luminaires calculated. Using this method of luminaire positioning was unsuitable for the purpose of this study since it yielded results which were difficult to interpret because the number of the luminaires changed from one case to an other for the same parameters. If obstruction density for instance was considered, the number of luminaires installed in each case of the four configurations would be different as well as that for the empty case since their respective SHRMAX values were different. This would make the comparison of results in terms of average illuminance between the empty and the obstructed cases difficult since the installed flux is different from one case to an other. As a consequence the effect of obstruction density on light loss which is based on the comparison of two different installed fluxes would be meaningless and difficult to use for the purpose of defining the particular relationship between the parameter examined and its effect on light loss. For these reasons a second series of runs was performed, in which the number of luminaires was fixed and the coordinates of their positions were input using external data files. Having the same installed flux for both empty and obstructed cases made the assessment of light loss easier by comparing their respective resulting average illuminance.

For each run, the program considers both empty and obstructed cases for which minimum, maximum and average illuminance values were calculated over a one meter grid across the working plane. Then the percentage reduction in average illuminance (total value of direct and indirect added together) was calculated using empty and obstructed values. Throughout the discussion of the results this will be referred to as the 'drop in average illuminance'.

All the data presented in this work were obtained using the second series of runs. The data for the effect of room surface reflectances when the light case was considered was not included in this discussion since the pattern of results was similar to that for the heavy case and the effect was negligible as it will be shown later when the results are discussed. Details for the number of luminaires used in the various runs is to be found in Tables 6.3 and 6.4.

6.6 Results of the simulation

A classification of results according to the type of the design parameters was adopted when the results are presented. This was favoured to luminaire type classification since the latter is itself a design parameter. For each design parameter, the variation of the drop in average illuminance, when changing the magnitude or the value of the parameter is, discussed for each of the six luminaires.

6.6.1 Effect of obstruction density

The increase in obstruction density was accompanied with an increase in the percentage drop in average illuminance for all cases simulated. The pattern of the results is quite similar for all luminaires but the magnitude of the variation from one obstructed case to an other depended on, primarily the luminaire type and to a much lesser extent the luminaire orientation.

When linear luminaires were considered, all three produced identical values of illuminance drop. These were around 5 %, 6 %, 7 % and 12 % for the four obstructed

Design Parameter	Number of luminaires used in simulation								
	Luminaire 1		Luminaire 2		Luminaire 3		Luminaire 4	Luminaire 5	Luminaire 6
	Parallel	Perpend.	Parallel	Perpend.	Parallel	Perpend.	Point source	Point source	Point source
Obstruction density	11 x 9	9 x 11	8 x 12	8 x 12	7 x 4	4 x 7	12 x 10	18 x 11	11 x 4
Partition height	11 x 6	6 x 11	8 x 8	5 x 12	7 x 4	4 x 7	12 x 6	18 x 11	11 x 4
Partition reflection factor	11 x 6	6 x 11	8 x 8	5 x 12	7 x 4	4 x 7	12 x 6	18 x 11	11 x 4

Table 6.3: Number of luminaires used for combinations of luminaire types and obstruction parametrs.

Design Parameter	Number of luminaires used in simulation								
	Luminaire 1		Luminaire 2		Luminaire 3		Luminaire 4	Luminaire 5	Luminaire 6
	Parallel	Perpend.	Parallel	Perpend.	Parallel	Perpend.	Point source	Point source	Point source
Room 0.75	3 x 3	2 x 4	2 x 3	1 x 5	2 x 1	1 x 2	3 x 2	4 x 3	2 x 2
Index 1.00	6 x 3	2 x 8	4 x 3	1 x 10	4 x 1	1 x 4	6 x 2	8 x 3	4 x 2
1.25	6 x 3	2 x 8	4 x 3	1 x 10	4 x 1	1 x 4	6 x 2	8 x 3	4 x 2
1.50	6 x 6	4 x 8	4 x 6	2 x 10	4 x 2	2 x 4	6 x 4	8 x 6	4 x 4
2.00	6 x 9	6 x 8	4 x 9	3 x 10	4 x 3	3 x 4	6 x 6	8 x 9	4 x 6
2.50	12 x 9	6 x 16	8 x 9	3 x 20	8 x 3	3 x 8	12 x 6	16 x 9	8 x 6
3.00	12 x 15	10 x 16	8 x 15	5 x 20	8 x 5	5 x 8	12 x 10	16 x 15	8 x 10
4.00	12 x 15	10 x 16	8 x 15	5 x 20	8 x 5	5 x 8	12 x 10	16 x 15	8 x 10
5.00	12 x 15	10 x 16	8 x 15	5 x 20	8 x 5	5 x 8	12 x 10	16 x 15	8 x 10
Room reflectances	12 x 6	6 x 12	8 x 10	5 x 14	8 x 3	3 x 8	13 x 7	20 x 11	8 x 6
Mounting height	11 x 6	6 x 11	8 x 8	5 x 12	7 x 4	4 x 7	12 x 6	16 x 9	8 x 6

Table 6.4: Number of luminaires used for combinations of luminaire types and room or mounting height parameters.

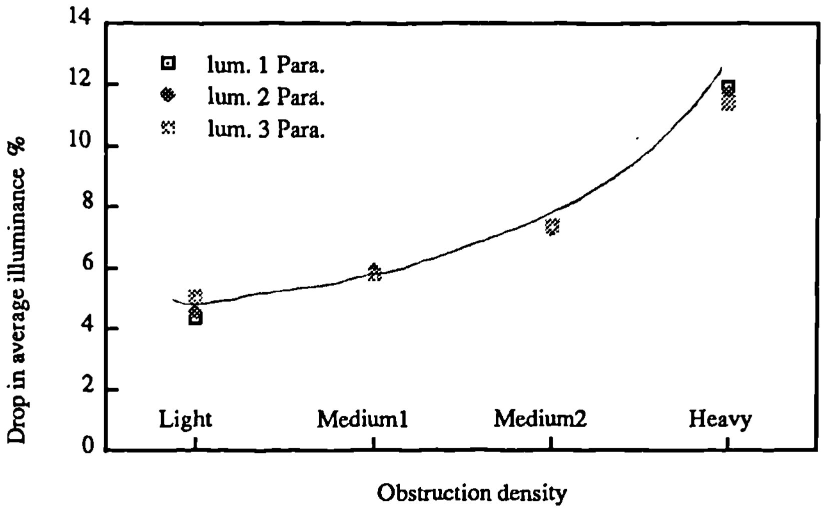

Figure 6.9: Drop in average illuminance as a function of obstruction density. Linear luminaires parallel to the room length.

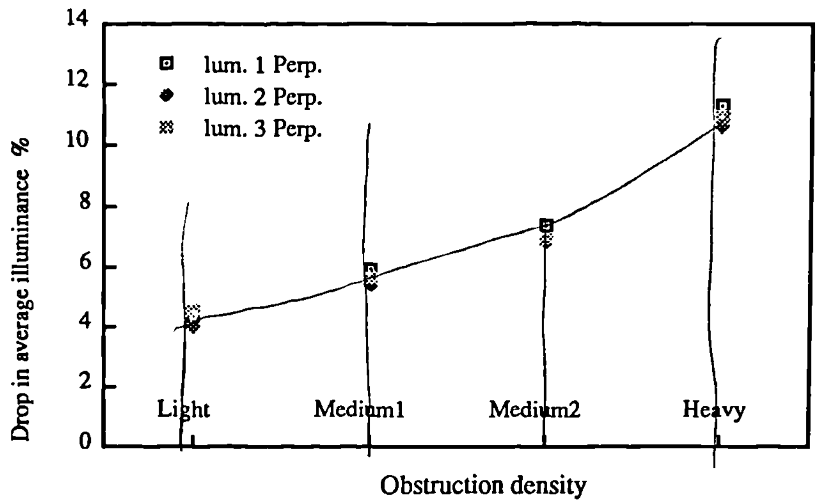

Figure 6.10: Drop in average illuminance as a function of obstruction density. Linear luminaires perpendicular to the room length.

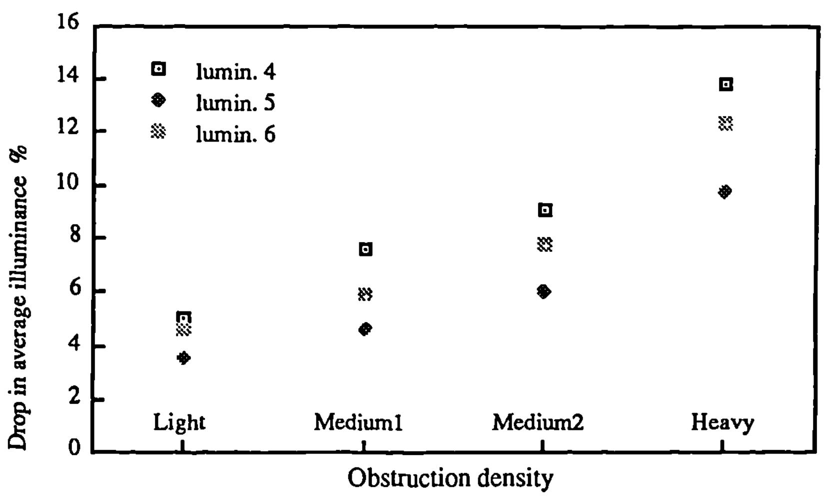

Figure 6.11: Drop in average illuminance as a function of obstruction density. Point source luminaires.

cases respectively when the luminaires were parallel to the room length. This is illustrated in Figure 6.9. Rotating the luminaires at 90 ° produced results in the order of 4 %, 6 %, 7 % and 11 % (see Figure 6.10).

Using point source luminaires yielded results with the same general direction of variation but with different magnitudes. The four standard obstructed cases experienced a percentage drop in average illuminance in the order of 5 %, 7 %, 9 % and 14 % when Luminaire 4 was considered. When Luminaire 5 was used in the installation, the magnitude of change was than in the previous case as the figure were 4 %, 5 %, 6 % and 10 %. The last point source luminaire produced drop in average illuminance in the order of 5 %, 6 %, 8 % and 12 %. These results are shown in Figure 6.11.

6.6.2 Effect of obstruction height (Partition)

Four heights of partition were used to run the program with the heavy obstruction case in order to asses their effect on the drop in average illuminance. These were 1.25 m, 1.50 m, 1.75 m and 2.00 m. Increasing the partition height resulted in an increase in the illuminance drop for which the pattern generally similar for all luminaires but the magnitude of variation differed according to the luminaire type.

When linear luminaires were used, varying the orientation from parallel to perpendicular did not affect the results considerably. Also the various intensity distributions of luminaires had a negligible effect. The drop in average illuminance for all luminaires was around 9 %, 11 %, 12 % and 14 % for the four heights respectively when a parallel orientation was used (see Figure 6.12). In the case of a perpendicular one these were 10 %, 12 %, 13 % and 15 % as shown in Figure 6.13.

The use of point source luminaires produced a different set of results. Although the principle of increase in illuminance drop with increased partition height remained a marked feature, the magnitude of variation was different for each luminaire. Luminaire 4, for instance values of average illuminance drop in the order of 11 %, 12 %, 19 % and 21% with a large difference between 1.50 m and 1.75 m which suggest that somewhere between these two heights the limit between the "see" and "no see" occurred. Luminaire 4 and 5 produced similar results in the order of 9 %, 10 %, 11 %

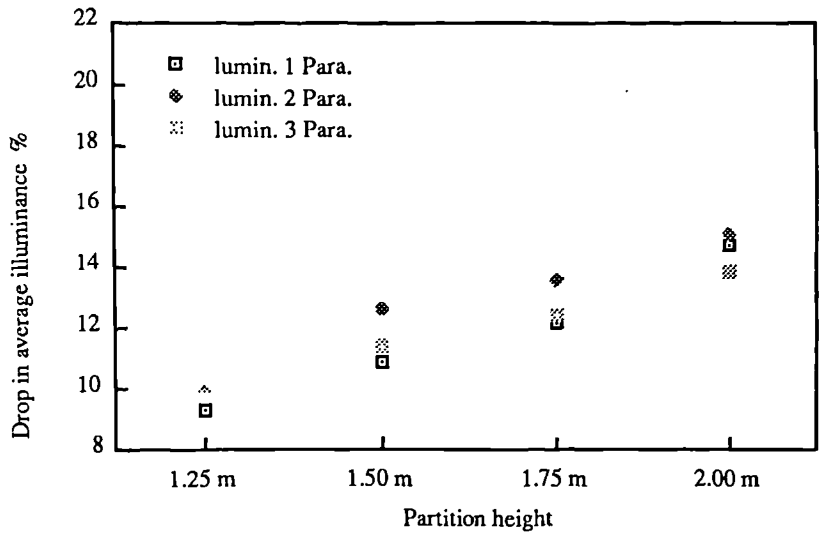

Figure 6.12: Drop in average illuminance as a function of partition height. Linear luminaires parallel to the room length.

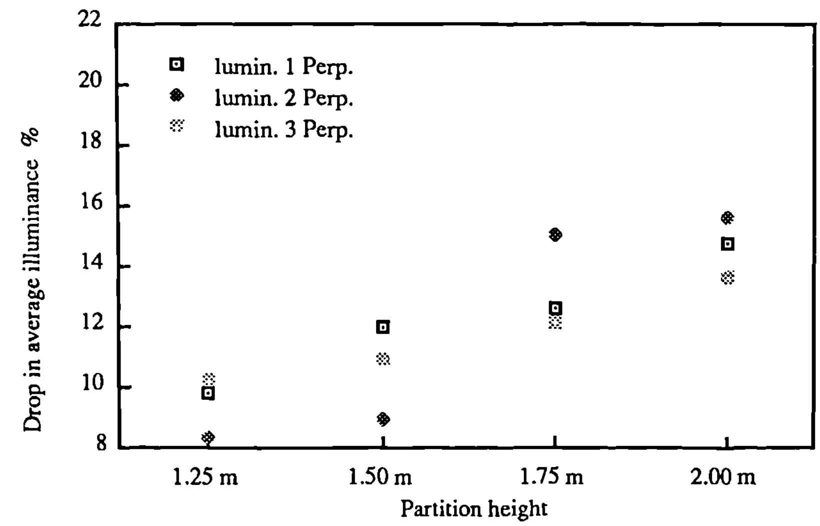

Figure 6.13: Drop in average illuminance as a function of partition height. Linear luminaires perpendicular to the room length.

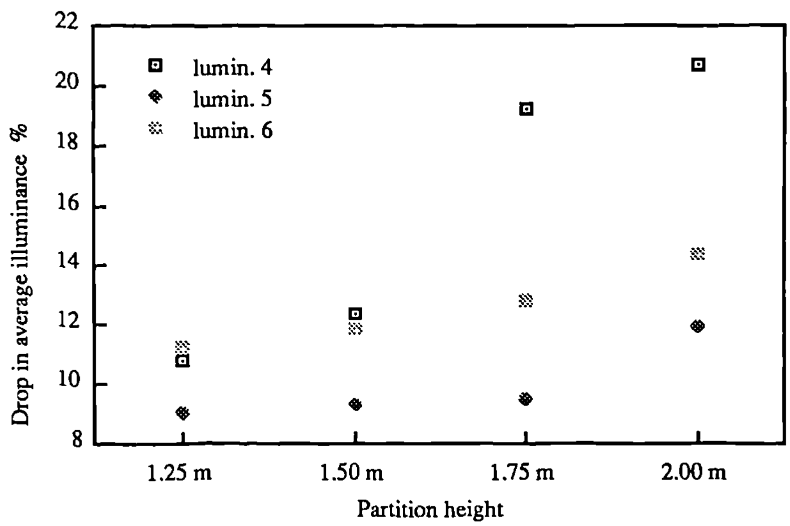

Figure 6.14: Drop in average illuminance as a function of partition height. Point source luminaires.

and 12 % for the first one and 10 %, 12 %, 13 % and 14 % for the second one.

6.6.3 Effect of Obstruction reflection factor

The effect of obstruction reflection factors on the drop in illuminance was investigated using four different reflectances, 30 %, 50 %, 60 % and 70 %, for the partition since it was the largest obstruction in size and surface area. Varying the partition reflectance across this range has produced negligible effect on light loss for all luminaire types and orientations used in the simulation (see Figures 6.15 to 17). for all luminaires, the variation in the drop in average illuminance across the reflectance range was below 0.5 %.

6.6.4 Effect of room index

When the effect of room index was investigated, the number of luminaires installed in all offices was proportional to the floor area for all luminaire types. The number of luminaires used in each case is to be found in Table 6.4. This assumption was introduced so that the likely effect of the luminaire position with respect to obstruction positions in the space was discarded. This assumption does not depart from reality, particularly in modern office interiors where the use of modular work stations is becoming very common. The interpretation of the results shown in Figures 6.18 to 20 is difficult since the room index is a combination of a number of parameters such as the mounting height and the size of the floor area and which determines the fraction of flux falling on walls rather than contributing directly to the working plane illuminance. The only feature which the results showed was the effect of varying the mounting height for the same floor area. Even then this effect was not very important as it will be shown later when the mounting height effect is discussed.

6.6.5 Effect of room surface reflectances

A whole range of surface reflection factor combinations similar to that used in the calculation of utilisation factors was used in this simulation in order to assess their effect of the drop in average illuminance. Both light and heavy standard obstruction cases were used. The pattern of the results obtained was the same for both obstruction configurations since they have the same room surface reflectances. The results of the

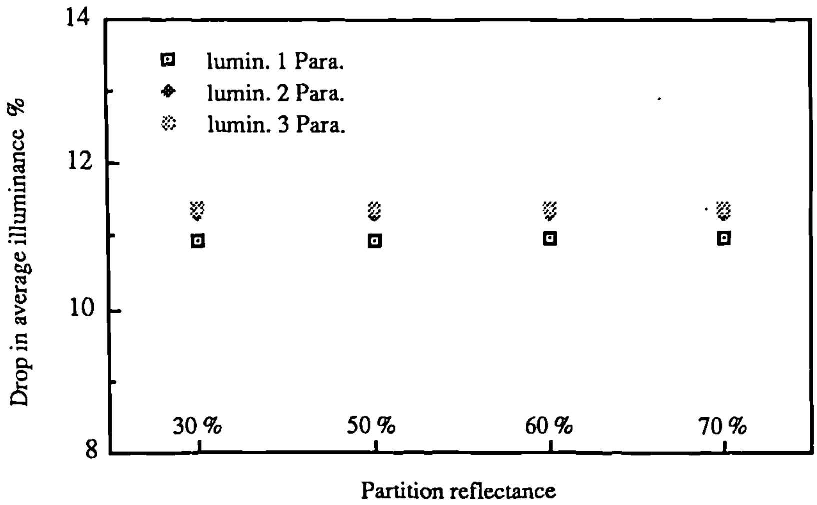

Figure 6.15: Drop in average illuminance as a function of partition reflectance. Linear luminaires parallel to the room length.

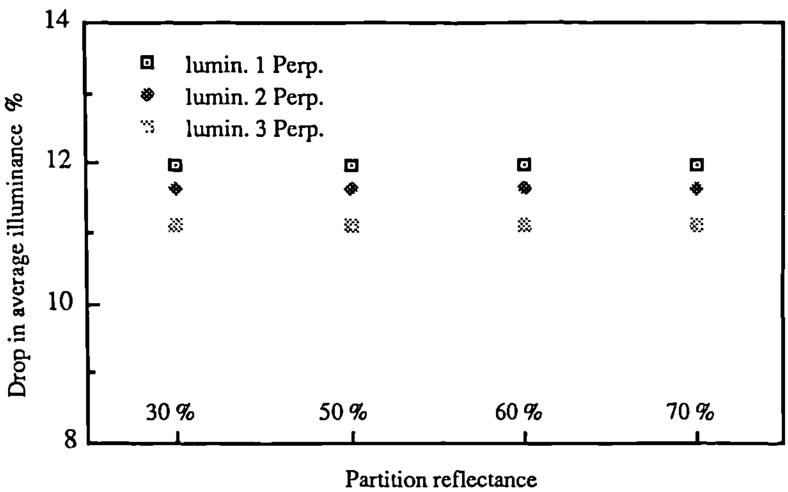

Figure 6.16: Drop in average illuminance as a function of partition reflectance. Linear luminaires perpendicular to the room length.

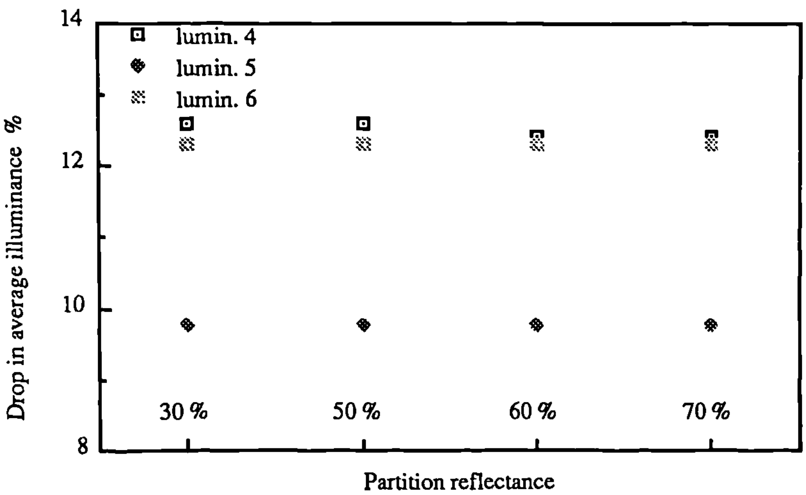

Figure 6.17: Drop in average illuminance as a function of partition reflectance. Point source luminaires.

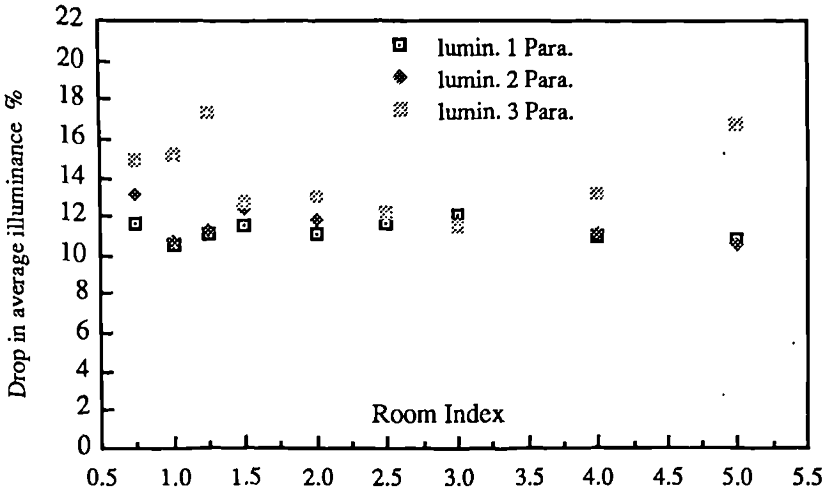

Figure 6.18: Drop in average illuminance as a function of Room Index. Linear luminaires parallel to the room length.

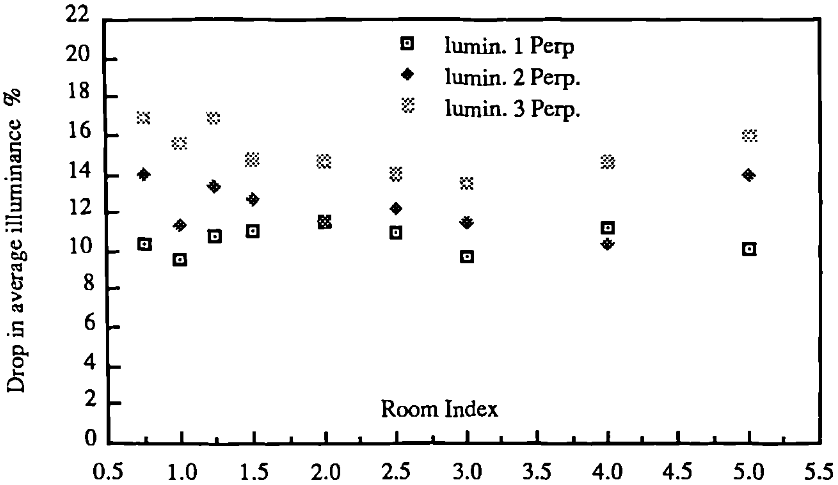

Figure 6.19: Drop in average illuminance as a function of Room Index. Linear luminaires perpendicular to the room length.

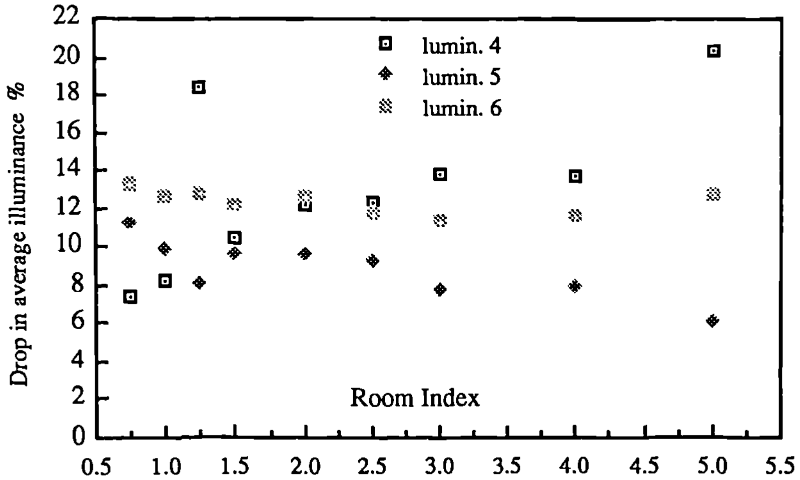

Figure 6.20: Drop in average illuminance as a function of Room Index. Point source luminaires.

heavy case are shown in Figures 6.21 to 23. For all luminaire types and orientations varying the room surface reflection factor combination had negligible effect on the drop in average illuminance. In all cases considered, the variation was less than 1 % across the whole range.

6.6.6 Effect of mounting height

Varying the mounting height from 2.00 m to 2.30 m and then to 2.50 m produced drop in average illuminance values which varied smoothly across the range of heights. The magnitude of change was low in all cases (lower than 2 % at most) but still of relative importance since it varied with both luminaire type and orientation for linear luminaires. For some luminaires the effect of the change in mounting height on the drop in average illuminance was negligible (difference between cases less than 1 %). In the case of other luminaires the difference in the drop in average illuminance between the various cases of mounting height was between 1 % and 2 %. Results for the linear luminaires are shown in Figures 6.24 and 25. Luminaire 1, for example had its lowest drop in average illuminance at 2.3 *m* when it was parallel and at 2.50 *m* when its orientation was perpendicular. Luminaire 4 on the other hand had its lowest drop at both 2.00 *m* and 2.50 *m* when positioned parallel to the room length and at 2.30 *m* when rotated at 90 °. When Luminaire 5 was considered, at a parallel orientation the effect of the mounting height was virtually negligible while at a perpendicular orientation it had its lowest drop at 2.00 *m*.

Similarly, the point source luminaires produced results which were different from one case to an other (see Figure 6.26). While Luminaires 4 and 5 had their lowest drop at 2.00 *m*, Luminaire 6 had the same drop in average illuminance at all three heights.

6.7 Discussion of the results

The results of the various simulations indicated that some parameters have much greater effects than others. Obstruction configuration has by far the largest effect with the drop in average illuminance in the examples ranging from 4 % to 14 %. The various heavy obstruction cases differed in partition height from 1.25 *m* to 2.00 *m* which caused variation in average illuminance drop over this range of approximately 6

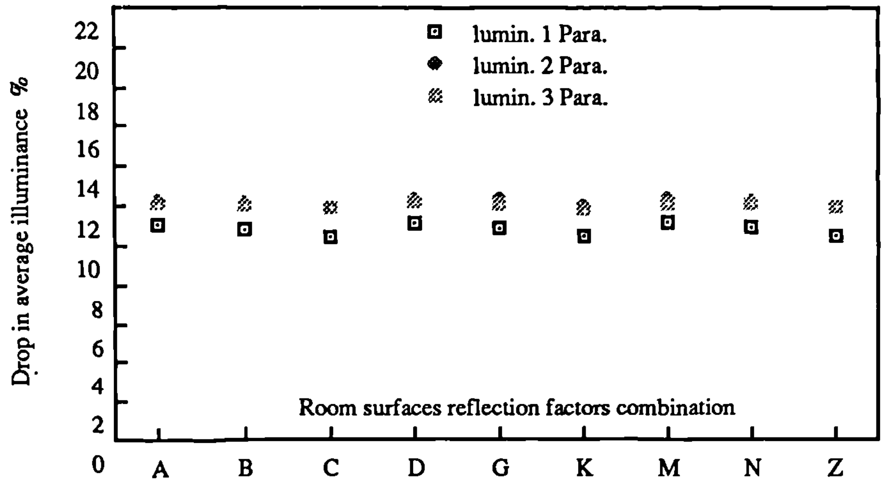

Figure 6.21: Drop in average illuminance as a function of room surfaces reflectances. Linear luminaires parallel to the room length.

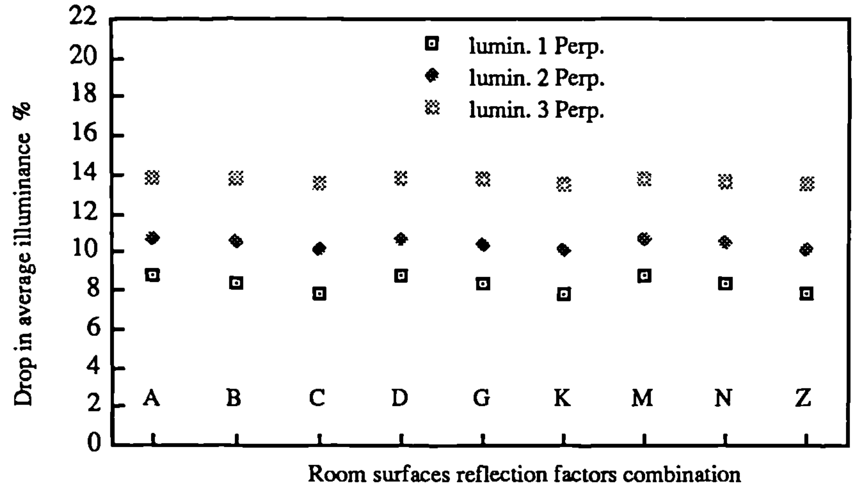

Figure 6.22: Drop in average illuminance as a function of room surfaces reflectances. Linear luminaires perpendicular to the room length.

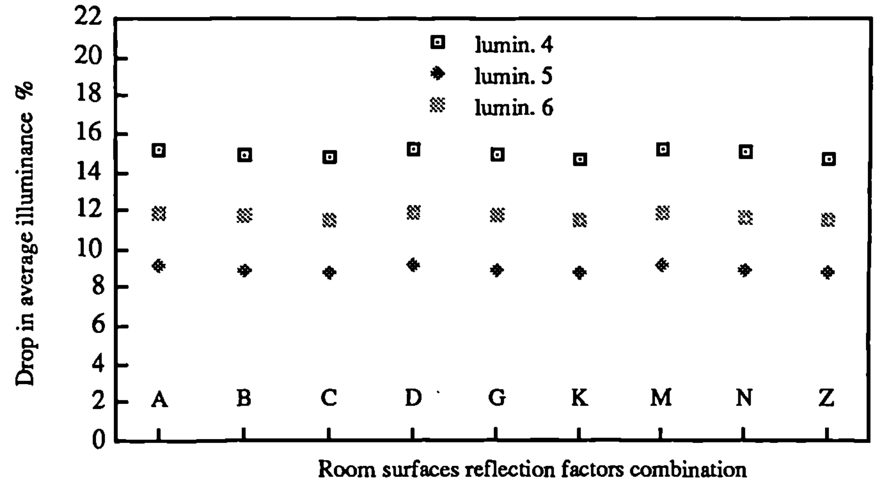

Figure 6.23: Drop in average illuminance as a function of room surfaces reflectances. Point source luminaires.

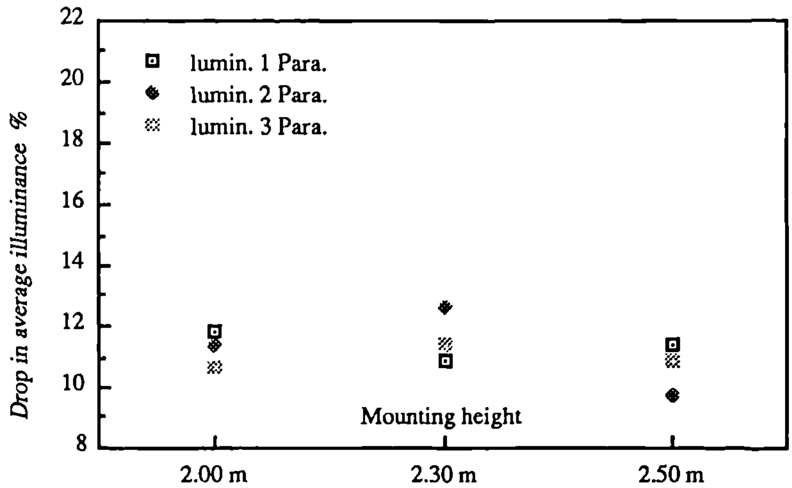

Figure 6.24: Drop in average illuminance as a function of the mounting height. Linear luminaires parallel to the room length.

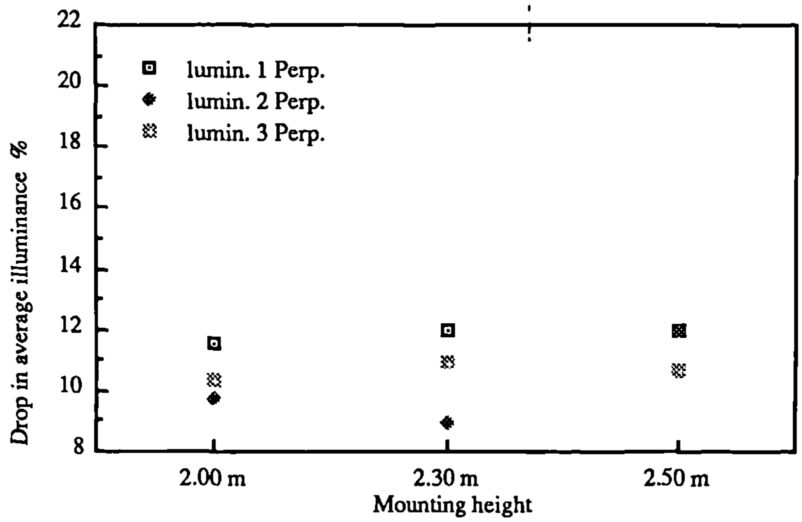

Figure 6.25: Drop in average illuminance as a function of the mounting height. Linear luminaires perpendicular to the room length.

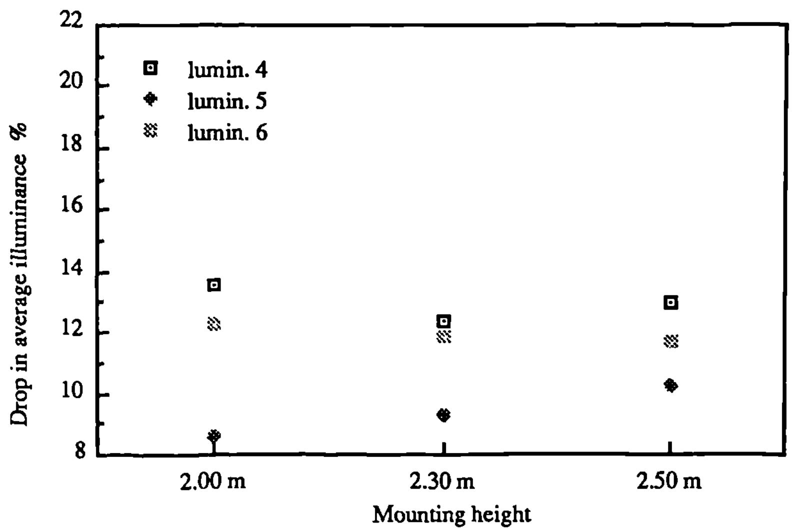

Figure 6.26: Drop in average illuminance as a function of the mounting height. Point source luminaires.

% for linear luminaires and up to 10 % for point sources.

The variation in average illuminance percentage drop with luminaire type is smaller than that caused by obstruction density but can be seen from the examples to still be substantial, particularly in the case of the point source luminaires. This is better illustrated on graphs in Figure 6.11 which shows variation in the drop in average illuminance against obstruction density for the point source luminaires. The individual points plotted on the graph correspond to the four Obstruction configurations. It is clear that the three linear luminaires in the examples in Figures 6.9 and 6.10 have similar drop in average illuminance values and that the orientation of the luminaire with respect to the work station has little effect on that drop. The variation in the drop in average illuminance between point source luminaires is greater than that for the linear luminaires due to luminaires with major illuminance contribution being either "seen" or "not seen" at the calculation point and to the intensity distributions of the different luminaires.

Variation of room and obstruction surface reflectances over a full range of values used in utilisation factor calculations caused negligible effect on the drop in average illuminance. The mounting height of luminaires also appeared to have a minimal effect, variation of between 2.00 m and 2.50 m for the luminaires shown in Figures 6.3 to 6.8 caused differences in the percentage drop in average illuminance in the order of 1 % to 2 %. Although negligible these differences are substantial since they determine the best mounting height considered. The room index results were difficult to interpret since this parameter is a combination of more than one. Nonetheless, the effect of the mounting height within the combination was noticeable.

6.8 Conclusion

The work described in this chapter investigated the effects of a number of design parameters on the drop on average illuminance across the working plane in obstructed interiors.

The results set out and quantify a series of relationships between the design parameters and their effect on illuminance drop. Some parameters however, were shown to have greater effect than others, while some had negligible effect.

Obstruction density was identified to have had a much greater effect than any other parameter. Obstruction height also had considerable effect at lesser magnitudes than obstruction density. Both room and obstruction surface reflectances had negligible effect while luminaire type and mounting height had their effects shown to be of small magnitude but of considerable importance. The room index is probably one area where more data need to be produced in order to fully quantify its effect on light loss.

6.9 References

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Chapter 7

A lighting design method for obstructed interiors

7.1 Introduction

It was established in the earlier discussion that light losses caused by room contents will have major effects on illuminance conditions over the working plane in general lighting installations [1]. Despite this however, conventional design methods do not provide suitable techniques which would enable designers to assess obstruction light loss and to take informed decisions accordingly.

The likely effects of obstructions are acknowledged in such documents as CIBSE TM5 [2]. This acknowledgement is in the form of a mere advice to reduce the spacing of luminaires. Any attempt to modify an installation to counter obstruction effects was left to the designer's discretion. With very little design guidance available on the measures needed to offset obstruction effect, a large number of inexperienced designers have, over a large number of years, routinely produced schemes based on the assumption of an empty space.

The lack of 'official' design guidance on obstruction effect is coupled with the non existence of synthesis design approaches to assess the likely light losses. Clearly there is a need for a reappraisal of conventional design methods such as the lumen method, which fell short of providing design techniques capable of dealing with obstruction effect. One way of accomplishing this task is to modify the traditional lumen design method to take account of the presence of obstructions in a space and and to assess their likely effects.

This chapter describes a series of modifications to the lumen method. These include the obstructed SHR concept which was complemented by a technique to assess light loss caused by obstructions in a range of interiors lit by a range of luminaire types. This technique is based on the results of the computer simulation discussed in Chapter six. The use of the modified lumen design method is explained through some design examples.

7.2 Light loss caused by obstructions

When obstructions are present in a space they block part of the direct flux and interfere in the inter-reflection process, the resulting effect would be a reduction in working plane illuminance and large variations to the illuminance distribution pattern as compared to that of an empty space. The photometric properties of interiors also affect illuminance conditions since they play an important part in the inter-reflection process. In order to fully identify the relationships the light loss and the physical and photometric properties of the interior and its contents an investigation into the lighting conditions in obstructed interiors lit by different luminaires was needed.

It was pointed out in the previous chapter that some tentative relationships between the characteristics of obstructed interiors and the light loss were put forward on the basis of the findings of some survey work. This method of investigation has the disadvantage of only being able to provide data for a limited range of variables at any one time. If a large number of design parameters required for a full understanding of the subject had to be surveyed, the time involved would be enormous.

Computer simulation presents a more attractive alternative which could be used to undertake such a sizable study. Chapter six showed how a computer analysis program can be used to examine the effects of the various design parameters on the light loss. The results illustrated the existence (if any) and the magnitude of the effect of each of the parameters on the drop in average working plane illuminance.

The results of the study in the previous chapter will be put into a form suitable for design use which will be incorporated into a modified lumen design method for obstructed interiors. The method will also make use of the obstructed SHR concept described in Chapter four.

7.3 Use of Obstruction Loss in design

Average working plane illuminance for both empty and obstructed cases were compared. The percentage reduction in average working plane illuminance caused by obstructions was derived. This was defined as Obstruction Loss 'OL' and was used to describe the magnitude of light loss caused by the various design parameters either combined or separately.

The Computer simulation study described in the previous chapter identified the relative effect on light loss of the various elements making up an obstructed space. Data in Table 7.1 shows typical values of OL in simulated interiors when lit by six types of luminaires identical to those described previously. Seven variations of standard obstruction were used, described by configuration with the heights for the heavy cases indicated. Axes of linear luminaires with respect to the axes of the work stations were either parallel or perpendicular.

The magnitude of these losses are such that they may have a considerable effect on working plane illuminance conditions. The obstruction configuration and height are the major factors causing light loss, with variation between types of luminaires causing smaller but still significant losses. On the other hand variation in the photometric properties of room or obstruction surfaces and of luminaire mounting height cause negligible changes in light losses.

The simulation methods used in the previous chapter are capable of calculating likely light losses not only for the large range of data described in this work, but also for almost endless combinations of design parameters with each commercially available luminaire.

The production of OL data in this form would be costly and the resulting data would be too voluminous to be conveniently used by practising designers. For this purpose some reduced data set is required which is capable of expressing the effects of the combinations of individual parameters on OL. An implicit assumption in the use of the Standard Obstruction concept is that obstructions in the interior to be lit are reasonably evenly distributed about the floor area. Standard Obstruction configurations have been used in this work to represent the range of obstructions present within an interior. The designer must initially decide which Standard Obstruction is appropriate to the known, or anticipated, contents of the interior. This decision is informed using one of two new parameters put forward to describe the interior and its contents and relate it to the light loss.

Luminaire type		Light	Medium V.D.U	Medium F.C.	Heavy 1.25 m	Heavy 1.50 m	Heavy 1.75 m	Heavy 2.00 m
	R.I.	2.50	2.50	2.50	2.50	2.50	2.50	2.50
1 Prismatic Panel Diffuser	Perp.	4.31	5.93	7.37	9.80	11.96	12.62	14.78
	Para.	4.31	5.75	7.34	9.33	10.83	12.16	14.66
2 Surf. Mount. Broadsp. Reflec	Perp.	3.96	5.40	6.83	8.35	8.96	15.07	15.68
	Para.	4.54	5.87	7.20	9.91	12.60	13.95	15.01
3 Recess. Broad Reflector	Perp.	4.49	5.69	6.99	10.22	10.97	12.16	13.67
	Para.	5.06	5.72	7.33	9.81	11.43	12.40	13.80
4 Surf. Mount. Diffuser		5.08	7.62	9.07	10.83	12.35	19.20	20.72
5 Recessed Diffuser		3.60	4.62	5.99	9.05	9.29	9.52	11.90
6 Recessed Reflector		4.69	5.90	7.81	11.22	11.86	12.82	14.42

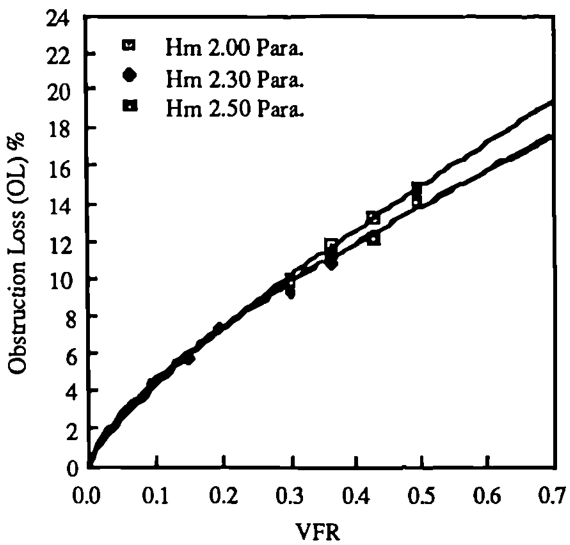
Table 7.1: Obstruction Loss for the simulated installations

7.3.1 Ratio of vertical surface of obstruction to floor area 'VFR'

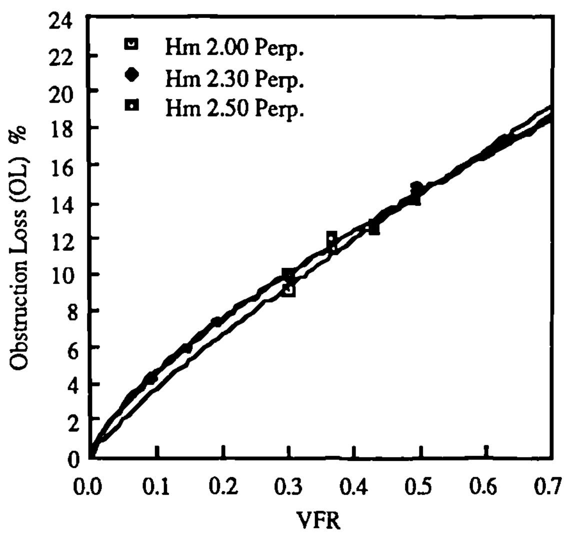
The ratio of vertical obstruction surface area to floor area or VFR, as the name implies, combines information on number of obstructions, geometric form of obstructions including height, and the density of obstruction surfaces with respect to floor area. These being the major factors that have been shown to influence light loss in a particular interior. When VFR is assessed, each obstruction is split into 4 vertical surfaces and the area for each one of them is calculated. Then the total vertical surface area for the obstruction is found. When all obstruction vertical surface areas are added up and the result is divided by the floor area VFR is found. Typical values for VFR for the standard obstructed cases are of the order 0.09, 0.14, 0.19 and 0.361. These values seem to bear a relationship to the obstruction density. Figures 7.1 to 7.6 show the relationship of VFR to OL for individual luminaires. If this data were widely available it would constitute a method of assessment of OL suitable for routine design purposes. Inspection of Figures 7.1 to 7.6 reveals close similarities of the basic form of the VFR/OL relationship for the linear luminaires and substantial similarity between the relationships for the point sources despite the very different nature of the six luminaires investigated. From this it can be postulated that similar VFR/OL will apply to a large number of commercially available luminaires. Thus the form of this data for routine use could be as a series of VFR/OL graphs for broad generic types of luminaires.

7.3.2 Ratio of obstruction height to mounting height 'OHR'

An alternative way of expressing the results of the simulation with respect to the installation parameters is by means of the ratio of average obstruction height above working plane to mounting height 'OHR'. This is obtained by dividing the average weighted height of obstruction by the mounting height of the luminaires. In calculating average height each obstruction is split into four vertical surface components each of which is weighted according to its length in plan. The total weighted height of the obstructions is divided by total floor area. Because of the method of calculation, OHR has a linear relationship with VFR for any mounting height. This is shown in Figures 7.7 and 7.8 for both the calculated data and the survey data of McEwan and Carter [4]. Expressing results in terms of OHR enables the effect of mounting height to be examined. Figure 7.9 shows a plot of OHR against OL for linear luminaire 1

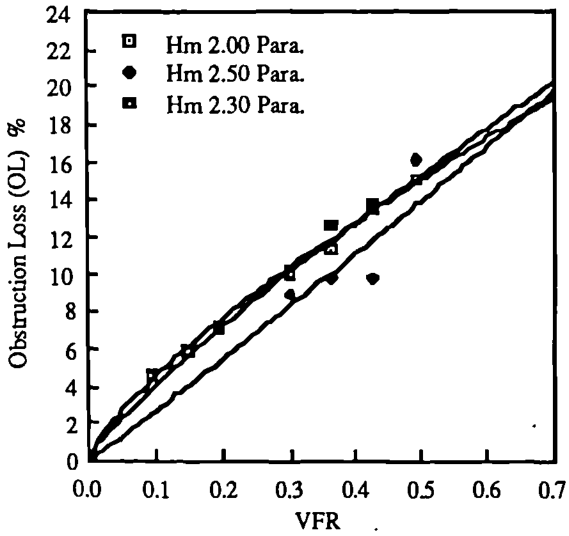


Case a: Luminaire 1 parallel to room length

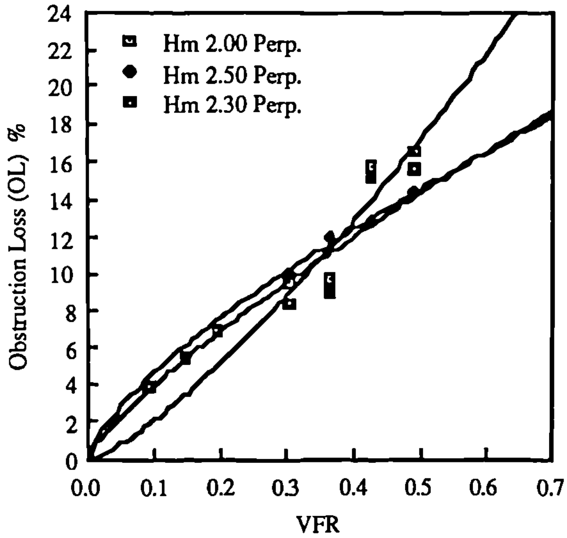


Case b: Luminaire 1 perpendicular to room length

Figure 7.1: Variation in Obstruction Loss as a function of VFR for luminaire 1

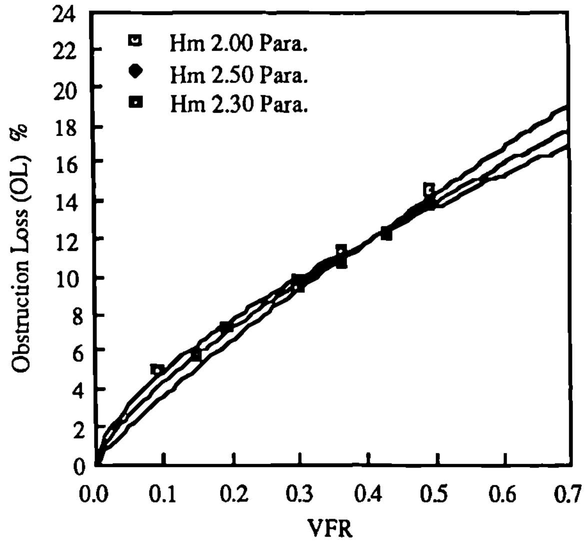


Case a: Luminaire 2 parallel to room length

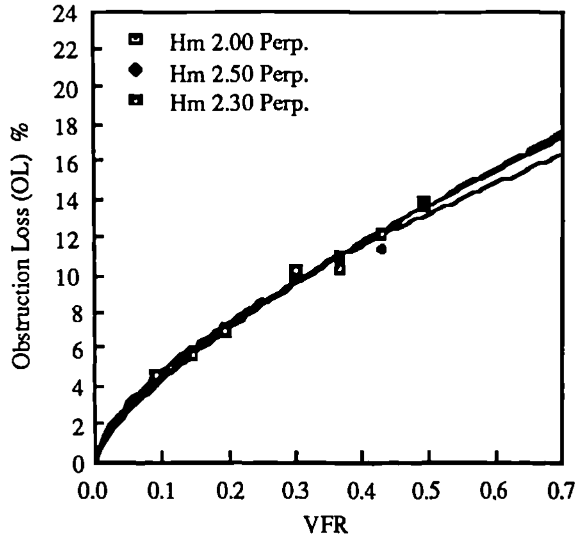


Case b: Luminaire 2 perpendicualr to room length

Figure 7.2: Variation in Obstruction Loss as a function of VFR for luminaire 2



Case a: Luminaire 3 parallel to room length



Case b: Luminaire 3 perpendicular to room length

Figure 7.3: Variation in Obstruction Loss as a function of VFR for luminaire 3

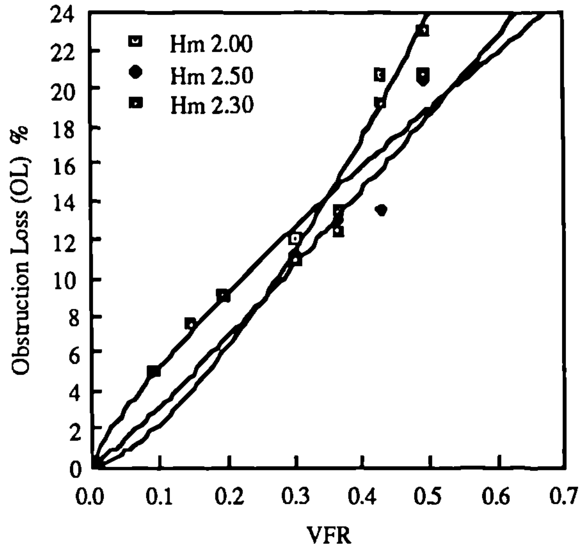


Figure 7.4: Variation in Obstruction Loss as a function of VFR for luminaire 4

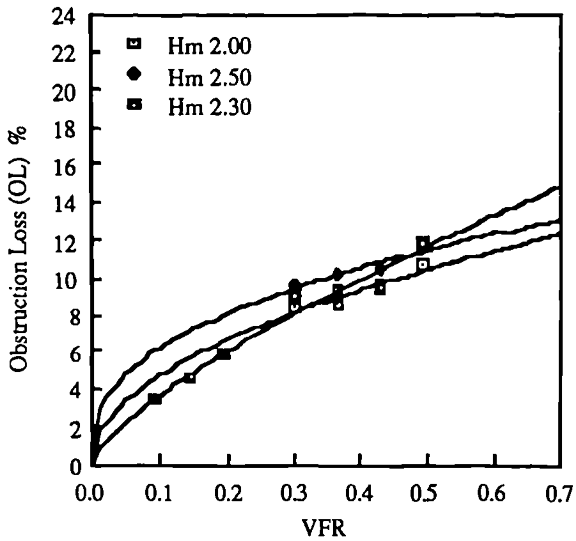


Figure 7.5: Variation in Obstruction Loss as a function of VFR for luminaire 5

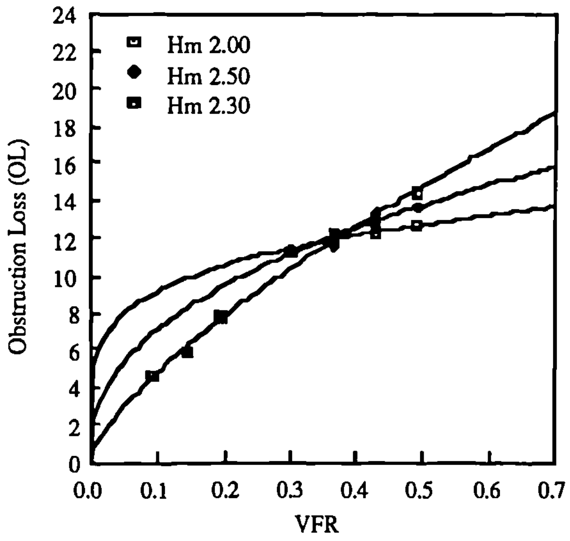


Figure 7.6: Variation in Obstruction Loss as a function of VFR for luminaire 6

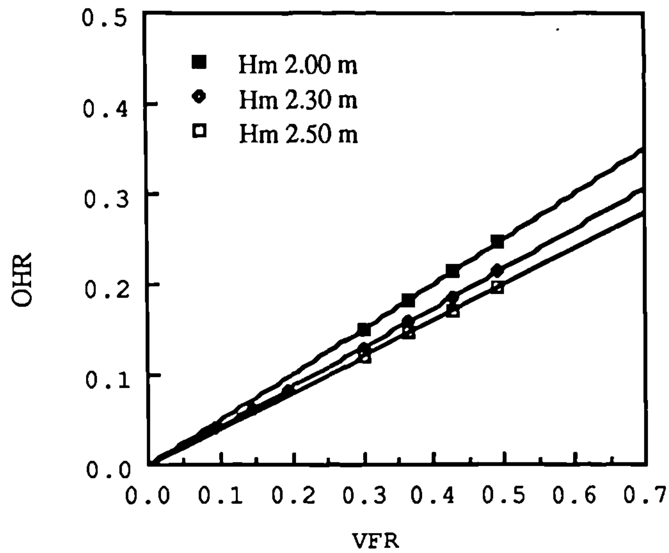


Figure 7.7: Variation in OHR as a function of VFR for calculated data with three mounting heights.

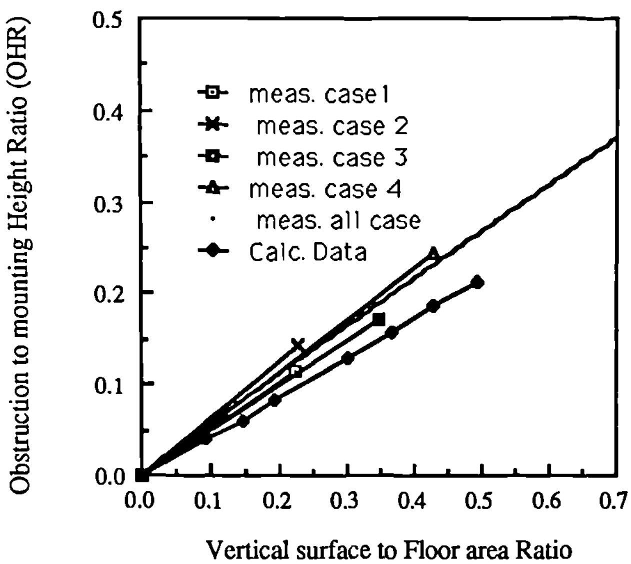
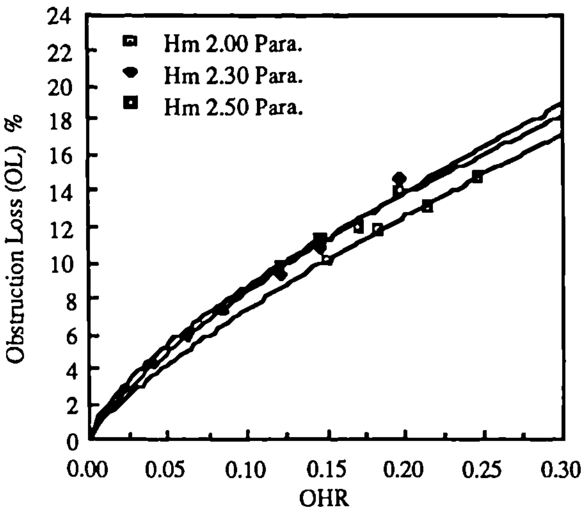
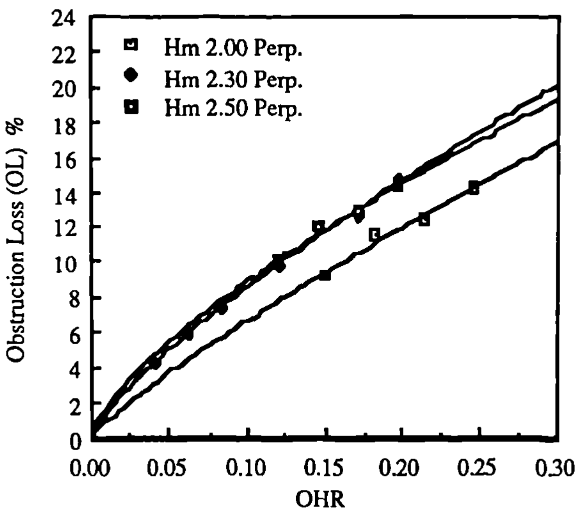


Figure 7.8: Variation in OHR as a function of VFR for calculated and measured data at various mounting heights



Case a: Luminaire 1 parallel to room length



Case b: Luminaire 1 perpendicular to room length

Figure 7.9: Variation in Obstruction Loss as a function of OHR for luminaire 1

positioned both perpendicular and parallel to room axis and illustrates in this case that a change of mounting height from 2.0 *m* to 2.5 *m* resulted in changes of OL of the order of 1 %. A detailed description of the calculation method of both VFR and OHR is given in Appendix D.

7.4 Design to acknowledge Obstruction Loss

To illustrate the application of the modified lumen method two examples are presented of a design of a general lighting scheme for small and medium size offices. For purpose of comparison designs are produced firstly, based on the assumption of an empty room and using data produced in accordance with CIBSE TM5 and secondly, using the SHROBS data and modification of total installed flux using OL.

7.4.1 Heavily obstructed office interior

The office is 15 *m* by 12 *m* with a ceiling height of 2.95 *m*. The standard service illuminance is 500 lx and the working plane height of 0.75 *m* is assumed. The office is to be occupied by 24 work stations for which the data was supplied by a large UK manufacturer [3] which are evenly distributed across the working plane in groups of four. A proposed layout is shown in Figure 7.10.

The first step of the design involves the calculation of VFR for the office. This was computed as 0.37. Using initially a linear prismatic panel diffuser (luminaire 1 in Table 7.1), for which the OL curve is shown in Figure 7.1, the obstruction loss was estimated at 11 % for both luminaire orientations This OL value is similar to that of a standard heavy obstruction for which the SHROBSMAX is 1.27 for the parallel position and 0.85 for the perpendicular, as compared to 1.70 for the empty case.

When the empty room case was considered the minimum number of luminaires needed was 34 when using twin 3200 lumen lamps. In a layout of 7 by 5 luminaires the axial and transverse SHR values were 0.97 and 1.09 respectively which were within the limits of SHRMAX. In the case of obstructed interiors the installed flux had to be increased to take account of light loss. The number of luminaires was increased to a minimum of 38 when positioned parallel to the room length and, in this case an 8 by 5 luminaire layout produced installed SHR's of 0.85 and 1.09. These were within the limit of SHROBSMAX and the installation gave an average illuminance of 527 lx. This is tabulated in Example 1 in Table 7.2.

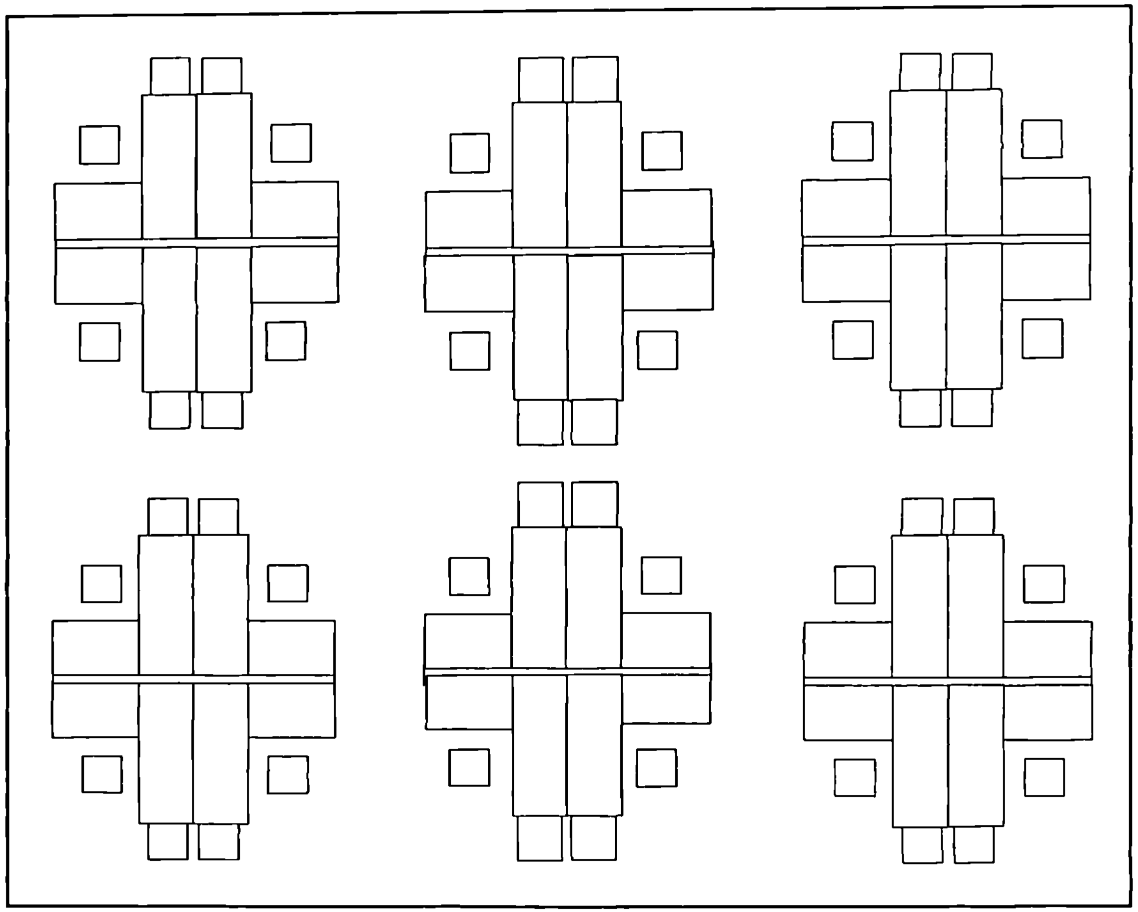


Figure 7.10 Layout of work stations in the office (design 1).

Design Example Number	Luminaire description			Empty case installation							Obstructed case installation										
	Type	Position with respect to partition	Lamp Lumen Output (Lm)	SHRMAX		Requi. number of lumin. N1	Layout1	Installed SHR		Eavg1 (Lux)	SHRMAX		Requi. number of lumin. N2	Layout2	Installed SHR		Eavg2 (Lux)	Layout3	Requi. number of lumin. N3	Eavg3 (Lux)	Dimmed output %
				Axial	Trans			Axial	Trans		Axial	Trans			Axial	Trans					
1	Prismatic panel diffuser	Parallel	2x3200	1.69	1.69	34	7x5	0.97	1.09	518	1.27	1.27	38	8x5	0.85	1.09	527				
2		Perpend.	2x3200	1.69	1.69	34	7x5	1.09	0.97	518	0.85	0.85	39	8x5	1.09	0.85	516	8x7	56	723	30
3		Perpend.	2x2750	1.69	1.69	40	8x5	1.09	0.85	508	0.85	0.85	45	9x5	1.09	0.76	499	8x7	56	621	15
4	Low brightness recessed reflector	Any	4x1200	1.80	1.80	35	7x5	0.97	1.09	507	1.29	1.29	40	8x5	0.85	1.09	509				
5		Any	3x1300	1.80	1.80	42	7x6	0.97	0.91	495	1.29	1.29	48	8x6	0.86	0.91	496				
6	Recessed broad-spread reflector	Parallel	2x5100	2.08	2.08	17	6x3	1.13	1.81	547	1.25	1.25	20	5x4	1.36	1.36	516	6x5	30	775	47
7		Parallel	2x4400	2.08	2.08	19	5x4	1.36	1.36	524	1.25	1.25	23	6x4	1.13	1.36	535	6x5	30	668	25
8		Parallel	2x3200	2.08	2.08	27	7x4	0.97	1.36	534	1.25	1.25	31	8x4	0.85	1.36	518	6x5	30	486	
9		Parallel	2x3200	2.08	2.08	27	7x4	0.97	1.36	534	1.25	1.25	31	8x4	0.85	1.36	518	7x5	35	567	11
10		Perpend.	2x2750	2.14	2.14	31	8x4	0.85	1.36	524	1.00	1.00	36	6x6	1.13	0.90	501	7x6	42	585	15
11	Surf. mount. diffuser	Any	1x2650	1.74	1.74	85	11x8	0.62	0.68	518	1.17	1.17	101	12x9	0.57	0.60	536				

Table 7.2 Summary of the first series of design examples

When the luminaires were positioned perpendicular to the room length (Example 2, Table 7.2), a different result was obtained in the obstructed case. In order to satisfy the SHROBS requirement the calculated number of luminaires (34) had to be increased to 56 which using the original lamp at mains voltage would give an installed average illuminance of 723 lx.

The average illuminance in this design is uneconomically high and may be reduced by either installation of lamps of lower lumen output or using a dimming system. For this example repeating the obstructed calculation using the lowest lumen output lamp available for use in the luminaire (Example 3, Table 7.2) gives a similar final layout to Example 2, but a final average illuminance of 621 lx. This may still be too high and consideration can then be given to either use of a dimming system to reduce the average illuminance or repeating the calculation with different luminaire / lamp combinations.

Table 7.2 shows three other possible solutions to the lighting of the office; one using a Broadspread mirrored reflector linear luminaire (Luminaire 3 on Table 7.1) and the other using prismatic and mirrored reflector point sources (luminaires 4 and 6 respectively on the same table). As would be expected the layouts for the obstructed cases contain more luminaires than those designed assuming an empty interior. The increase in these examples is in the range from approximately 7 % up to 60 % depending on the luminaire / lamp combination chosen. The production of the obstructed case layout is generally in two parts, "layout 2" satisfying the design criterion of average illuminance, and "layout 3" acknowledging uniformity across the task. In general the point source luminaires satisfy both at the layout 2 stage. This is due to the relatively large number of luminaires used to give the requested average working plane illuminance and which provide multiple illuminance contributions to each task area. The linear luminaires layouts, on the other hand, require adjustment to satisfy the SHROBSMAX requirement at the layout 3 stage. There are large differences between the installed fluxes in the final layouts using linear luminaire installed in either parallel or perpendicular directions with respect to the partitions. The major changes occurring at the layout 3 stage for the reasons set out above. This information may be used to inform the designer's decision as to whether the increases in installed fluxes in some potential layouts are justified, whether to use an other luminaire, or whether to supplement the task lighting with some form of local lighting.

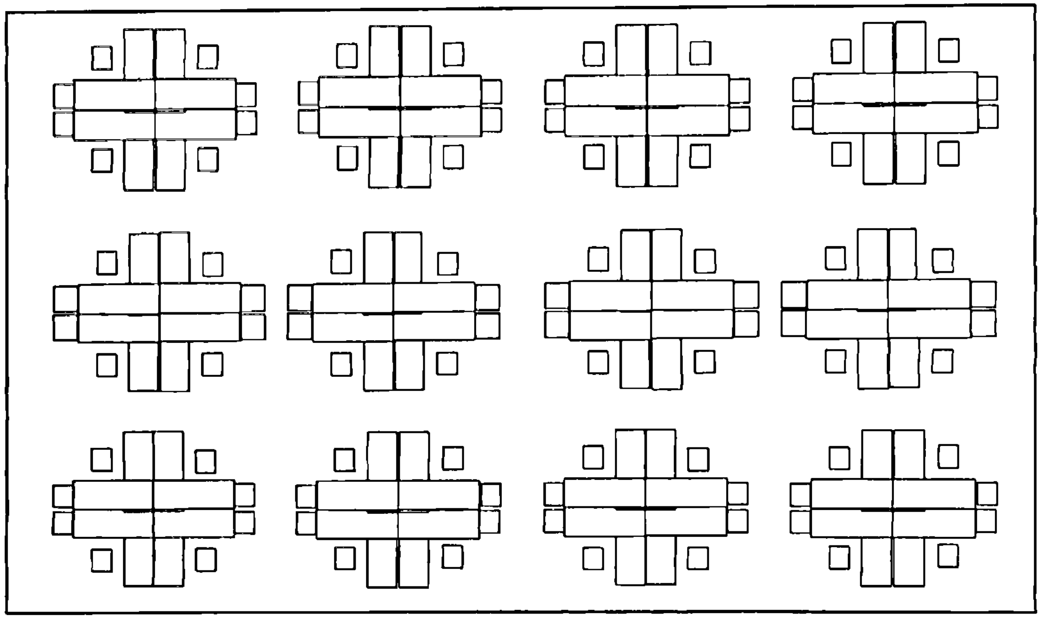


Figure 7.11: Layout of work stations in the office (design 2).

7.4.2 Medium obstructed office interior

The second office is of a larger floor area covering 24 *m* by 15 *m* with a ceiling height of 3.05 *m*. As in the case of the first design example, the working plane height was taken at 0.75 *m*. The same principle of modular work stations is used in this design. The office is occupied by 48 work stations for which the data were supplied by the same manufacturer as that in the previous example. The layout of the furniture in the office is shown in Figure 7.11. Each of the work stations is of either a filing cabinet or a V.D.T, as well as the person seated at the desk.

When VFR was calculated it was found to be 0.22. For each of the luminaires to be used in this design, the OL was calculated from their respective curves in Figures 7.1 to 7.6. This was found to be 8 % for a perpendicular orientation and 8.5 % for a parallel one when a linear prismatic panel diffuser was considered (luminaire 1 in Table 7.1). The value of OL was 8 % when a Recessed diffuser was used (luminaire 5 in Table 7.1). For a surface mounted Broadspread reflector (luminaire 2 in Table 7.1) OL was 8 % for the parallel orientation and 7.5 % for the perpendicular one. These figures were similar to those of a standard medium obstruction case lit by these luminaires for which the SHROBSMAXs are to be found in Tables 4.4 and 4.5. Both empty and obstructed SHR values are given with the design data in Table 7.3 which shows the results of the various combinations of luminaire orientation and lamp size. The main features of these results could be summarised in the following:

a): When the difference between empty and obstructed SHR values is not very large as in the case of Examples 1, 4 and 10, the layout of luminaires for the obstructed case need only to be modified to account for the light loss. In this case, although the number of luminaires has increased in proportion to the OL, the Layout 2 for instance satisfies the obstructed SHR requirements without modification.

b): When the difference in SHR between empty and obstructed cases is large as in the case of Examples 2 and 6, the obstructed case layout has to be modified to satisfy both SHR and average illuminance. In Example 2, the number of luminaires required for a 500 lx when obstructions are considered is 73. This will give installed SHR values which are beyond the maximum permissible. In order to satisfy these requirements the number of luminaires has to be increased to 104 (as for N3). This increase in the number of luminaires was accompanied by an increase in the installed flux and consequently the average illuminance.

Design Example Number	Luminaire description			Empty case installation								Obstructed case installation												
	Type	Position with respect to partition	Lamp Lumen Output (Lm)	SHRMAX		Requi. number of lumin. N1	Layout1	Installed SHR		Eavg1 (Lux)	SHRMAX		Requi. number of lumin. N2	Layout2	Installed SHR		Eavg2 (Lux)	Layout3	Requi. number of lumin. N3	Eavg3 (Lux)	Dimmed output %
				Axial	Trans			Axial	Trans		Axial	Trans			Axial	Trans					
1	Prismatic panel diffuser	Perpend.	2x3200	1.69	1.69	65	11 x 6	1.09	0.95	507	1.33	1.33	71	9 x 8	0.82	1.16	509				
2		Parallel	2x3200	1.69	1.69	65	11 x 6	0.95	0.95	507	0.85	0.85	13	10 x 8	1.04	0.82	554	13 x 8	104	901	44
3		Parallel	2x2750	1.69	1.69	76	11 x 6	0.95	1.09	502	0.85	0.85	84	11 x 8	0.95	0.82	525	13 x 8	104	620	19
4	Recessed diffuser	Any	925	1.32	1.32	459	27 x 17	0.39	0.39	500	1.15	1.15	499	28 x 18	0.37	0.36	505				
6	Surface mounted Broadspread reflector	Parallel	2 x 3200	1.90	1.90	66	11 x 6	0.95	1.09	507	0.75	0.75	75	11 x 7	0.95	0.93	514	14 x 9	126	841	40
7		Parallel	2 x 2800	1.90	1.90	75	11 x 7	0.95	0.93	517	0.75	0.75	86	11 x 8	0.95	0.82	514	14 x 9	126	736	32
9		Parallel	2 x 2750	1.90	1.90	76	11 x 7	0.95	0.93	508	0.75	0.75	88	11 x 8	0.95	0.82	505	14 x 9	126	723	31
10		Perpend.	2 x 3200	1.90	1.90	66	11 x 6	1.09	0.95	507	1.40	1.40	72	9 x 8	0.82	1.16	502				

Table 7.3 Summary of the second series of design examples

c): When such a case occurs, there are two possibilities of modifying the layout in such a way that both SHR and average illuminance are satisfied. The designer will have to choose either to use a smaller lamp size or to or to dim the luminaire output as shown in some of the examples in Table 7.3.

7.5 Discussion

It is apparent from both survey work and the computer simulation that in general lighting installations light losses caused by room contents will have a major effect on illuminance conditions over the working plane. The present work outlines techniques that attempt to limit both variations in illuminance uniformity and reduction in average illuminance due to obstruction loss. The techniques are based on a modified version of the familiar lumen method. The major departure from the existing method is that the designer must assign a classification of degree of obstruction to the likely contents of the space to be lit. From this an SHR to enable an appropriate luminaire layout is established together with a factor which enables the installed flux to be increased by an amount to compensate for obstruction light loss. It is evident that the installation layouts produced by the traditional lumen method and the modified method differ, in some cases greatly, and thus has profound implications for the specifier, the designer and the user of the installation.

The traditional lumen method enables a desired average illuminance to be provided over the working plane of an empty interior whilst attempting to limit the variation of illuminance by control of the spacing of luminaires. The likely effects of obstruction are acknowledged in such documents as CIBSE TM5 and are in terms of advice to reduce the spacing of luminaires. Beyond this any attempt to modify an installation to counter obstruction effects is left to the experience of the designer. The lumen method however remains by far the most popular design tool used by designers. It is at least arguable that whilst experienced designers using the method are capable of interpreting the scant design guidance on the measures needed to counter the effect of obstruction, a large number of inexperienced designers are not and have routinely produced designs over a large number of years based only on the assumption of an empty interior. One may speculate why the traditional lumen method has survived apparently without major debate, for 70 years. It is possible that the Maintenance Factors and (in the UK at least) the concepts of lighting design lamp lumen and Standard Service Illuminance which have been associated with the lumen method have allowed enough over - design in terms of flux to compensate for light loss caused by room contents. Also the popularity of general diffusing and prismatic luminaires for general lighting installations meant that walls and ceilings tended to be directly illuminated and the resulting relatively high levels of indirect illuminance tended to counter the worst effects of shadowing caused by room contents. It is clear that a compelling argument needs to be set out to suggest modification of a design tool that has so well stood the best of time but the author believes that recent changes in lighting equipment and the nature of interiors of commercial buildings and of forthcoming changes in the illuminance design criteria may mean that a reappraisal of the traditional lumen method may be required. Much use is now made of mirrored and louvred luminaires designed for use at large spacing to height ratios. The directional lighting characteristics of these luminaires mean that areas of the working plane remote from the luminaire are particularly at risk from shadows. Fashions in design of commercial interiors now dictate that the density of obstruction in a modern office has increased in recent years due to, for example the use of partitions to enhance the working environment and the widespread use of IT equipment. Finally there is the likely harmonisation of European design illuminance specifications, in terms of 'maintained illuminance' which are appropriate for fully fitted interiors, that is including a notional allowance to counter the effects of any light losses due to the the room contents normally associated with the activity within the space. This will have the effect of increasing designer awareness of effects of obstructions and mean that a method of allowing for obstruction over and above those normally associated with an activity is required. The modifications to the traditional lumen design method put forward in this paper is one way of accomplishing this task.

The modified method requires two additional items of design data. The SHROBS may be provided by a relatively minor additions to the CIBSE TM5 method of calculating SHR for empty rooms and on the evidence of the computer simulation relationships between OL and VFR apply to broad ranges of luminaires. The proposed method requires the designer to assess the likely contents of the interior to be lit to assign a Standard Obstruction classification. Most Commercial interiors are likely to be amenable to this form of classification and this process has the major feature of making the designer think at the outset of the lighting design process of the general problem of obstruction. In contrast the anecdotal evidence is that in the use of the traditional lumen method, room contents are ignored.

The modified lumen method presented in this chapter is not a prescriptive process to provide an exact design solution but rather a means of providing the designer of a general lighting system with some information on which to take informed decisions. The method adds two extra qualifications to the existing routine lumen design method and in doing so enables the designer to generate a range of possible solutions which can be related to both the proposed lighting equipment and the layout of the interior of the room.

7.6 Conclusion

The work reported in this chapter showed the existence of a relationship between the characteristics of a space and its contents and the likely light losses. This relationship was identified in terms of variation in obstruction loss as a function of the ratio of vertical surface area of obstruction to floor area 'VFR' and enabling the concept of Obstruction Loss to be incorporated into the lumen design method. Although the modified method is by no means a prescriptive process to provide exact design solutions, it can be used as a means of providing the designer with some information which enables him to take informed decisions on the proposed lighting scheme.

7.7 References

(1): McEwan, I., The effect of obstructions in the design of interior lighting installations, Ph.D thesis, University of Liverpool, 1986.

(2): Chartered Institution of Building Services Engineers, The calculation and use of utilisation factors Technical Memoranda No.5, CIBSE, London, 1980.

(3): Steel Case, Handbook of Products Series 9000 Specifications, Steel Case, Michigan, USA, 1984.

Chapter 8

Conclusions and recommendations

The presence of obstructions in an interior can affect the lighting conditions and cause some light loss. Published work shows that only few researchers have examined the problem of assessing obstruction effects. This could be attributed to the complexity of the problem coupled with the scarcity of suitable computer facilities available to researchers until comparatively recent years. Early attempts to examine the problem of obstructions in lumen design such as those of Spencer , were not effective for these reasons. However the lumen method of design which assumes an empty space between the working plane and the plane of luminaires remains the most popular design tool despite the shortcomings associated with its assumptions. The survival and popularity of this method could be attributed to some concepts such as the Maintenance Factor, Lighting Design Lumens and Standard Service Illuminance which allow enough over-design in terms of installed flux to compensate for the light loss caused by obstructions. The widespread use of general diffusing luminaires has arguably also contributed to the continued use of the lumen method since walls and ceilings have tended to be directly illuminated and the resulting high levels of indirect illuminance have countered the worst effects of shadows caused by obstructions.

Recent changes in lighting equipment and the nature of commercial interiors may force a reappraisal of the conventional lumen design method. The directional lighting characteristics of mirrored and louvred luminaires which are widely used nowadays have resulted in areas of the working plane remote from the luminaire being at risk from shadows.The design of commercial interiors has, in recent years, been characterised by an increase in obstruction density due to the use of partitions and IT equipment. Forthcoming changes in the European design illuminance design criteria may also mean that a re-examination of the lumen method may be required. Design illuminance would be specified in terms of 'maintained illuminance' which are appropriate to fully fitted interiors and with a notional allowance to counter light loss due to room contents.

Literature search shows that despite an urgent need for methods and ways of assessing obstruction effects few workable design tools exist. Those that do are computer analysis methods of considerable complexity and are only suitable if geometric and photometric properties of the space are known. Also there is little design guidance available in Codes which relates to obstruction effects. Arguably most lighting design is done by non expert designers concerned with spaces where design information is sparse as in the case of speculative office developments. These designers both lack sophisticated tools and are largely unable to interpret the technical literature and Codes giving advice on obstructions and, more worryingly, may not appreciate that the recent development in lighting equipment and the nature of interiors can cause problems that did not exist ten years ago. The need for development of additional workable techniques for synthesis of lighting design to acknowledge obstructions remains a major one. This problem was partially addressed by previous work at Liverpool.

The present work examined the effect of obstructions on the lighting conditions in interiors in two ways: the implication of introducing obstructions into a space on the spacing of luminaires when an adequate uniformity of illuminance level is required, and the drop in average working plane illuminance caused by obstructions of known size, density and layout when combined with other design parameters.

The work on the effect of obstructions on the calculation of spacing to height ratio has shown that contents of interiors have a major effect on illuminance conditions. These effects are being ignored by designers at their peril. Results of this work have also shown that, as far as the effect of obstructions is concerned, not only their presence is important but also their size and disposition. The discussion of these results has lead to the suggestion that the modified method for calculating spacing to height ratio which was put forward could be used in the design either to indicate the design SHR at which acceptable task uniformity will be obtained or to take informed decisions on the need for local lighting.

In the course of this work representations of uniformity of illuminance is considered were examined. The work tested a number of alternative uniformity measures for use in the spacing to height ratio calculations. It was shown that using a number of uniformity measures as the basis of SHR calculations gave different results. The minimum/maximum/average illuminance measures gave results which lack consistency between maximum and average measures despite these two being the basis of CIBSE TM5 calculations for luminaire spacing and the specification of uniformity in CIBSE Code for interior lighting respectively. These problems arise from being the nature of these measures being reliable on local isolated point minimum or maximum point values which adversely affect the results particularly when the variation in illuminance is not smooth as in the case of obstructed interiors. The lack of robustness in these measures could be overcome by the use of 16 point minimum/maximum which was shown to have potential for development. The two statistical measures examined were shown to be able to produce more robust results. The complexity of their derivation makes them unsuitable for hand calculations. This however should not be seen as a serious disadvantage since most lighting calculations are carried out these days using computers. Gradient measures under their present form have been shown unsuitable for representing uniformity of illuminance particularly in obstructed interiors. More subjective work would have to be carried out if an acceptable limiting value is to be found. If the results of this subjective work were in terms of gradient or any other measure the techniques of calculating obstructed SHR still work whatever the limits considered.

The effect of a number of design parameters, related to the space and its contents, on the drop in average illuminance across the working plane was investigated. The results of this work showed the existence of a series of relationships between the various design parameters and their effect on illuminance drop. Obstruction density was identified as having the greatest effect than any other parameter. Obstruction height was shown to have a considerable effect at lesser magnitudes than obstruction density. Room and obstruction surface reflection factors had negligible effects on the drop in average working plane illuminance while the luminaire type and its mounting height had effects of small magnitude but of considerable importance. Results concerning the effect of room index were difficult to interpret and more data was felt to be needed in order to fully quantify its effects on light loss.

The relationships quantified using the results of the work referred to earlier were identified in terms of variation in Light Loss as a function of VFR. The concept of Obstruction Loss was incorporated into the lumen design method together with the obstructed SHR discussed earlier. It was shown that the modified lumen method can be used to provide the designer with some information which enable him to address the problem of obstruction effect and take informed decisions on the lighting scheme at the design stage. It is for the first time that the effect of obstruction above the working plane can be quantified using this method of design.

The results of the work presented in this thesis have shown the need for new design tools and a reappraisal of the current design methods. Work on the effect of obstructions on the spacing of luminaires showed the inconsistency between the empty space assumption when calculating the spacing of luminaires and the difference in terms of SHR between empty and occupied interior. These differences are in some cases so large that the use of empty space assumptions for an obstructed interior would have adverse consequences on both the uniformity of and average illuminance. It was also shown that the introduction of obstructions into a space incurred an inconsistency between uniformity measures used for SHR requirements and illuminance specification. This was not necessarily the case for for empty spaces. The discrepancies between design practice and actual lighting conditions likely to be achieved was further highlighted in the study of the effect of design parameters on the drop in average working plane illuminance. It is therefore necessary if not imperative to increase the awareness of both designers and luminaire manufacturers of the effects of obstructions so that design methods are improved to the level of being capable of enabling the designer to account for obstruction effects. An increase in such awareness will pave the way for a reappraisal of the existing design methods and development of design guidance and tools which would provide the designer with means of assessing the likely effects of obstructions. One way of doing this was demonstrated in the discussion of the modified lumen design method which provides some information on which informed decisions on the proposed lighting scheme could be taken at the design stage.

Although it can not be claimed that the present work is a total solution to the problem because it relates to a limited data set and it was not tried in practice, it represents the basis of a workable method capable of acknowledging obstructions. It became also clear that there is a need to bring the problem to the attention of designers through field trials. It is also felt the existence of a problem of dissemination of information. This could be overcome by persuading designers, Standards Institutions and lighting bodies when producing codes, to pay more attention to the subject.

The present work has achieved its targets in improving and modifying the obstructed SHR concept and then extending it into the representation of uniformity of illuminance. In examining the effects of the various design parameters the work has also achieved the setting out and quantifying the various relationships between light loss and the room characteristics. These relationships were then incorporated into a modified lumen design method which forms part of the objectives set out for this work to develop some means of providing design guidance.

For the obstructed SHR work, as long as the present classification of standard obstruction is judged satisfactory, the work was taken as far as it can go but other Standard Obstructions in, for example, industrial applications may need to be developed. Illuminance uniformity representation, on the other hand, still presents some areas where more work could be carried out in particularly where the gradient techniques of representing uniformity are concerned. In this regard some survey work on the subjective assessment of acceptable illuminance gradients would be of necessary in order to establish limiting values for acceptable maximum gradient.

As far as the work on the effect of design parameters of the light loss is concerned, there a scope for further investigation which would follow the same principles and methods described in this work.Some design parameters such as the room index would a larger amount of data in order to be able to fully identify its effect on light loss. In the present study six different luminaires were used. It would more useful to produce sets of data on the various parameters for a large number of luminaire types. Such data would enable the classification of luminaires commercially available into classes each one of them would have an appropriate OL curve which in turn could be used in the modified lumen design method. Once such a study has been undertaken, it would be more meaningful and useful from a practical point of view to extend these investigations to cover a range of industrial and institutional buildings.

Appendices

Appendix A: SHROBS computer program for point source luminaires

The obstructed spacing to height ratio computer program listing is given in this appendix to together with the execution file and an example of an input file. The program calculates the maximum spacing to height ratio for a heavily obstructed interior lit by any type of point source luminaires. The program could also be run for the empty case by changing the value of the constant EMCASE, in the declaration section, from 2 to 1. The listing given in this appendix is similar to other versions written for other standard obstruction configurations.

A1: The execution file used to run the SHROBS program

```
&trace on
exec test fortvs
exec library vspascal fortvs gino glib cmslib
exec vspascal hvsource (margin(1,100
FI data disk mltcell data
FI g disk hvmcell term
load hvsource (nomap clear start
&exit
```

A2: An intensity distribution file used to run the SHROBS program

```
1100

1 3
1 1 3
214 215 229 243 273 302 301 299 308 317 223 129
67 4 2 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
214 215 225 235 254 273 283 292 287 281 208 135
71 7 4 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
214 214 212 211 212 214 219 223 216 208 176 144
79 13 6 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
214 213 207 202 194 186 175 163 146 128 100 72
40 7 4 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
214 214 212 211 212 214 219 223 216 208 176 144
79 13 6 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
214 215 225 235 254 273 283 292 287 281 208 135
71 7 4 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
214 215 229 243 273 302 301 299 308 317 223 129
67 4 2 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
214 215 225 235 254 273 283 292 287 281 208 135
71 7 4 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
214 214 212 211 212 214 219 223 216 208 176 144
79 13 6 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
214 213 207 202 194 186 175 163 146 128 100 72
40 7 4 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
214 214 212 211 212 214 219 223 216 208 176 144
79 13 6 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
214 215 225 235 254 273 283 292 287 281 208 135
71 7 4 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
0.66 0.00
12 12
```

Line 1: Lamp lumen output.
Line 2: Luminaire type and luminaire number (for identification).
Line 3: Scale factor indicator, indicator of number of intensity planes and number of lamps per luminaire.
Lines 4 and 5: A column of intensity distribution at 5° interval in elevation for 0° in azimuth.
Each subsequent pair of lines contain similar values for an azimuth angle at 30 ° interval.
DLOR and ULOR.
number of intensity planes for both multiples of 5° and 10° in elevation.

A3: Listing of the SHROBS program

```
PROGRAM FORTCOPY(G,DATA);
{CALCULATES THE ILLUMINANCE AT UP TO A 20x20
ARRAY}
{OVER THE CENTRAL AREA . IT CAN READ ALL THE DATA
}
{LIMITED BY ARRAY SPECIFICATION THEREFORE
INCREASEABLE}
{FROM A FILE  AND PRINT IT ALL OUT INTO A FILE G}
CONST PI=3.14159;
   NPP=21;
   NNP=12;
   WDT=1.2;
   LGT=2.1;
   EMCASE=2;
   CMAX 8;
   YGRAD=19;
   XGRAD=10;
   POINTS=220;
TYPE DY=ARRAY[0..36,0..15] OF REAL;
   DIY=ARRAY[0..36,0..3] OF REAL;
   MS=ARRAY[0..CMAX,1..27] OF REAL;
   ILL1=ARRAY[0..10,0..19] OF REAL;
   LLL1=ARRAY[0..12,0..21] OF REAL;
   ILLI1=ARRAY[0..12,0..21] OF INTEGER;
   QQ=ARRAY[0..CMAX] OF REAL;
   QQQQ=ARRAY[0..CMAX] OF REAL;
   PP=ARRAY[0..CMAX] OF REAL;
   SS=ARRAY[1..2] OF REAL;
   TT=ARRAY[1..2] OF REAL;
   NOB=ARRAY[0..CMAX] OF REAL;
   LLLL=ARRAY[1..12] OF PACKED ARRAY[1..4] OF CHAR ;
   CAP11=ARRAY[0..2,0..6] OF REAL;
   CAB11=ARRAY[0..2,0..6] OF INTEGER;
   CAP12=ARRAY[0..3,0..5] OF REAL;
   CAB12=ARRAY[0..3,0..5] OF INTEGER;
   CAP=ARRAY[0..11,0..20] OF REAL;
   CAPA=ARRAY[0..3,0..6] OF REAL;
VAR TNTS:DY;
   TTTT:DIY;
   ILLUMIN1:ILL1;
   ILLUMIN11:ILLI1;
   PREILLUM1:LLL1;
   MASTER,IMASTER,IPETE,IMAXTER,IDMAXTER,PETE:PP;
   G,DATA:TEXT;
   QQQ,NONOB,BEDOC,SSS,TTT,PPP:QQ;
 STDROOT:CAP;
EE1,EV1:CAPA;
MEANILUM1,DIFFILUM1,HORIZON1:CAP11;
HORGRAD1:CAB11;
MEANILUM2,DIFFILUM2,VERTICAL1:CAP12;
VERGRAD1:CAB12;
XDIFF,YDIFF,ILLUMINANCE,XCOORD,YCOORD:REAL;
INTENS,LUMANG,ILLUMATPT,LUMANG2:REAL;
ILTOT,AB,DIST,SHRMAX,SHRNOM,UNIF,INTENSITY,ANG,ST
ORAGE,LOR:REAL;
LUMXDIFF,SHM,HM,MINAV,XMEASPOINT,YMEASPOINT,DL
OR,ULOR,SHR:REAL;
AVMIN,MAXMIN,AVMAX,MAXAV,ILLMIN,ILLMAX,ILLAV,IL
LUMINTOT:REAL;
LUMTYPE,DUMMY1,DUMMY2,DUMMY3,OCCASION,IPICT,N
P,NPTS:INTEGER;
OBYDF,OBXDF1,OBXDF2,ILLMIN2,ILLMAX2,ILLAV2,MASTE
R2,IMASTER2:REAL;
IMAXTER2,IDMAXTER2,PETE2,IPETE2,UNIF2,MAXMIN2,M
AXAV2,AVMAX2:REAL;
MINAV2,AVMIN2,STORE:REAL;
DUMMY4,NUMLAMP,ILMIN,ILMAX,ILAV,ILMIN2,ILMAX2,IL
AV2:INTEGER;
PERPILLUM1,PERPILLUM2,PERPILLUM3,PARILLUM1,PARIL
LUM2,PARILLUM3:REAL;
   YDISTLAB,XLABELS,YLABELS:LLLL;


     PROCEDURE INITVS;FORTRAN;
     PROCEDURE GINO;FORTRAN;
     PROCEDURE WINDO2(CONST
X1,X2,Y1,Y2:REAL);FORTRAN;
     PROCEDURE DEVPAP(const Z1,Z2:REAL;
             const Z3:INTEGER);FORTRAN;
     PROCEDURE GRAF(VAR PPP:PP;
             VAR QQQ:QQ;
             VAR NPTS,ISC : INTEGER);FORTRAN;
     PROCEDURE GRAPOL(VAR QQQ:QQ;
             VAR VVV:QQ;
             VAR NPTS : INTEGER);FORTRAN;
     PROCEDURE SAVDRA;FORTRAN;
     PROCEDURE MOVTO2(CONST SHR,MINAV
:REAL);FORTRAN;
     PROCEDURE CHASIZ(CONST
WIDTH,HEIGHT:REAL);FORTRAN;
     PROCEDURE AXIDRA(CONST TICK,VAL,XORY
:INTEGER);FORTRAN;
     PROCEDURE AXIPOS(const IOR :INTEGER;
             const XXR,YYR,AXLEN :REAL;
           const XORY : INTEGER);FORTRAN;
     PROCEDURE AXISCA(CONST SCALE,INTS:INTEGER;
             CONST FROM,UPTO:REAL;
             CONST XORY:INTEGER);FORTRAN;
     PROCEDURE AXILAB(CONST LABS : LLLL;
             CONST N,CHARS,WORDS : INTEGER;
             CONST POSITION : REAL;
             CONST XORY : INTEGER);FORTRAN;
     PROCEDURE LINTO2(CONST X,Y:REAL);FORTRAN;
     PROCEDURE CHAANG(CONST
ANGLE:REAL);FORTRAN;
     PROCEDURE CHAHOL(CONST STNG:STRING);FORTRAN;
     PROCEDURE CHAFIX(VAR NUMBER:REAL;
             CONST WIDTH,PLACES:INTEGER);FORTRAN;
     PROCEDURE CHAINT(CONST
INT,WIDTH:INTEGER);FORTRAN;
     PROCEDURE DASHED(VAR MODE:INTEGER;
             VAR
REPETITON,DASH,DOT:REAL);FORTRAN;
     PROCEDURE BROKEN(CONST I:INTEGER);FORTRAN;
     PROCEDURE DEVEND;FORTRAN;
     PROCEDURE LINBY2(CONST X,Y: REAL);FORTRAN;
     PROCEDURE PICBEG(CONST
PICNUMBER:INTEGER);FORTRAN;
     PROCEDURE PICCLE;FORTRAN;
     PROCEDURE PICEND;FORTRAN;
     PROCEDURE GINEND;FORTRAN;
     PROCEDURE TRACER(CONST
ISWI:INTEGER);FORTRAN;
     PROCEDURE ENDVS;FORTRAN;


PROCEDURE INDB;
    VAR I,J:INTEGER;
    BEGIN
    FOR J:=0 TO 11 DO
    FOR I:=0 TO 36 DO BEGIN
    READ(DATA,TNTS[I,J]);
    IF EOLN THEN READLN;
    END
    END;



     PROCEDURE ZONFACT(VAR I:INTEGER;VAR KM:REAL);
     VAR ANGLE,ALPHA,BETA:REAL;
     BEGIN
     ANGLE:=5*I;
     ALPHA:=(ANGLE+5)*PI/180;
     BETA:=(ANGLE-5)*PI/180;
     KM:=ABS(4*PI*(SIN((ALPHA-
BETA)/2))*SIN((ALPHA+BETA)/2));
     END;



     PROCEDURE INDE;
     (*TO PRODUCE COLUMN OF ZONAL FLUX*)
     VAR SF,ZFTOT,KL,KM,SUM:REAL;
     J,II,I,TT,L:INTEGER;
     BEGIN
     IF DUMMY4=1 THEN BEGIN
     INDB;
     READLN(DATA,DLOR,ULOR);
     READLN(DATA,TT,L);
     FOR I:=0 TO 36 DO BEGIN
     SUM:=0;
     FOR J:=0 TO 11 DO BEGIN
     SUM:=SUM+TNTS[I,J];
     END;
     TNTS[I,12]:=SUM/TT;
     END;
     FOR II:=1 TO 18 DO BEGIN
     I:=2*II-1;
     KL:=TNTS[I,12];
     ZONFACT(I,KM);
     TNTS[I,13]:=KM;
     TNTS[I,14]:=KL*KM;
     ZFTOT:=ZFTOT+TNTS[I,14];
     END;
  IF DUMMY3=1 THEN SF:=1
  ELSE BEGIN
   LOR:=DLOR+ULOR;
   SF:=DLOR*1000/ZFTOT;
  END;
     FOR I:=0 TO 36 DO BEGIN
     TNTS[I,15]:=SF*TNTS[I,12];
     END;
     END;
```

```
IF DUMMY4 > 1 THEN BEGIN
FOR I:=0 TO 36 DO BEGIN
READ(DATA,TTTT[I,0]);
END;
ZFTOT:=0;
FOR II:=1 TO 9 DO BEGIN
I:=II*2-1;
KL:=TTTT[I,0];
ZONFACT(I,KM);
TTTT[I,1]:=KM;
TTTT[I,2]:=KL*KM;
ZFTOT:=ZFTOT+TTTT[I,2];
END;
IF DUMMY3=1 THEN SF:=1
ELSE BEGIN
READLN(DATA,DLOR,ULOR);
LOR:=DLOR+ULOR;
SF:=LOR*1000/ZFTOT;
END;
FOR I:=0 TO 36 DO BEGIN
TTTT[I,3]:=SF*TTTT[I,0];
END;
END
END;

    PROCEDURE NTHD;
    VAR AA,BB,XX,YY,TT:REAL;
       L:INTEGER;
    BEGIN
    ANG:=ANG*180/PI;
    L:=1;
    WHILE (5*L)<(ANG) DO BEGIN
    L:=L+1;
    END;
    AA:=5*L;
    IF DUMMY4 =1 THEN XX:=TNTS[L,15]
    ELSE
    XX:=TTTT[L,3];
    L:=L-1;
    IF DUMMY4 =1 THEN YY:=TNTS[L,15]
    ELSE
    YY:=TTTT[L,3];
    BB:=5*L;
    TT:=(XX-YY)/(AA-BB);
    INTENS:=TT*ANG+(YY-TT*BB);
    INTENSITY:=INTENS*NUMLAMP*DUMMY1/1000;
    ANG:=ANG*PI/180;
    END;


 PROCEDURE SHRMAXCALC;
 (*TO CALCULATE SHR ETC. FROM ARRAY PETE*)
VAR I:INTEGER;
   SHRMAX1,SHRMAX2:REAL;
 BEGIN
I:=0;
WHILE PETE[I] > 0.7 DO BEGIN
I:=I+1;
END;
SHRNOM:=PPP[I-1];
SHRMAX1:= (0.25 *(PETE[I-1]-0.7));
SHRMAX2:=(PETE[I-1]-PETE[I]);
SHRMAX:=SHRNOM+(SHRMAX1/SHRMAX2);
WRITELN(G,'MODIFIED  HUMAN FORM,PARTITION  AND F.
CABINET OBSTRUCTION');
WRITELN(G,'SHRMAX = ',SHRMAX:3:2);
WRITELN(G,'SHRNOM = ',SHRNOM:3:2);
END;



Procedure Grid_Illuminance1;

  VAR TOTGRAD,MEANGRAD:REAL;

procedure New_Grid1;

var iii,jjj,ii,jj:integer;

begin
 illmin2:=3000;
 illmax2:=0;
 for jjj:=0 to 19 do begin
    jj:=jjj+1;
    for iii:=0 to 10 do begin
       ii:=iii+1;
       illumin1[iii,jjj]:=preillum1[ii,jj];
       if illumin1[iii,jjj] > illmax2 then begin
        illmax2:=illumin1[iii,jjj];
        ilmax2:=round(illmax2);
       end;
       if illumin1[iii,jjj] < illmin2 then begin
        illmin2:=illumin1[iii,jjj];
        ilmin2:=round(illmin2);
        if ilmin2=0 then ilmin2:=1;
        end;
      illumintot:=illumintot+illumin1[iii,jjj];
      end;
    end;
    illav2:=illumintot/(20*11);
    ilav2:=round(illav2);
    minav2:=ilmin2/ilav2;
    master2:=minav2;
    avmin2:=ilav2/ilmin2;
    imaster2:=avmin2;
    unif2:=ilmin2/ilmax2;
    pete2:=unif2;
    maxmin2:=ilmax2/ilmin2;
    ipete2:=maxmin2;
    maxav2:=ilmax2/ilav2;
    imaxter2:=maxav2;
    avmax2:=ilav2/ilmax2;
    idmaxter2:=avmax2;
WRITELN(G,'NEW MAXIMUM ILLUMINANCE = ',ilmax2:1);
WRITELN(G,'NEW AVERAGE ILLUMINANCE = ',ilav2:1);
WRITELN(G,'NEW MINIMUM ILLUMINANCE = ',ilmin2:1);
WRITELN(G,'NEW MIN / MAX  U.R      = ',pete2:3:2);
WRITELN(G,'NEW MAX / MIN  U.R      = ',ipete2:3:2);
WRITELN(G,'NEW MIN / AVG  U.R      = ',master2:3:2);
writeln(g,'NEW AVG / MIN  U.R      = ',imaster2:3:2);
writeln(g,'NEW MAX / AVG  U.R      = ',imaxter2:3:2);
writeln(g,'NEW AVG / MAX  U.R      = ',idmaxter2:3:2);
   end;


Procedure Horzgrad; { to calculate the gradient of illumnance }
            {along the x axis which is the width of task area}


 var i,j,ii,jj,s,p,n,m,xx,yy:integer;

 Begin
   writeln(g,'Gradient of illuminance in the x-direction  ( % )');
   for j:=0 to 19 do
   Begin
     yy:=j mod 3;
     if yy=0 then
     Begin
       jj:=round(j/3);
       for i:=1 to 10 do
       Begin
         xx:=i mod 3;
         if xx=1 then
         Begin
           ii:=round((i-1)/3);
           ee1[ii,jj]:=illumin1[i,j];
         End;
       End;
     End;
   End;
   for jj:=0 to 6 do
   Begin
     p:=jj;
     for ii:=0 to 3 do
     Begin
       if (ii>0) then
       Begin
         s:=ii-1;
         meanilum1[s,p]:=(ee1[ii,jj]+ee1[ii-1,jj])/2;
         diffilum1[s,p]:=(ee1[ii,jj]-ee1[ii-1,jj]);
         horizon1[s,p]:=(diffilum1[s,p]/meanilum1[s,p]);
         horgrad1[s,p]:=round(horizon1[s,p]*100);
         totgrad:=totgrad+abs(horgrad1[s,p]);
         write(g,horgrad1[s,p]:1,'  ');
           if (s=2) then Begin
             writeln(g,'  ');
             writeln(g,'  ');
           End;
       End;
     End;{i counter}
   End;{j counter}
 End;{procedure horzgrad}


Procedure Vertgrad;{to calculate gradient of illuminance in}
           {the y direction from top to bottom}
 var i,j,ii,jj,s,p,n,m,xx,yy:integer;

 Begin
   writeln(g,'Gradient of illuminance in the y-direction  ( % )');
   for j:=0 to 19 do
```

```
 Begin
   yy:=j mod 3;
   if yy=0 then
   Begin
     jj:=round(j/3);
     for i:=1 to 10 do
     Begin
       xx:=i mod 3;
       if xx=1 then
       Begin
         ii:=round((i-1)/3);
         ev1[ii,jj]:=illumin1[i,j];
       End;
     End;
   End;
  End;
  for jj:=0 to 6 do
  Begin
    if (jj > 0) then
    Begin
      p:=jj-1;
      for ii:=0 to 3 do
      Begin
        s:=ii;
        meanilum2[s,p]:=(ev1[ii,jj]+ev1[ii,jj-1])/2;
        diffilum2[s,p]:=(ev1[ii,jj]-ev1[ii,jj-1]);
        vertical1[s,p]:=(diffilum2[s,p]/meanilum2[s,p]);
        vergrad1[s,p]:=round(vertical1[s,p]*100);
        totgrad:=totgrad+abs(vergrad1[s,p]);
        write(g,vergrad1[s,p]:1,' ');
        if (s=3) then Begin
        writeln(g,' ');
        writeln(g,' ');
        End;
      End;{ii counter}
    End;{if j > 0}
  End;{jj counter}
End;{procedure vertgrad}


Procedure Mahler;
 var i,j:integer;
   STDTOT,STD,SU,stdratio:REAL;


 Begin
   writeln(g,'Mean and standard deviation in illuminance');
   stdtot:=0;
   for j:=0 to 19 do
   Begin
     for i:=0 to 10 do
     Begin
       STDROOT[I,J]:=SQR(ILLUMIN1[I,J]-ILLAV2);
       stdtot:=stdtot+stdroot[i,j];
     End;
   End;
   std:=sqrt(stdtot/points);
   stdratio:=std/illav2*100;
   writeln(g,'Standard deviation                 : ',std:3:2);
 writeln(g,'ratio std/Eavg                    : ',stdratio:3:2,' %');
   SU:=(ILLAV2+STD)/(ILLAV2-STD);
   writeln(g,'Statistical uniformity             : ',su:3:2);
   writeln(g,' ');
   writeln(g,' ');
End;


 PROCEDURE SQR_ADJACENT1;
  var a,b,xx,yy,n,m,count1,count2:integer;
    totalum,avgfour,minlav,maxlav,uratio,newratio:real;

 begin
  minlav:=2500;
  maxlav:=0;
  count2:=0;
  writeln(g,' ');
     FOR B:=0 TO 5 DO
     begin
       count1:=0;
       FOR A:=0 TO 2 DO
       begin
        for yy:=0 to 3 do
         begin
          m:=yy+count2;
          for xx:=0 to 3 do
           begin
             N:=XX+COUNT1+1;
             TOTALUM:=TOTALUM+ILLUMIN1[N,M];
            end;
           end;
          count1:=count1+3;
          avgfour:=totalum/16;
          if (avgfour > maxlav) then maxlav:=avgfour;
          if (avgfour < minlav) then minlav:=avgfour;
          totalum:=0;
         end;
        count2:=count2+3;
       end;
     uratio:=minlav/maxlav;
     newratio:=minlav/illav;
writeln(g,'largest average illuminance (4X4)  : ',maxlav:4:1);
writeln(g,'smallest average illuminance (4X4) : ',minlav:4:1);
writeln(g,'Uniformity ratio Smallest/Largest  : ',uratio:3:2);
writeln(g,'Uniformity ratio small. avg/Eavg   : ',newratio:3:2);
writeln(g,' ');
writeln(g,' ');
 end;


Begin
  New_grid1;
  Mahler;
  SQR_ADJACENT1;
  Horzgrad;
  Vertgrad;
  meangrad:=totgrad/45;
  writeln(g,'Average gradient                   : ',meangrad:4:1);
End;


PROCEDURE NOOBFFC; {CALCULATES THE SHR AS IN TM5
WITHOUT ANY OBSTRUCTION
          FOR USE IN THE COMPARISON}
 VAR AA,BB:REAL;
   SH,III,II,JJ,I,J,JJJ:INTEGER;
     BEGIN
     HM:=1.80;
     FOR SH:=0 TO CMAX DO BEGIN
     SHR:=0.5+SH*0.25;
     PPP[SH]:=SHR;
     ILTOT:=0;
     ILLMIN:=3000;
     ILLMAX:=0;
     SHM:=SHR*HM;
     AA:=SHM/2;
     BB:=0.10;
     FOR III:=0 TO NPP DO
     BEGIN
     J:=NPP-III;
     YMEASPOINT:=((III*BB)-(LGT/2))+(2*SHM);
     FOR JJJ:=0 TO NNP DO
     BEGIN
     I:=JJJ;
     XMEASPOINT:=(2*SHM)-((NNP-JJJ)*BB);
     ILLUMATPT:=0;
     FOR II:=0 TO 3 DO
     BEGIN
     YCOORD:=AA+II*SHM;
     FOR JJ:=0 TO 3 DO
     BEGIN   (*EVERY LUMINAIRE*)
     XCOORD:=AA+JJ*SHM;
     YDIFF:=ABS(YMEASPOINT-YCOORD);
     LUMXDIFF:=ABS(XMEASPOINT-XCOORD);
     AB:=SQRT(SQR(YDIFF)+SQR(LUMXDIFF));
(*DIAGONAL*)
     ANG:=ARCTAN(AB/HM);
     DIST:=SQRT(SQR(AB)+SQR(HM));
     NTHD;

ILLUMINANCE:=INTENSITY*ABS(COS(ANG))/SQR(DIST);
     ILLUMATPT:=ILLUMATPT+ILLUMINANCE;
     ILTOT:=ILTOT+ILLUMINANCE;
     PREILLUM1[I,J]:=PREILLUM1[I,J]+ILLUMINANCE;
     END
     END;
     ILLUMINI1[I,J]:=ROUND(PREILLUM1[I,J]);
 IF ILLUMINI1[I,J] < 1000 THEN WRITE(G,ILLUMINI1[I,J]:4,'
');
```

```
IF ILLUMINI1[I,J] > 999 THEN WRITE(G,ILLUMINI1[I,J]:1,' ');
IF I=NNP THEN BEGIN
WRITELN(G,' ');
WRITELN(G,' ');
WRITELN(G,' ');
 END;
    IF PREILLUM1[I,J] > ILLMAX THEN BEGIN
    ILLMAX:=PREILLUM1[I,J];
    ILMAX:=ROUND(ILLMAX);
    END;
    IF (PREILLUM1[I,J] < ILLMIN) THEN BEGIN
    ILLMIN:=PREILLUM1[I,J];
    ILMIN:=ROUND(ILLMIN);
    IF ILMIN=0 THEN ILMIN:=1;
    END;
    END;
    END;
    ILLAV:=ILTOT/((NPP+1)*(NNP+1));
    ILAV:=ROUND(ILLAV);
    MINAV:=ILMIN/ILAV;
    AVMIN:=ILAV/ILMIN;
    MASTER[SH]:=MINAV;
    IMASTER[SH]:=AVMIN;
    UNIF:=ILMIN/ILMAX;
    PETE[SH]:=UNIF;
    MAXMIN:=ILMAX/ILMIN;
    IPETE[SH]:=MAXMIN;
    MAXAV:=ILMAX/ILAV;
    IMAXTER[SH]:=MAXAV;
    AVMAX:=ILAV/ILMAX;
    IDMAXTER[SH]:=AVMAX;
writeln(g,' ');
WRITELN(G,'SPACING TO HEIGHT RATIO = ',SHR:3:2);
IF OCCASION=2 THEN WRITELN(G,' ');
WRITELN(G,'MAXIMUM ILLUMINANCE = ',ilmax:1);
WRITELN(G,'AVERAGE ILLUMINANCE = ',ilav:1);
WRITELN(G,'MINIMUM ILLUMINANCE = ',ilmin:1);
WRITELN(G,'MIN / MAX  U.R      = ',pete[sh]:3:2);
WRITELN(G,'MAX / MIN  U.R      = ',ipete[sh]:3:2);
WRITELN(G,'MIN / AVG  U.R      = ',master[sh]:3:2);
writeln(g,'AVG / MIN  U.R      = ',imaster[sh]:3:2);
writeln(g,'MAX / AVG  U.R      = ',imaxter[sh]:3:2);
writeln(G,'AVG / MAX  U.R      = ',idmaxter[sh]:3:2);
writeln(g,' ');
Grid Illuminance1;
ILLUMINTOT:=0;
FOR J:=0 TO 19 DO BEGIN
FOR I:=0 TO 10 DO BEGIN
ILLUMIN1[I,J]:=0;
END;
END;
FOR J:=0 TO NPP DO BEGIN
FOR I:=0 TO NNP DO BEGIN
ILLUMINI1[I,J]:=0;
PREILLUM1[I,J]:=0;
END;
END;
END;{shr}
END;{PROCEDURE NOOBFFC}
```

```
PROCEDURE PERPEND_RIGHT1;

 LABEL 1,2;
 VAR
XOBEND,YOBEND1,YOBEND2,OBXDF,OBYDF1,OBYDF2,OB
ANG,LUMANG,

LUMTHETA,THETA1,THETA2,THETA3,OBHITE,OBWIDTH,XD
ISTOB:REAL;


BEGIN
 OBHITE:=0.48;
 OBWIDTH:=0.16;
 XDISTOB:=0.20;
 XOBEND:=2*SHM+XDISTOB;
 YOBEND1:=2*SHM-0.5*OBWIDTH;
 YOBEND2:=2*SHM+0.5*OBWIDTH;
 OBXDF:=ABS(XOBEND-XMEASPOINT);
 IF OBXDF=0 THEN OBXDF:=0.001;
 OBYDF1:=ABS(YOBEND1-YMEASPOINT);
 IF OBYDF1=0 THEN OBYDF1:=0.001;
 OBYDF2:=ABS(YOBEND2-YMEASPOINT);
 IF OBYDF2=0 THEN OBYDF2:=0.001;
 THETA1:=ARCTAN(OBYDF1/OBXDF);
 THETA2:=ARCTAN(OBYDF2/OBXDF);
 LUMTHETA:=ARCTAN(YDIFF/XDIFF);
 LUMANG:=ARCTAN(HM/XDIFF);
 OBANG:=ARCTAN(OBHITE/OBXDF);
 IF (XCOORD < XOBEND) THEN GOTO 1;
 IF (YMEASPOINT >= YOBEND2) THEN BEGIN
   IF (YCOORD >= YOBEND2) THEN GOTO 1;
   IF (LUMTHETA >= THETA2) AND (LUMTHETA <=
THETA1) THEN BEGIN
     IF (OBANG >= LUMANG) THEN BEGIN
       ILLUMINANCE:=0;
       GOTO 2;
     END;
     GOTO 1;
   END;
   GOTO 1;
 END;
 IF (YMEASPOINT >= YOBEND1) AND (YMEASPOINT <=
YOBEND2) THEN BEGIN
   IF YCOORD >= YMEASPOINT THEN THETA3:=THETA2
   ELSE THETA3:=THETA1;
   IF (LUMTHETA <= THETA3) THEN BEGIN
     IF (OBANG >= LUMANG) THEN BEGIN
       ILLUMINANCE:=0;
       GOTO 2;
     END;
     GOTO 1;
   END;
   GOTO 1;
 END;
 IF (YMEASPOINT <= YOBEND1) THEN BEGIN
   IF (YCOORD <= YOBEND1) THEN GOTO 1;
   IF (LUMTHETA >= THETA1) AND (LUMTHETA <=
THETA2) THEN BEGIN
     IF (OBANG >= LUMANG) THEN BEGIN
       ILLUMINANCE:=0;
       GOTO 2;
     END;
     GOTO 1;
   END;
   GOTO 1;
 END;
 1:AB:=SQRT(SQR(XDIFF)+SQR(YDIFF));
 ANG:=ARCTAN(AB/HM);
 DIST:=SQRT(SQR(AB)+SQR(HM));
 NTHD;
 ILLUMINANCE:=INTENSITY*ABS(COS(ANG))/SQR(DIST);
 2:PERPILLUM1:=ILLUMINANCE;
 END;
```

```
PROCEDURE PERPEND_RIGHT2;

 LABEL 1,2;
 VAR
XOBEND,YOBEND1,YOBEND2,OBXDF,OBYDF1,OBYDF2,OB
ANG,LUMANG,

LUMTHETA,THETA1,THETA2,THETA3,OBHITE,OBWIDTH,XD
ISTOB:REAL;


BEGIN
 OBHITE:=0.30;
 OBWIDTH:=0.40;
 XDISTOB:=0.20;
 XOBEND:=2*SHM+XDISTOB;
 YOBEND1:=2*SHM-0.5*OBWIDTH;
 YOBEND2:=2*SHM+0.5*OBWIDTH;
 OBXDF:=ABS(XOBEND-XMEASPOINT);
 IF OBXDF=0 THEN OBXDF:=0.001;
 OBYDF1:=ABS(YOBEND1-YMEASPOINT);
 IF OBYDF1=0 THEN OBYDF1:=0.001;
 OBYDF2:=ABS(YOBEND2-YMEASPOINT);
 IF OBYDF2=0 THEN OBYDF2:=0.001;
 THETA1:=ARCTAN(OBYDF1/OBXDF);
 THETA2:=ARCTAN(OBYDF2/OBXDF);
 LUMTHETA:=ARCTAN(YDIFF/XDIFF);
 LUMANG:=ARCTAN(HM/XDIFF);
 OBANG:=ARCTAN(OBHITE/OBXDF);
 IF (XCOORD < XOBEND) THEN GOTO 1;
 IF (YMEASPOINT >= YOBEND2) THEN BEGIN
   IF (YCOORD >= YOBEND2) THEN GOTO 1;
   IF (LUMTHETA >= THETA2) AND (LUMTHETA <=
THETA1) THEN BEGIN
     IF (OBANG >= LUMANG) THEN BEGIN
       ILLUMINANCE:=0;
       GOTO 2;
     END;
     GOTO 1;
   END;
   GOTO 1;
 END;
 IF (YMEASPOINT >= YOBEND1) AND (YMEASPOINT <=
YOBEND2) THEN BEGIN
```

```
  IF YCOORD >= YMEASPOINT THEN THETA3:=THETA2
  ELSE THETA3:=THETA1;
  IF (LUMTHETA <= THETA3) THEN BEGIN
    IF (OBANG >= LUMANG) THEN BEGIN
      ILLUMINANCE:=0;
      GOTO 2;
    END;
    GOTO 1;
  END;
  GOTO 1;
 END;
 IF (YMEASPOINT <= YOBEND1) THEN BEGIN
  IF (YCOORD <= YOBEND1) THEN GOTO 1;
  IF (LUMTHETA >= THETA1) AND (LUMTHETA <=
THETA2) THEN BEGIN
    IF (OBANG >= LUMANG) THEN BEGIN
      ILLUMINANCE:=0;
      GOTO 2;
    END;
    GOTO 1;
  END;
  GOTO 1;
 END;
 1:AB:=SQRT(SQR(XDIFF)+SQR(YDIFF));
 ANG:=ARCTAN(AB/HM);
 DIST:=SQRT(SQR(AB)+SQR(HM));
 NTHD;
 ILLUMINANCE:=INTENSITY*ABS(COS(ANG))/SQR(DIST);
 2:PERPILLUM2:=ILLUMINANCE;
 END;
```

```
PROCEDURE PARALLEL_UP;

 LABEL 1,2;
 VAR
YOBEND,XOBEND1,XOBEND2,OBYDF,OBXDF1,OBXDF2,OB
ANG,LUMANG,

LUMTHETA,THETA1,THETA2,OBHITE,OBWIDTH,YDISTOB:R
EAL;


BEGIN
 OBHITE:=0.75;
 OBWIDTH:=1.50;
 YDISTOB:=1.05;
 YOBEND:=2*SHM+YDISTOB;
 XOBEND1:=2*SHM-1.2;
 XOBEND2:=2*SHM+0.3;
 OBYDF:=ABS(YOBEND-YMEASPOINT);
 IF OBYDF=0 THEN OBYDF:=0.001;
 OBXDF1:=ABS(XOBEND1-XMEASPOINT);
 IF OBXDF1=0 THEN OBXDF1:=0.001;
 OBXDF2:=ABS(XOBEND2-XMEASPOINT);
 IF OBXDF2=0 THEN OBXDF2:=0.001;
 THETA1:=ARCTAN(OBXDF1/OBYDF);
 THETA2:=ARCTAN(OBXDF2/OBYDF);
 LUMTHETA:=ARCTAN(XDIFF/YDIFF);
 LUMANG:=ARCTAN(HM/YDIFF);
 OBANG:=ARCTAN(OBHITE/OBYDF);
 IF (YCOORD < YOBEND) THEN GOTO 1;
 IF (XMEASPOINT <= XOBEND1) THEN BEGIN
  IF (XCOORD <= XOBEND1) THEN GOTO 1;
  IF (LUMTHETA <= THETA2) AND (LUMTHETA >=
THETA1) THEN BEGIN
    IF (OBANG >= LUMANG) THEN BEGIN
      ILLUMINANCE:=0;
      GOTO 2;
    END;
    GOTO 1;
  END;
  GOTO 1;
 END;
 IF (XMEASPOINT >= XOBEND1) AND (XMEASPOINT <=
XOBEND2) THEN BEGIN
  IF (LUMTHETA <= THETA2) AND (LUMTHETA <=
THETA1) THEN BEGIN
    IF (OBANG >= LUMANG) THEN BEGIN
      ILLUMINANCE:=0;
      GOTO 2;
    END;
    GOTO 1;
  END;
  GOTO 1;
 END;
 IF (XMEASPOINT >= XOBEND2) THEN BEGIN
  IF (XCOORD >= XOBEND2) THEN GOTO 1;
  IF (LUMTHETA >= THETA2) AND (LUMTHETA <=
THETA1) THEN BEGIN
    IF (OBANG >= LUMANG) THEN BEGIN
      ILLUMINANCE:=0;
      GOTO 2;
    END;
    GOTO 1;
  END;
  GOTO 1;
 END;
 1:AB:=SQRT(SQR(XDIFF)+SQR(YDIFF));
 ANG:=ARCTAN(AB/HM);
 DIST:=SQRT(SQR(AB)+SQR(HM));
 NTHD;
 ILLUMINANCE:=INTENSITY*ABS(COS(ANG))/SQR(DIST);
 2:PARILLUM1:=ILLUMINANCE;
 END;
```

```
PROCEDURE PARALLEL_DOWN;

 LABEL 1,2;
 VAR
YOBEND,XOBEND1,XOBEND2,OBYDF,OBXDF1,OBXDF2,OB
ANG,LUMANG,

LUMTHETA,THETA1,THETA2,OBHITE,OBWIDTH,YDISTOB:R
EAL;


BEGIN
 OBHITE:=0.50;
 OBWIDTH:=0.60;
 YDISTOB:=1.05;
 YOBEND:=2*SHM-YDISTOB;
 XOBEND1:=2*SHM-0.5*OBWIDTH;
 XOBEND2:=2*SHM+0.5*OBWIDTH;
 OBYDF:=ABS(YOBEND-YMEASPOINT);
 IF OBYDF=0 THEN OBYDF:=0.001;
 OBXDF1:=ABS(XOBEND1-XMEASPOINT);
 IF OBXDF1=0 THEN OBXDF1:=0.001;
 OBXDF2:=ABS(XOBEND2-XMEASPOINT);
 IF OBXDF2=0 THEN OBXDF2:=0.001;
 THETA1:=ARCTAN(OBXDF1/OBYDF);
 THETA2:=ARCTAN(OBXDF2/OBYDF);
 LUMTHETA:=ARCTAN(XDIFF/YDIFF);
 LUMANG:=ARCTAN(HM/YDIFF);
 OBANG:=ARCTAN(OBHITE/OBYDF);
 IF (YCOORD > YOBEND) THEN GOTO 1;
 IF (XMEASPOINT <= XOBEND1) THEN BEGIN
  IF (XCOORD <= XOBEND1) THEN GOTO 1;
  IF (LUMTHETA <= THETA2) AND (LUMTHETA >=
THETA1) THEN BEGIN
    IF (OBANG >= LUMANG) THEN BEGIN
      ILLUMINANCE:=0;
      GOTO 2;
    END;
    GOTO 1;
  END;
  GOTO 1;
 END;
 IF (XMEASPOINT >= XOBEND1) AND (XMEASPOINT <=
XOBEND2) THEN BEGIN
  IF (LUMTHETA <= THETA2) AND (LUMTHETA <=
THETA1) THEN BEGIN
    IF (OBANG >= LUMANG) THEN BEGIN
      ILLUMINANCE:=0;
      GOTO 2;
    END;
    GOTO 1;
  END;
  GOTO 1;
 END;
 IF (XMEASPOINT >= XOBEND2) THEN BEGIN
  IF (XCOORD >= XOBEND2) THEN GOTO 1;
  IF (LUMTHETA >= THETA2) AND (LUMTHETA <=
THETA1) THEN BEGIN
    IF (OBANG >= LUMANG) THEN BEGIN
      ILLUMINANCE:=0;
      GOTO 2;
    END;
    GOTO 1;
  END;
  GOTO 1;
 END;
 1:AB:=SQRT(SQR(XDIFF)+SQR(YDIFF));
 ANG:=ARCTAN(AB/HM);
 DIST:=SQRT(SQR(AB)+SQR(HM));
 NTHD;
 ILLUMINANCE:=INTENSITY*ABS(COS(ANG))/SQR(DIST);
 2:PARILLUM2:=ILLUMINANCE;
 END;
```

```
PROCEDURE AXISLABELS;
BEGIN
XLABELS[1]:='0.5';
XLABELS[2]:='1.0';
XLABELS[3]:='1.5';
XLABELS[4]:='2.0';
XLABELS[5]:='2.5';
 YLABELS[1]:='0.0';
 YLABELS[2]:='0.1';
 YLABELS[3]:='0.2';
 YLABELS[4]:='0.3';
 YLABELS[5]:='0.4';
 YLABELS[6]:='0.5';
 YLABELS[7]:='0.6';
 YLABELS[8]:='0.7';
 YLABELS[9]:='0.8';
 YLABELS[10]:='0.9';
 YLABELS[11]:='1.0';
 YDISTLAB[1]:='0.0';
 YDISTLAB[2]:='0.2';
 YDISTLAB[3]:='0.4';
 YDISTLAB[4]:='0.6';
 YDISTLAB[5]:='0.8';
 YDISTLAB[6]:='1.0';
 YDISTLAB[7]:='1.2';
 YDISTLAB[8]:='1.4';
 YDISTLAB[9]:='1.6';
 YDISTLAB[10]:='1.8';
 YDISTLAB[11]:='2.0';
 END; {PROCEDURE AXISLABELS}

PROCEDURE FFC;
LABEL 1,2;
VAR AA,BB REAL;
 SH,II,JJ,I,J,III,JJJ:INTEGER;
 BEGIN
 HM:=1.80;
 FOR SH:=0 TO 8 DO BEGIN
 SHR:=0.5+SH*0.25;
 PPP[SH]:=SHR;
 ILTOT:=0;
 ILLMIN:=3000;
 ILLMAX:=0;
 SHM:=SHR*HM;
 AA:=SHM/2;
 BB:=0.10;
 FOR III:=NPP DOWNTO 0 DO
 BEGIN
 J:=NPP-III;
 YMEASPOINT:=((III*BB)-(LGT/2))+(2*SHM);
 FOR JJJ:=0 TO NNP DO
 BEGIN
 I:=JJJ;
 XMEASPOINT:=(2*SHM)-((NNP-JJJ)*BB);
 ILLUMATPT:=0;
 FOR II:=0 TO 3 DO
 BEGIN
 YCOORD:=AA+II*SHM;
 FOR JJ:=0 TO 3 DO
 BEGIN   (*EVERY LUMINAIRE*)
 STORAGE:=0;
 STORE:=0;
 XCOORD:=AA+JJ*SHM;
 YDIFF:=ABS(YMEASPOINT-YCOORD);
 IF YDIFF=0 THEN YDIFF:=0.001;
 XDIFF:=ABS(XMEASPOINT-XCOORD);
 IF XDIFF=0 THEN XDIFF:=0.001;
 PERPEND RIGHT1;
 IF PERPILLUM1=0 THEN BEGIN
 STORE:=PERPILLUM1;
 GOTO 1;
 END
 ELSE BEGIN
 STORAGE:=PERPILLUM1;
 PERPEND_RIGHT2;
 IF PERPILLUM2=0 THEN BEGIN
 STORE:=PERPILLUM2;
 GOTO 1;
 END
 ELSE BEGIN
 STORAGE:=PERPILLUM2;
 PARALLEL_UP;
 IF PARILLUM1=0 THEN BEGIN
 STORE:=PARILLUM1;
 GOTO 1;
 END
 ELSE BEGIN
   STORAGE:=PARILLUM1;
   PARALLEL_DOWN;
   IF PARILLUM2=0 THEN BEGIN
   STORE:=PARILLUM2;
   GOTO 1;
   END
   ELSE BEGIN
   STORAGE:=PARILLUM2;
   END;
   END;
   END
   END;
   GOTO 2;
   1:STORAGE:=STORE;
   2:ILLUMINANCE:=STORAGE;
   ILLUMATPT:=ILLUMATPT+ILLUMINANCE;
   ILTOT:=ILTOT+ILLUMINANCE;
   PREILLUM1[I,J]:=PREILLUM1[I,J]+ILLUMINANCE;
   END
   END;
   ILLUMINI1[I,J]:=ROUND(PREILLUM1[I,J]);
 IF ILLUMINI1[I,J] < 1000 THEN WRITE(G,ILLUMINI1[I,J]:4,'
');
IF ILLUMINI1[I,J] > 999 THEN WRITE(G,ILLUMINI1[I,J]:1,' ');
IF I=NNP THEN BEGIN
WRITELN(G,' ');
WRITELN(G,' ');
WRITELN(G,' ');
 END;
   IF PREILLUM1[I,J] > ILLMAX THEN BEGIN
   ILLMAX:=PREILLUM1[I,J];
   ILMAX:=ROUND(ILLMAX);
   END;
  IF (PREILLUM1[I,J] < ILLMIN) THEN BEGIN
   ILLMIN:=PREILLUM1[I,J];
   ILMIN:=ROUND(ILLMIN);
   IF ILMIN=0 THEN ILMIN:=1;
   END;
   END
   END;
   ILLAV:=ILTOT/((NPP+1)*(NNP+1));
   ILAV:=ROUND(ILLAV);
   MINAV:=ILMIN/ILAV;
   AVMIN:=ILAV/ILMIN;
   MASTER[SH]:=MINAV;
   IMASTER[SH]:=AVMIN;
   UNIF:=ILMIN/ILMAX;
   PETE[SH]:=UNIF;
   MAXMIN:=ILMAX/ILMIN;
   IPETE[SH]:=MAXMIN;
   MAXAV:=ILMAX/ILAV;
   IMAXTER[SH]:=MAXAV;
   AVMAX:=ILAV/ILMAX;
   IDMAXTER[SH]:=AVMAX;
writeln(g,' ');
WRITELN(G,'SPACING TO HEIGHT RATIO = ',SHR:3:2);
WRITELN(G,'MAXIMUM ILLUMINANCE = ',ilmax:1);
WRITELN(G,'AVERAGE ILLUMINANCE = ',ilav:1);
WRITELN(G,'MINIMUM ILLUMINANCE = ',ilmin:1);
WRITELN(G,'MIN / MAX  U.R     = ',pete[sh]:3:2);
WRITELN(G,'MAX / MIN  U.R     = ',ipete[sh]:3:2);
WRITELN(G,'MIN / AVG  U.R     = ',master[sh]:3:2);
writeln(g,'AVG / MIN  U.R     = ',imaster[sh]:3:2);
writeln(g,'MAX / AVG  U.R     = ',imaxter[sh]:3:2);
writeln(g,'AVG / MAX  U.R     = ',idmaxter[sh]:3:2);
Grid_Illuminance1;
ILLUMINTOT:=0;
FOR J:=0 TO 19 DO BEGIN
FOR I:=0 TO 10 DO BEGIN
ILLUMIN1[I,J]:=0;
END;
END;
FOR J:=0 TO NPP DO BEGIN
FOR I:=0 TO NNP DO BEGIN
ILLUMINI1[I,J]:=0;
PREILLUM1[I,J]:=0;
END;
END;
END;{shr}
END;{PROCEDURE FFC}

  PROCEDURE XTRAINFO;
  VAR NOP:INTEGER;
  BEGIN
  MOVTO2(13.0,123.0);
  CHAHOL('NUMBER OF CALCULATION POINTS*.');
  NOP:=(NP+1)*(NP+1);
  CHAINT(NOP,2);
```

```
MOVTO2(13.0,130.0);
IF LUMTYPE=1 THEN
CHAHOL('THORN SYMMETRIC POINT VOL 1 P 7.4*.');
IF LUMTYPE=2 THEN
CHAHOL('CIBSE TM5 TYPE LUMINAIRE*.');
IF LUMTYPE=3 THEN
CHAHOL('POINT SOURCE BATWING LUMINAIRE*.');
IF LUMTYPE=4 THEN
CHAHOL('THIS WAS NOT CHOSEN*.');
MOVTO2(13.0,116.0);
CHAHOL('THE STANDARD OBSTRUCTION
SITUATIONS*.');
END;

PROCEDURE NEWGRAPH;
VAR I:INTEGER;
BEGIN
PICCLE; {CLEARS THE DRAWING AREA}
IPICT:=IPICT+1;
PICBEG(IPICT);
BROKEN(0);
MOVTO2(207.0,140.0);
LINTO2(12.0,140.0);
LINTO2(12.0,11.0);
LINTO2(207.0,11.0);
LINTO2(207.0,140.0);
MOVTO2(205.0,138.0);
LINTO2(14.0,138.0);
LINTO2(14.0,13.0);
LINTO2(205.0,13.0);
LINTO2(205.0,138.0);
NPTS:=9;
CHASIZ(2.2,2.2);
AXIPOS(1,31.0,29.0,160.0,1);
AXISCA(2,4,0.5,2.5,1);
AXIDRA(1,0,1);
AXILAB(XLABELS,5,4,1,24.0,1);
AXIPOS(1,31.0,29.0,75.0,2);
AXISCA(2,10,0.0,1.0,2);
AXIDRA(-1,0,2);
AXILAB(YLABELS,11,3,1,23.0,2);
MOVTO2(60.0,19.0);
CHASIZ(2.7,2.7);
CHAHOL(' SPACING TO HEIGHT RATIO*.');
MOVTO2(8.0,5.0);
CHASIZ(3.0,3.0);
CHAHOL('FIGURE 13 VARIATION IN UNIFORMITY WITH
SPACING TO HEIGHT RATIO*.');
CHASIZ(2.2,2.2);
XTRAINFO;
END;


PROCEDURE DIST1AN2;
BEGIN
PICCLE; {CLEARS THE DRAWING AREA}
IPICT:=IPICT+1;
PICBEG(IPICT);
XTRAINFO;
BROKEN(0);
MOVTO2(265.0,200.0);
LINTO2(12.0,200.0);
LINTO2(12.0,12.0);
LINTO2(265.0,12.0);
LINTO2(265.0,200.0);
MOVTO2(263.0,198.0);
LINTO2(14.0,198.0);
LINTO2(14.0,14.0);
LINTO2(263.0,14.0);
LINTO2(263.0,198.0);
NPTS:=9;
CHASIZ(2.5,2.5);
AXIPOS(1,45.0,40.0,200.0,1);
AXISCA(2,4,0.5,2.5,1);
AXIDRA(1,0,1);
AXILAB(XLABELS,5,4,1,35.0,1);
AXIPOS(1,45.0,40.0,100.0,2);
AXISCA(2,10,0.0,2.0,2);
AXIDRA(-1,0,2);
AXILAB(YDISTLAB,11,3,1,35.0,2);
MOVTO2(100.0,25.0);
CHASIZ(3.0,3.0);
CHAHOL(' SPACING TO HEIGHT RATIO*.');
CHASIZ(2.5,2.5);
BROKEN(5);
NPTS:=9;
{ GRAPOL(PPP,MINDISCREP,NPTS); }
MOVTO2(145.0,174.0);
LINBY2(30.0,0.0);
BROKEN(0);
MOVTO2(180.0,174.0);
CHAHOL('MINIMUM ILLUMINANCE CASE*.');
BROKEN(3);
NPTS:=9;
{ GRAPOL(PPP,MAXDISCREP,NPTS); }
MOVTO2(145.0,182.0);
LINBY2(30.0,0.0);
BROKEN(0);
MOVTO2(180.0,182.0);
CHAHOL('MAXIMUM ILLUMINANCE CASE*.');
CHAANG(90.0);
MOVTO2(22.0,40.0);
CHASIZ(3.0,3.0);
CHAHOL(' DISTANCE FROM EXPECTED E1*.');
MOVTO2(28.0,40.0);
CHAHOL(' OR E2 MIN OR MAX POINT (m)*.');
CHASIZ(2.5,2.5);
CHAANG(0.0);
END;


PROCEDURE POINT8;
BEGIN
TTT[0]:=0.8;
TTT[1]:=0.8;
SSS[0]:=0.5;
SSS[1]:=2.5;
BROKEN(6);
NPTS:=2;
GRAPOL(SSS,TTT,NPTS);
BROKEN(5);
NPTS:=9;
GRAPOL(PPP,BEDOC,NPTS);
MOVTO2(145.0,190.0);
LINBY2(30.0,0.0);
BROKEN(0);
MOVTO2(180.0,190.0);
CHAHOL('NO OBSTRUCTION CASE*.');
MOVTO2(28.0,50.0);
BROKEN(0);
CHAANG(90.0);
CHASIZ(3.0,3.0);
CHAHOL(' UNIFORMITY RATIO MIN/AV *.');
CHASIZ(2.5,2.5);
CHAANG(0.0);
END;


PROCEDURE POINT7;
BEGIN
TTT[0]:=0.7;
TTT[1]:=0.7;
SSS[0]:=0.5;
SSS[1]:=2.5;
BROKEN(6);
NPTS:=2;
GRAPOL(SSS,TTT,NPTS);
BROKEN(5);
NPTS:=9;
GRAPOL(PPP,NONOB,NPTS);
MOVTO2(101.0,130.0);
LINBY2(20.0,0.0);
BROKEN(0);
MOVTO2(122.0,130.0);
CHAHOL('NO OBSTRUCTION CASE*.');
MOVTO2(19.0,18.0);
CHAANG(90.0);
BROKEN(0);
CHASIZ(2.7,2.7);
CHAHOL(' UNIFORMITY RATIO MIN/MAX*.');
CHASIZ(2.2,2.2);
CHAANG(0.0);
END;


PROCEDURE MAST;
LABEL 1,2;
VAR K,I,J,BROK:INTEGER;
AAA,YVAL:REAL;
BEGIN
REWRITE(G);
RESET(DATA);
READLN(DATA,DUMMY1);
READLN(DATA,DUMMY2,LUMTYPE);
READLN(DATA,DUMMY3,DUMMY4,NUMLAMP);
INDE; {AVERAGES THE INTENSITY IN EACH ANGLE OF
AZIMUTH PLANE OF
      INTEREST}
IF EMCASE=2 THEN GOTO 1 {OBSTRUCTED CASE}
ELSE
NOOBFFC; {EMPTY CASE}
GOTO 2;
```

```
1:FFC;
{SHRMAXCALC;
IPICT:=0;
INITVS;
GINO;
SAVDRA;}
{* WINDO2(0,280.0,0,210.0);     *}
{DEVPAP(280.0,210.0,0);
AXISLABELS;
NEWGRAPH;
POINT7;
FOR I:=0 TO 8 DO BEGIN
QQQ[I]:=PETE[I];
END;
BROKEN(1);
NPTS:=9;
GRAPOL(PPP,QQQ,NPTS);
    DEVEND;
    GINEND;
    ENDVS;}
    2:END;

    BEGIN
    MAST;
    END.
```

Appendix B: SHROBS computer program for linear luminaires

This program calculates the maximum spacing to height ratio for a heavily obstructed interior lit by any type of linear luminaires. The program could also be run for the empty case by changing the value of the constant EMCASE, in the declaration section, from 2 to 1. The listing given in this appendix is similar to other versions written for other standard obstruction configurations. Examples of the execution file and the input file are also given.

B1: The execution file used to run the SHROBS program

```
&trace on
exec library vspascal fortvs gino nagfglib nagglib glib gino cmslib
exec vspascal uniheavy (margin(1,100
FI data disk tho1214 lumdata
FI g disk hvth1214 term
load uniheavy (nomap clear start
&exit
```

B2: Example of the intensity distribution file used to run the SHROBS program

```
1500
2 1
1.2 0.6 1 2 2
214 214 213 212 211 209 205 190 160 128 98 74 57 43 31 20 11 5
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
214 213 210 206 199 191 179 163 143 119 94 72 53 36 26 20 15 6
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
214 214 213 212 211 209 205 190 160 128 98 74 57 43 31 20 11 5
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
214 213 210 206 199 191 179 163 143 119 94 72 53 36 26 20 15 6
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
214 214 213 212 211 209 205 190 160 128 98 74 57 43 31 20 11 5
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
214 213 210 206 199 191 179 163 143 119 94 72 53 36 26 20 15 6
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
214 214 213 212 211 209 205 190 160 128 98 74 57 43 31 20 11 5
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
214 213 210 206 199 191 179 163 143 119 94 72 53 36 26 20 15 6
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
214 214 213 212 211 209 205 190 160 128 98 74 57 43 31 20 11 5
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
214 213 210 206 199 191 179 163 143 119 94 72 53 36 26 20 15 6
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
214 214 213 212 211 209 205 190 160 128 98 74 57 43 31 20 11 5
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
214 213 210 206 199 191 179 163 143 119 94 72 53 36 26 20 15 6
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
0.54 0.00
12 12
```

Line 1: Lamp lumen output.
Line 2: Luminaire type and luminaire number (for identification).
Line 3: Luminaire length, luminaire width, scale factor indicator, indicator of number of intensity planes and number of lamps per luminaire.
Lines 4 and 5: A column of intensity distribution at 5° interval in elevation for 0° in azimuth.
Each subsequent pair of lines contain similar values for an azimuth angle at 30 ° interval.
DLOR and ULOR.
Last line: number of intensity planes for both multiples of 5° and 10° in elevation.

B3: Listing of the SHROBS program using a linear luminaire.

```
(*GOTO+*)
PROGRAM FORTCOPY(G,LUMDATA);
{CALCULATES THE ILLUMINANCE AT UP TO A 20x20
ARRAY}
{LIMITED BY ARRAY SPECIFICATION THEREFORE
INCREASEABLE}
{OVER THE CENTRAL AREA . IT CAN READ ALL THE
INTENSITY DATA }
{FROM A FILE AND PRINT IT ALL OUT INTO A FILE G}
{TWO OBSTRUCTIONS ARE CONSIDERED ONE PARRALEL
AND ONE}
{PERPENDICULAR TO THE MEASURING POINT}
{THE VALUE STANDOBKIND MUST BE SET TO CHANGE
THE STANDARD OBSTRUCTION}
CONST PI=3.14159;
    WDT=1.20;
    LGT=2.10;
    YGRAD=19;
    XGRAD=10;
    YGRAD2=10;
    XGRAD2=19;
    POINTS=220;
    EMCASE=2;
TYPE DY=ARRAY[0..36,1..18] OF REAL;
    MS=ARRAY[0..8,1..2] OF REAL;
    ILL1=ARRAY[0..10,0..19] OF REAL;
    LLL1=ARRAY[0..12,0..21] OF REAL;
    ILLI1=ARRAY[0..12,0..21] OF INTEGER;
    ILL2=ARRAY[0..19,0..10] OF REAL;
    LLL2=ARRAY[0..21,0..12] OF REAL;
    ILLI2=ARRAY[0..21,0..12] OF INTEGER;
    QQ=ARRAY[0..8] OF REAL;
    PP=ARRAY[0..8] OF REAL;
    STX=ARRAY[0..2] OF REAL;
    STY=ARRAY[0..2] OF REAL;
    SS=ARRAY[1..2] OF REAL;
    TT=ARRAY[1..2] OF REAL;
    NOB=ARRAY[0..8] OF REAL;
    LLLL=ARRAY[1..12] OF PACKED ARRAY[1..4] OF CHAR;
    IL=ARRAY[0..20,0..20] OF REAL;
    SMILL=ARRAY[0..3,0..3] OF REAL;
    NOOB=ARRAY[0..21,0..12] OF REAL;
    CAP11=ARRAY[0..2,0..6] OF REAL;
    CAB11=ARRAY[0..2,0..6] OF INTEGER;
    CAP12=ARRAY[0..3,0..5] OF REAL;
    CAB12=ARRAY[0..3,0..5] OF INTEGER;
    CAP21=ARRAY[0..5,0..3] OF REAL;
    CAB21=ARRAY[0..5,0..3] OF INTEGER;
    CAP22=ARRAY[0..6,0..2] OF REAL;
    CAB22=ARRAY[0..6,0..2] OF INTEGER;
    CAP=ARRAY[0..11,0..20] OF REAL;
    CAP2=ARRAY[0..20,0..11] OF REAL;
    CAPA=ARRAY[0..3,0..6] OF REAL;
    CAPB=ARRAY[0..6,0..3] OF REAL;
VAR TNTS:DY;
   G,LUMDATA:TEXT;
   ILLUMIN1:ILL1;
   ILLUMINI1:ILLI1;
   PREILLUM1:LLL1;
   PREILLUM2:LLL2;
   ILLUMIN2:ILL2;
   ILLUMINI2:ILLI2;

MASTER,IMASTER,IPETE,IMAXTER,IDMAXTER,PETE,MAX
DISCREP,MINDISCREP:MS;
   BEDOC,QQQ,NONOB,TTT:QQ;
   SMIL:SMILL;
   NOOBILLUMATPT:NOOB;
   ILLUM:IL;
   STORXOB:STX;
   STORYOB:STY;
   SSS,PPP:PP;
   YDISTLAB,XLABELS,YLABELS:LLLL;
  STDROOT:CAP;
  STDROOT2:CAP2;
EE1,EV1:CAPA;
EE2,EV2:CAPB;
MEANILUM1,DIFFILUM1,HORIZON1:CAP11;
HORGRAD1:CAB11;
MEANILUM2,DIFFILUM2,VERTICAL1:CAP12;
VERGRAD1:CAB12;
MEANILUM21,DIFFILUM21,HORIZON2:CAP21;
HORGRAD2:CAB21;
MEANILUM22,DIFFILUM22,VERTICAL2:CAP22;
VERGRAD2:CAB22;
illmin2,illmax2,illav2,illumintot,hiti:real;
master2,imaster2,imaxter2,idmaxter2,pete2,ipete2:real;
minav2,avmin2,unif2,maxmin2,maxav2,avmax2:real;
ilmin2,ilav2,ilmax2:integer;

STORAGE,NOOBILTOT,NOOBILMAX,NOOBILMIN,NOOBILA
V,ILTOT:REAL;
DUMMY4,PREVSHSTO,NOWSHSTO,ISTO,JSTO,NPP,NNP,HS,H
V,VV,VS:INTEGER;
INTENS,ANGLUM,ANGOB,YDIFF,SHM,LOR,ULOR,SSSS:REAL
;
  ILAV,ILMAX,ILMIN,XXGRAD:INTEGER;

DUMMY1,DUMMY2,DUMMY3,ALPHA1,ALPHA2,BETA1,BETA
2,TIME:INTEGER;

XCOORD,YCOORD,ILLUMATPT,OBXDF,SISA,SISB,SOCA,SOC
B,

INTENSITY,ANG,ALPHA,BETA,HM,ANGLED,ALPHAD,BETA
D:REAL;
LUMTYPE,AFNOTADD,I,J,II,JJ,NUMLAMP:INTEGER;
LUMLEN,X1,X2,K,KFACTOR,XMEASPOINT,YMEASPOINT,DL
OR,SHR,UNIF:REAL;

AB,AF1,AF2,AF,ILLUMINANCE,AVMAX,ILLMIN,ILLMAX,IL
LAV,
XDF1,XDF2,XDF3,XDF4,AVMIN,MAXMIN,MAXAV,
LUMANG1,LUMANG2,LUMANG3,LUMANG4,PERPILLUM2,P
ERPILLUM3,PARILLUM3,
 OBANG1,OBANG2,OBANG3,OBANG4,

NUMBER,MINAV,PARILLUM1,PARILLUM2,PERPILLUM1,NO
OBILLUM,XDF5,XDF6:REAL;
COUNT,SHSTO,OCCASION,GOTO1,GOTO2,IPICT,NP,NPTS:INT
EGER;
LUMWIDTH:REAL;

    PROCEDURE INITVS;FORTRAN;
    PROCEDURE GINO;FORTRAN;
    PROCEDURE WINDO2(CONST
X1,X2,Y1,Y2:REAL);FORTRAN;
    PROCEDURE DEVPAP(const Z1,Z2:REAL;
            const Z3:INTEGER);FORTRAN;
    PROCEDURE GRAF(VAR PPP:PP;
            VAR QQQ:QQ;
            VAR NPTS,ISC : INTEGER);FORTRAN;
    PROCEDURE GRAPOL(VAR PPP:PP;
            VAR QQQ:QQ;
            VAR NPTS : INTEGER);FORTRAN;
    PROCEDURE SAVDRA;FORTRAN;
    PROCEDURE MOVTO2(CONST SHR,MINAV
:REAL);FORTRAN;
    PROCEDURE CHASIZ(CONST
WIDTH,HEIGHT:REAL);FORTRAN;
    PROCEDURE AXIDRA(CONST TICK,VAL,XORY
:INTEGER);FORTRAN;
    PROCEDURE AXIPOS(const IOR :INTEGER;
            const XXR,YYR,AXLEN :REAL;
            const XORY : INTEGER);FORTRAN;
    PROCEDURE AXILAB(CONST LABS : LLLL;
            CONST N,CHARS,WORDS : INTEGER;
            CONST POSITION : REAL;
            CONST XORY : INTEGER);FORTRAN;
    PROCEDURE AXISCA(CONST SCALE,INTS:INTEGER;
            CONST FROM,UPTO:REAL;
            CONST XORY:INTEGER);FORTRAN;
    PROCEDURE LINTO2(CONST X,Y:REAL);FORTRAN;
    PROCEDURE CHAANG(CONST
ANGLE:REAL);FORTRAN;
    PROCEDURE CHAHOL(CONST STNG:STRING);FORTRAN;
    PROCEDURE CHAINT(CONST
INT,WIDTH:INTEGER);FORTRAN;
    PROCEDURE CHAFIX(VAR NUMBER:REAL;
            CONST WIDTH,PLACES:INTEGER);FORTRAN;
    PROCEDURE DASHED(VAR MODE:INTEGER;
            VAR
REPETITON,DASH,DOT:REAL);FORTRAN;
    PROCEDURE BROKEN(CONST I:INTEGER);FORTRAN;
    PROCEDURE DEVEND;FORTRAN;
    PROCEDURE LINBY2(CONST X,Y: REAL);FORTRAN;
    PROCEDURE PICBEG(CONST
PICNUMBER:INTEGER);FORTRAN;
    PROCEDURE PICCLE;FORTRAN;
    PROCEDURE PICEND;FORTRAN;
    PROCEDURE GINEND;FORTRAN;
    PROCEDURE TRACER(CONST
ISWI:INTEGER);FORTRAN;
    PROCEDURE ENDVS;FORTRAN;


PROCEDURE INDB;
    LABEL 2;
    VAR I,J,M,N,NN,MM:INTEGER;
    BEGIN
IF (DUMMY4 = 1) THEN BEGIN
    FOR J:=1 TO 12 DO BEGIN
    M:=(J*30)-30;
    MM:=(M+90) MOD 90;
```

```
    FOR I:=0 TO 36 DO BEGIN
    TNTS[I,J]:=0;
    N:=I*5;
    NN:=(N+10) MOD 10;
    IF (NN=0) AND (MM>0) THEN GOTO 2;
    READ(LUMDATA,TNTS[I,J]);
    IF EOLN THEN READLN;
    2:END
    END;
END; {IF DUMMY4 = 1 }
IF DUMMY4=3 THEN BEGIN
  FOR J:=1 TO 4 DO BEGIN
   FOR I:=0 TO 36 DO BEGIN
     READ(LUMDATA,TNTS[I,J]);
     IF EOLN THEN READLN;
   END;
  END
END;
IF DUMMY4=2 THEN BEGIN
 {INTENSITY DISTRIBUTION FILE HAS ALL VALUES IN IT}
    FOR J:=1 TO 12 DO BEGIN
    FOR I:=0 TO 36 DO BEGIN
    READ(LUMDATA,TNTS[I,J]);
    IF EOLN THEN READLN;
    END
    END;
    END {INTENSITY DISTRIBUTION FILE HAS ALL
VALUES IN IT}
   END;  {PROCEDURE  INDB  }


    PROCEDURE ZONFACT(VAR I:INTEGER;VAR KM:REAL);
    VAR ANGLE,ALPHA,BETA:REAL;
    BEGIN
    ANGLE:=5*I;
    ALPHA:=(ANGLE+5)*PI/180;
    BETA:=(ANGLE-5)*PI/180;
    KM:=ABS(4*PI*(SIN((ALPHA-
BETA)/2))*SIN((ALPHA+BETA)/2));
    END;


    PROCEDURE INDE;
    (*TO PRODUCE COLUMN OF ZONAL FLUX*)

    VAR KL,KM,ZFTOT,SF,SUM:REAL;
      II,I,J,KK,L,MM,TT:INTEGER;
    BEGIN
    READ(LUMDATA,DLOR,ULOR);
    READLN(LUMDATA,TT,L);

    FOR I:=0 TO 18 DO BEGIN
    SUM:=0;
    FOR J:=1 TO 12 DO BEGIN
    SUM:=SUM+TNTS[I,J];
    END;
    MM:=(I+2) MOD 2;
    IF (MM=0) THEN KK:=L
    ELSE KK:=TT;
    IF (KK<1) THEN KK:=1;
    TNTS[I,13]:=SUM/KK;
    END;
    ZFTOT:=0;
    FOR II:=1 TO 9 DO BEGIN
    I:=II*2-1;
    KL:=TNTS[I,13];
    ZONFACT(I,KM);
    TNTS[I,14]:=KM;
    TNTS[I,15]:=KL*KM;
    ZFTOT:=ZFTOT+TNTS[I,15];
    END;
 IF DUMMY3=1 THEN SF:=1
 ELSE BEGIN
   LOR:=DLOR+ULOR;
   SF:=LOR*1000/ZFTOT;
   END;
   FOR I:=0 TO 18 DO BEGIN
   TNTS[I,16]:=0.5*SF*(TNTS[I,1]+TNTS[I,7]);
   TNTS[I,17]:=0.5*SF*(TNTS[I,4]+TNTS[I,10]);
   END;
   K:=TNTS[9,17]/TNTS[0,17];
   KFACTOR:=K;
   END;


   PROCEDURE NTHD;
    VAR AA,BB,XX,YY,TT:REAL;
      L:INTEGER;
    BEGIN
    ANG:=ANG*180/PI;
    L:=1;
    WHILE (5*L)<(ANG) DO BEGIN
    L:=L+1;
    END;
    AA:=5*L;
    XX:=TNTS[L,16];
    L:=L-1;
    YY:=TNTS[L,16];
    BB:=5*L;
    TT:=(XX-YY)/(AA-BB);
    INTENS:=TT*ANG+(YY-TT*BB);
    INTENSITY:=INTENS*NUMLAMP*DUMMY1/1000;
    ANG:=ANG*PI/180;
    END;


    PROCEDURE ASPCALC(M,HL:REAL;
              VAR SUM:REAL);
    VAR I:INTEGER;
      Y,XB,RT:REAL;
    BEGIN
    SUM:=0;
    XB:=HL/10;
    FOR I:=1 TO 10 DO BEGIN
    Y:=EXP(M*LN(COS(I*XB)));
    RT:=XB*Y;
    SUM:=SUM+RT;
    END
    END;


    PROCEDURE
ILLUMFROMLUM(SISA,SISB,SOCA,SOCB,ALPHA,BETA:REAL
;
     VAR FFFF:REAL);
    VAR AF11,AF12,AF21,AF22:REAL;
    BEGIN
    IF (K>0.65) THEN BEGIN
    AF1:=((SISA)*(SOCA)+(ALPHA))/2.0;
    AF2:=((SISB)*(SOCB)+(BETA))/2.0;
    END
    ELSE IF (K>0.545) THEN BEGIN
    AF11:=((SISA)*(SOCA)+(ALPHA))/2.0;
    AF21:=((SISB)*(SOCB)+(BETA))/2.0;
    AF12:=(SISA)-(SQR(SISA)*(SISA)/3.0);
    AF22:=(SISB)-(SQR(SISB)*(SISB)/3.0);
    AF1:=(AF11+AF12)/2.0;
    AF2:=(AF21+AF22)/2.0;
    END
    ELSE IF (K>0.46) THEN BEGIN
    AF1:=(SISA)-(SQR(SISA)*(SISA)/3.0);
    AF2:=(SISB)-(SQR(SISB)*(SISB)/3.0);
    END
    ELSE IF (K>0.385) THEN BEGIN
AF1:=((SISA)*(((SOCA)*SQR(SOCA))+(1.5*(SOCA)))/4)+((3/8)*(
ALPHA));
AF2:=((SISB)*(((SOCB)*SQR(SOCB))+(1.5*(SOCB)))/4)+((3/8)*(
BETA));
    END
    ELSE IF (K>0.385) THEN BEGIN
    AF1:=(SISA)*((SQR(SOCA)*SQR(SOCA))+4-
(4*SQR(SISA)/3))/5.0;
    AF2:=(SISB)*((SQR(SOCB)*SQR(SOCB))+4-
(4*SQR(SISB)/3))/5.0;
    END
    ELSE BEGIN
    ASPCALC(3.5,ALPHA,AF1);
    ASPCALC(3.5,BETA,AF2);
    END;
    IF (XMEASPOINT>X1) AND (XMEASPOINT<X2) AND
(AFNOTADD = 1)
    THEN FFFF:=AF1+AF2
    ELSE FFFF:=ABS(AF1-AF2);
    AFNOTADD:=1;
    END;


    PROCEDURE ILLUMCALC;
    BEGIN
    ALPHA:=ARCTAN(XDF1/AB);
    ALPHAD:=ALPHA*180/PI;
    BETA:=ARCTAN(XDF2/AB);
    BETAD:=BETA*180/PI;
    SISA:=SIN(ALPHA);
    SISB:=SIN(BETA);
    SOCA:=COS(ALPHA);
    SOCB:=COS(BETA);
```

```
ILLUMFROMLUM(SISA,SISB,SOCA,SOCB,ALPHA,BETA,AF);
    NTHD;

ILLUMINANCE:=AF*SQR(COS(ANG))*INTENSITY/(LUMLEN
*HM);
    {THIS EQUATION COMES FROM P7 IES TECH REPORT
11 1968 EQ 1a}
    END;

    PROCEDURE
YDISTALONGOB(XVALUE,LUMANG,HITE:REAL);
    VAR OPPOSITE:REAL;
    BEGIN
    OPPOSITE:=OBXDF*SIN(LUMANG)/COS(LUMANG);

ANGOB:=ARCTAN(HITE/SQRT(SQR(OPPOSITE)+SQR(OBXDF)
));

ANGLUM:=ARCTAN(HM/SQRT(SQR(YDIFF)+SQR(XVALUE)));
    END;


    PROCEDURE FINDPOINT(DISTALONGLUM:REAL);
    VAR LUMANG:REAL;
    BEGIN
    REPEAT
    DISTALONGLUM:=DISTALONGLUM+0.1;
    LUMANG:=ARCTAN(YDIFF/DISTALONGLUM);
    YDISTALONGOB(DISTALONGLUM,LUMANG,HITI);
    UNTIL ANGOB >= ANGLUM;
    END;


    Procedure findpoint2(distalonglum:real);
        var lumang:real;
    Begin
      repeat
      distalonglum:=distalonglum - 0.1;
      lumang:=arctan(ydiff/distalonglum);
      ydistalongob(distalonglum,lumang,hiti);
      until angob >= anglum;
      end;



   {Procedure ydistalongobp(xvalue,lumang,hite:real);
      var obsopp:real;
    begin
      obsopp:=obydf/cos(lumang);
      angob:=arctan(hite/obsopp);
      anglum:=arctan(hm/sqrt(sqr(ydiff)+sqr(xvalue)));
    end;}


  {Procedure findpointp(distalonglump:real);
    var lumang:real;
  Begin
    repeat
    distalonglump:=distalonglump+0.1;
    lumang:=arctan(distalonglump/ydiff);
    ydistalongobp(distalonglump,lumang,hiti);
    until angob >= anglum;
    end;}


  {Procedure findpointp2(distalonglump:real);
    var lumang:real;
  Begin
    repeat
    distalonglump:=distalonglump-0.1;
    lumang:=arctan(distalonglump/ydiff);
    ydistalongobp(distalonglump,lumang,hiti);
    until angob >= anglum;
  end;}



    PROCEDURE ENQUIRY;
    LABEL 1;
    BEGIN
    GOTO1:=0;
    GOTO2:=0;
    YDISTALONGOB(XDF1,LUMANG1,HITI);
    IF ANGLUM <= ANGOB THEN BEGIN
    ILLUMINANCE:=0;
    GOTO1:=1;
    GOTO 1;
    END
    ELSE BEGIN
    XDF3:=XDF1;
    FINDPOINT(XDF3);
    XDF2:=XDF3;
      GOTO2:=1;
      END;
      1:END;


Procedure perpendicular_right1;

 label 1,2;
var illumpt1,obydf1,obydf2,obydf3,obydf4,yobend1,yobend2,
    xobend,obhite,obwidth,xdistob,OBYDF:REAL;

Begin
if occasion=1 then begin
   obhite:=0.48;
   hiti:=obhite;
   xdistob:=0.20;
   obwidth:=0.16;
   xobend:=2*shm+xdistob;
   yobend1:=2*shm-0.5*obwidth;
   yobend2:=2*shm+0.5*obwidth;
end
else begin
   obhite:=0.75;
   hiti:=obhite;
   xdistob:=1.05;
   obwidth:=1.50;
   xobend:=2*shm+xdistob;
   yobend1:=2*shm-0.30;
   yobend2:=2*shm+1.20;
end;
obxdf:=abs(xobend-xmeaspoint);
if obxdf =0 then obxdf:=0.001;
obydf1:=abs(yobend1-ymeaspoint);
if obydf1 =0 then obydf1:=0.001;
obydf2:=abs(yobend2-ymeaspoint);
if obydf2 =0 then obydf2:=0.001;
lumang1:=arctan(ydiff/xdf1);
lumang2:=arctan(ydiff/xdf2);
obang1:=arctan(obydf1/obxdf);
obang2:=arctan(obydf2/obxdf);
if ycoord > ymeaspoint then begin
   obang3:=obang2;
   obydf3:=obydf2;
   obang4:=obang1;
   obydf4:=obydf1;
end
else begin
   obang3:=obang1;
   obydf3:=obydf1;
   obang4:=obang2;
   obydf4:=obydf2;
end;
if (x2 <= xobend) then goto 2;
if (ymeaspoint >= yobend2) and (ycoord >= yobend2) then goto 2;
if (ymeaspoint <= yobend1) and (ycoord <= yobend1) then goto 2;
if (lumang1 <= obang4) then goto 2;
if (lumang2 >= obang3) then goto 2;
if (lumang2 < obang4) and (lumang1 <= obang3) then begin
   ydistalongob(xdf1,lumang1,obhite);
   if anglum > angob then begin
     goto 2;
   end
   else begin
     xdf3:=xdf2;
     findpoint2(xdf3);
     xdf1:=xdf3;
     goto 2;
   end;
end;
if (lumang2 >= obang4) and (lumang1 <= obang3) then begin
   enquiry;
   if goto1 =1 then goto 1;
   if goto2 =1 then goto 2;
end;
if (lumang1 > obang3) and (lumang2 >= obang4) then begin
   ydistalongob(xdf2,lumang2,obhite);
   if anglum > angob then begin
     goto 2;
   end
   else begin
     xdf3:=xdf1;
     findpoint(xdf3);
     xdf2:=xdf3;
     goto 2;
   end;
end;
if (lumang2 < obang4) and (lumang1 > obang3) then begin
   xdf3:=xdf1;
   xdf4:=xdf2;
   xdf2:=ydiff*obxdf/obydf3;
   xdf5:=xdf2;
```

```
    illumcalc;
    illumpt1:=illuminance;
    xdf1:=ydiff*obxdf/obydf4;
    xdf6:=xdf1;
    xdf2:=xdf4;
    illumcalc;
    illumpt1:=illuminance+illumpt1;
    lumang3:=lumang1;
    lumang4:=lumang2;
    lumang1:=arctan(ydiff/xdf5);
    lumang2:=arctan(ydiff/xdf6);
    xdf1:=xdf5;
    xdf2:=xdf6;
    enquiry;
    if goto1 =1 then begin
      illuminance:=illumpt1;
      goto 1;
    end;
    illumcalc;
    illumpt1:=illumpt1+illuminance;
    illuminance:=illumpt1;
    lumang1:=lumang3;
    lumang2:=lumang4;
    xdf1:=xdf3;
    xdf2:=xdf4;
    goto 1;
    end;
  2:illumcalc;
  1:perpillum1:=illuminance;
  end;


Procedure perpend right2;

 label 1,2;
 var illumpt1,obydf1,obydf2,obydf3,obydf4,yobend1,yobend2,
    xobend,obhite,obwidth,xdistob,OBYDF:REAL;

Begin
   obhite:=0.30;
   hiti:=obhite;
   xdistob:=0.20;
   obwidth:=0.40;
   xobend:=2*shm+xdistob;
   yobend1:=2*shm-0.5*obwidth;
   yobend2:=2*shm+0.5*obwidth;
 obxdf:=abs(xobend-xmeaspoint);
 if obxdf =0 then obxdf:=0.001;
 obydf1:=abs(yobend1-ymeaspoint);
 if obydf1 =0 then obydf1:=0.001;
 obydf2:=abs(yobend2-ymeaspoint);
 if obydf2 =0 then obydf2:=0.001;
 lumang1:=arctan(ydiff/xdf1);
 lumang2:=arctan(ydiff/xdf2);
 obang1:=arctan(obydf1/obxdf);
 obang2:=arctan(obydf2/obxdf);
 if ycoord > ymeaspoint then begin
   obang3:=obang2;
   obydf3:=obydf2;
   obang4:=obang1;
   obydf4:=obydf1;
 end
 else begin
   obang3:=obang1;
   obydf3:=obydf1;
   obang4:=obang2;
   obydf4:=obydf2;
 end;
 if (x2 <= xobend) then goto 2;
 if (ymeaspoint >= yobend2) and (ycoord >= yobend2) then goto 2;
 if (ymeaspoint <= yobend1) and (ycoord <= yobend1) then goto 2;
 if (lumang1 <= obang4) then goto 2;
 if (lumang2 >= obang3) then goto 2;
 if (lumang2 < obang4) and (lumang1 <= obang3) then begin
   ydistalongob(xdf1,lumang1,obhite);
   if anglum > angob then begin
     goto 2;
   end
   else begin
     xdf3:=xdf2;
     findpoint2(xdf3);
     xdf1:=xdf3;
     goto 2;
   end;
 end;
 if (lumang2 >= obang4) and (lumang1 <= obang3) then begin
   enquiry;
   if goto1 =1 then goto 1;
   if goto2 =1 then goto 2;
 end;
 if (lumang1 > obang3) and (lumang2 >= obang4) then begin
     ydistalongob(xdf2,lumang2,obhite);
     if anglum > angob then begin
       goto 2;
     end
     else begin
       xdf3:=xdf1;
       findpoint(xdf3);
       xdf2:=xdf3;
       goto 2;
     end;
   end;
   if (lumang2 < obang4) and (lumang1 > obang3) then begin
     xdf3:=xdf1;
     xdf4:=xdf2;
     xdf2:=ydiff*obxdf/obydf3;
     xdf5:=xdf2;
     illumcalc;
     illumpt1:=illuminance;
     xdf1:=ydiff*obxdf/obydf4;
     xdf6:=xdf1;
     xdf2:=xdf4;
     illumcalc;
     illumpt1:=illuminance+illumpt1;
     lumang3:=lumang1;
     lumang4:=lumang2;
     lumang1:=arctan(ydiff/xdf5);
     lumang2:=arctan(ydiff/xdf6);
     xdf1:=xdf5;
     xdf2:=xdf6;
     enquiry;
     if goto1 =1 then begin
       illuminance:=illumpt1;
       goto 1;
     end;
     illumcalc;
     illumpt1:=illumpt1+illuminance;
     illuminance:=illumpt1;
     lumang1:=lumang3;
     lumang2:=lumang4;
     xdf1:=xdf3;
     xdf2:=xdf4;
     goto 1;
     end;
   2:illumcalc;
   1:perpillum2:=illuminance;
   end;


 PROCEDURE PERPENDICULAR_LEFT;

  label 1,2;
  var illumpt1,obydf1,obydf2,obydf3,obydf4,yobend1,yobend2,
      xobend,obhite,obwidth,xdistob,OBYDF:REAL;

 Begin
    OBHITE:=0.50;
    hiti:=obhite;
    XDISTOB:=1.05;
    OBWIDTH:=0.50;
    XOBEND:=2*SHM-XDISTOB;
    yobend1:=2*shm-0.25;
    yobend2:=2*shm+0.25;
  obxdf:=abs(xobend-xmeaspoint);
  if obxdf =0 then obxdf:=0.001;
  obydf1:=abs(yobend1-ymeaspoint);
  if obydf1 =0 then obydf1:=0.001;
  obydf2:=abs(yobend2-ymeaspoint);
  if obydf2 =0 then obydf2:=0.001;
  lumang1:=arctan(ydiff/xdf1);
  lumang2:=arctan(ydiff/xdf2);
  obang1:=arctan(obydf1/obxdf);
  obang2:=arctan(obydf2/obxdf);
  if ycoord > ymeaspoint then begin
    obang3:=obang2;
    obydf3:=obydf2;
    obang4:=obang1;
    obydf4:=obydf1;
  end
  else begin
    obang3:=obang1;
    obydf3:=obydf1;
    obang4:=obang2;
    obydf4:=obydf2;
  end;
  IF (X1 >= XOBEND) THEN GOTO 2;
  if (ymeaspoint >= yobend2) and (ycoord >= yobend2) then goto 2;
  if (ymeaspoint <= yobend1) and (ycoord <= yobend1) then goto 2;
  IF (LUMANG2 <= OBANG4) THEN GOTO 2;
  IF (LUMANG1 >= OBANG3) THEN GOTO 2;
  IF (LUMANG1 < OBANG4) AND (LUMANG2 <= OBANG3)
 THEN BEGIN
    YDISTALONGOB(XDF2,LUMANG2,OBHITE);
```

```
    if anglum > angob then begin
      goto 2;
    end
    else begin
      XDF3:=XDF1;
      FINDPOINT(XDF3);
      XDF2:=XDF3;
      goto 2;
    end;
  end;
 IF (LUMANG1 >= OBANG4) AND (LUMANG2 <= OBANG3)
 THEN BEGIN
    enquiry;
    if goto1 =1 then goto 1;
    if goto2 =1 then goto 2;
 end;
 IF (LUMANG2 > OBANG3) AND (LUMANG1 >= OBANG4)
 THEN BEGIN
    YDISTALONGOB(XDF1,LUMANG1,OBHITE);
    if anglum > angob then begin
      goto 2;
    end
    else begin
      XDF3:=XDF2;
      FINDPOINT2(XDF3);
      XDF1:=XDF3;
      goto 2;
    end;
  end;
 IF (LUMANG1 < OBANG4) AND (LUMANG2 > OBANG3)
 THEN BEGIN
    xdf3:=xdf1;
    xdf4:=xdf2;
    XDF2:=YDIFF*OBXDF/OBYDF4;
    xdf5:=xdf2;
    illumcalc;
    illumpt1:=illuminance;
    XDF1:=YDIFF*OBXDF/OBYDF3;
    xdf6:=xdf1;
    xdf2:=xdf4;
    illumcalc;
    illumpt1:=illuminance+illumpt1;
    lumang3:=lumang1;
    lumang4:=lumang2;
    lumang1:=arctan(ydiff/xdf5);
    lumang2:=arctan(ydiff/xdf6);
    xdf1:=xdf5;
    xdf2:=xdf6;
    enquiry;
    if goto1 =1 then begin
      illuminance:=illumpt1;
      goto 1;
    end;
    illumcalc;
    illumpt1:=illumpt1+illuminance;
    illuminance:=illumpt1;
    lumang1:=lumang3;
    lumang2:=lumang4;
    xdf1:=xdf3;
    xdf2:=xdf4;
    goto 1;
    end;
 2:illumcalc;
 1:PERPILLUM3:=ILLUMINANCE;
 end;



Procedure parallel up;
label 1,2;
var xobend1,xobend2,yobend,obydf,
   obxdf1,obxdf2,ydistob,obwidth,obhite:real;

   Begin
obhite:=0.75;
hiti:=obhite;
obwidth:=1.50;
ydistob:=1.05;
xobend1:=2*shm-1.20;
xobend2:=2*shm+0.30;
yobend:=2*shm+ydistob;
obydf:=abs(yobend-ymeaspoint);
if obydf=0 then obydf:=0.0001;
obxdf1:=abs(xobend1-xmeaspoint);
if obxdf1=0 then obxdf1:=0.0001;
obxdf2:=abs(xobend2-xmeaspoint);
if obxdf2=0 then obxdf2:=0.0001;
if (x2 < xmeaspoint) and (xobend1 > xmeaspoint) then goto 2;
if (x1 > xmeaspoint) and (xobend2 < xmeaspoint) then goto 2;
if (ycoord > ymeaspoint) then begin
  anglum:=arctan(hm/ydiff);
```

```
  angob:=arctan(obhite/obydf);
  if (angob > anglum) then begin
    lumang1:=arctan(xdf1/ydiff);
    lumang2:=arctan(xdf2/ydiff);
    lumang3:=arctan(xdf3/ydiff);
    lumang4:=arctan(xdf4/ydiff);
    OBANG1:=ARCTAN(OBXDF1/OBYDF);
    OBANG2:=ARCTAN(OBXDF2/OBYDF);

    if (xmeaspoint >= x1) and (xmeaspoint <= x2) then begin
      if (xmeaspoint < xobend1) then begin
        if (obang1 >=lumang2) then goto 2;
        xdf2:=ydiff*obxdf1/obydf;
        goto 2;
      end;
  if (xmeaspoint >= xobend1) and (xmeaspoint <= xobend2) then
begin
        if (obang1 >= lumang1) and (obang2 >= lumang2) then
begin
          illuminance:=0;
          goto 1;
        end;
        if (lumang1 > obang1) then begin
          xdf2:=ydiff*obxdf1/obydf;
          afnotadd:=0;
          goto 2;
        end;
        if (lumang2 > obang2) then begin
          xdf1:=ydiff*obxdf2/obydf;
          afnotadd:=0;
          goto 2;
        end
      end;
      if (xmeaspoint > xobend2) then begin
        if (lumang1 <= obang2) then goto 2;
        xdf1:=ydiff*obxdf2/obydf;
        goto 2;
      end
    end;
    if (xmeaspoint > x2) then begin
  if (xmeaspoint >= xobend1) and (xmeaspoint <= xobend2) then
begin
        if (obang1 <= lumang2) then goto 2;
        if (obang1 >= lumang1) then begin
          illuminance:=0;
          goto 1;
        end;
        xdf2:=ydiff*obxdf1/obydf;
        goto 2;
      end;
      if (xmeaspoint > xobend2) then begin
        if (obang2 <= lumang2) and (obang1 >= lumang1) then
begin
          illuminance:=0;
          goto 1;
        end;
        if (obang2 <= lumang2) and (obang1 < lumang1) then begin
          if (lumang2 > obang1) then goto 2;
          xdf2:=ydiff*obxdf1/obydf;
          goto 2;
        end;
        if (obang1 > lumang1) and (obang2 > lumang2) then begin
          if (lumang1 <= obang2) then goto 2;
          xdf1:=ydiff*obxdf2/obydf;
          goto 2;
        end
      end
    end;
    if (xmeaspoint < x1) then begin
      if (xmeaspoint < xobend1) then begin
        if (obang1 <= lumang1) and (obang2 >= lumang2) then
begin
          illuminance:=0;
          goto 1;
        end;
        if (obang1 <= lumang1) and (obang2 < lumang2) then begin
          if (lumang1 >= obang2) then goto 2;
          xdf1:=ydiff*obxdf2/obydf;
          goto 2;
        end;
        if (obang2 > lumang2) and (obang1 > lumang1) then begin
          if (lumang2 <= obang1) then goto 2;
          xdf2:=ydiff*obxdf1/obydf;
          goto 2;
        end
      end;
  if (xmeaspoint >= xobend1) and (xmeaspoint <= xobend2) then
begin
        if (obang2 < lumang2) then begin
          if (lumang1 >= obang2) then goto 2;
          xdf1:=ydiff*obxdf2/obydf;
          goto 2;
```

```
        end;
        if (obang2 >= lumang2) then begin
          illuminance:=0;
          goto 1;
        end
      end
    end
  end{angob > anglum}
end;{ycoord > ymeaspoint}
2:illumcalc;
1:parillum1:=illuminance;
end;



Procedure parallel down;
label 1,2;
var xobend1,xobend2,yobend,obydf,
   obxdf1,obxdf2,ydistob,obwidth,obhite:real;

   Begin
obhite:=0.48;
hiti:=obhite;
obwidth:=0.16;
ydistob:=0.20;
yobend:=2*shm-ydistob;
xobend1:=2*shm-0.5*obwidth;
xobend2:=2*shm+0.5*obwidth;
obydf:=abs(yobend-ymeaspoint);
if obydf=0 then obydf:=0.0001;
obxdf1:=abs(xobend1-xmeaspoint);
if obxdf1=0 then obxdf1:=0.0001;
obxdf2:=abs(xobend2-xmeaspoint);
if obxdf2=0 then obxdf2:=0.0001;
if (x2 < xobend1) and (xmeaspoint < xobend1) then goto 2;
if (x1 > xobend2) and (xmeaspoint > xobend2) then goto 2;
if (ycoord < ymeaspoint) then begin
  anglum:=arctan(hm/ydiff);
  angob:=arctan(obhite/obydf);
  if (angob > anglum) then begin
    lumang1:=arctan(xdf1/ydiff);
    lumang2:=arctan(xdf2/ydiff);
    lumang3:=arctan(xdf3/ydiff);
    lumang4:=arctan(xdf4/ydiff);
    obang1 =arctan(obxdf1/obydf);
    obang2 =arctan(obxdf2/obydf);
    if (xmeaspoint >= x1) and (xmeaspoint <= x2) then begin
      if (xmeaspoint < xobend1) then begin
        if (obang1 >=lumang2) then goto 2;
        xdf2.=ydiff*obxdf1/obydf;
        goto 2;
      end;
  if (xmeaspoint >= xobend1) and (xmeaspoint <= xobend2) then
begin
        if (obang1 >= lumang1) and (obang2 >= lumang2) then
begin
          illuminance:=0;
          goto 1;
        end;
        if (lumang1 > obang1) then begin
          xdf2:=ydiff*obxdf1/obydf;
          afnotadd:=0;
          goto 2;
        end;
        if (lumang2 > obang2) then begin
          xdf1:=ydiff*obxdf2/obydf;
          afnotadd:=0;
          goto 2;
        end
      end;
      if (xmeaspoint > xobend2) then begin
        if (lumang1 <= obang2) then goto 2;
        xdf1:=ydiff*obxdf2/obydf;
        goto 2;
      end
    end;
    if (xmeaspoint > x2) then begin
  if (xmeaspoint >= xobend1) and (xmeaspoint <= xobend2) then
begin
        if (obang1 <= lumang2) then goto 2;
        if (obang1 >= lumang1) then begin
          illuminance:=0;
          goto 1;
        end;
        xdf2:=ydiff*obxdf1/obydf;
        goto 2;
      end;
      if (xmeaspoint > xobend2) then begin
        if (obang2 <= lumang2) and (obang1 >= lumang1) then
begin
          illuminance:=0;
          goto 1;
```

```
          end;
          if (obang2 <= lumang2) and (obang1 < lumang1) then begin
            if (lumang2 > obang1) then goto 2;
            xdf2:=ydiff*obxdf1/obydf;
            goto 2;
          end;
          if (obang1 > lumang1) and (obang2 > lumang2) then begin
            if (lumang1 <= obang2) then goto 2;
            xdf1:=ydiff*obxdf2/obydf;
            goto 2;
          end
        end
      end;
      if (xmeaspoint < x1) then begin
        if (xmeaspoint < xobend1) then begin
          if (obang1 <= lumang1) and (obang2 >= lumang2) then
begin
            illuminance:=0;
            goto 1;
          end;
          if (obang1 <= lumang1) and (obang2 < lumang2) then begin
            if (lumang1 >= obang2) then goto 2;
            xdf1:=ydiff*obxdf2/obydf;
            goto 2;
          end;
          if (obang2 > lumang2) and (obang1 > lumang1) then begin
            if (lumang2 <= obang1) then goto 2;
            xdf2:=ydiff*obxdf1/obydf;
            goto 2;
          end
        end;
  if (xmeaspoint >= xobend1) and (xmeaspoint <= xobend2) then
begin
          if (obang2 < lumang2) then begin
            if (lumang1 >= obang2) then goto 2;
            xdf1:=ydiff*obxdf2/obydf;
            goto 2;
          end;
          if (obang2 >= lumang2) then begin
            illuminance:=0;
            goto 1;
          end
        end
      end
    end{angob > anglum}
end;{ycoord < ymeaspoint}
2:illumcalc;
1:parillum2:=illuminance;
end;



Procedure parallel_down2;
label 1,2;
var xobend1,xobend2,yobend,obydf,
   obxdf1,obxdf2,ydistob,obwidth,obhite:real;

   Begin
if occasion=1 then begin
   obhite:=0.50;
   hiti:=obhite;
   obwidth:=0.50;
   ydistob:=1.05;
   yobend:=2*shm-ydistob;
   xobend1:=2*shm-0.25;
   xobend2:=2*shm+0.25;
end;
if occasion=2 then begin
obhite:=0.30;
hiti:=obhite;
obwidth:=0.40;
ydistob:=0.20;
xobend1:=2*shm-0.5*obwidth;
xobend2:=2*shm+0.5*obwidth;
yobend:=2*shm-ydistob;
end;
obydf:=abs(yobend-ymeaspoint);
if obydf=0 then obydf:=0.0001;
obxdf1:=abs(xobend1-xmeaspoint);
if obxdf1=0 then obxdf1:=0.0001;
obxdf2:=abs(xobend2-xmeaspoint);
if obxdf2=0 then obxdf2:=0.0001;
if (x2 < xobend1) and (xobend1 > xmeaspoint) then goto 2;
if (x1 > xobend2) and (xobend2 < xmeaspoint) then goto 2;
if (ycoord < ymeaspoint) then begin
  anglum:=arctan(hm/ydiff);
  angob:=arctan(obhite/obydf);
  if (angob > anglum) then begin
    lumang1:=arctan(xdf1/ydiff);
```

```
        lumang2:=arctan(xdf2/ydiff);
        lumang3:=arctan(xdf3/ydiff);
        lumang4:=arctan(xdf4/ydiff);
        obang1:=arctan(obxdf1/obydf);
        obang2:=arctan(obxdf2/obydf);

        if (xmeaspoint >= x1) and (xmeaspoint <= x2) then begin
          if (xmeaspoint < xobend1) then begin
            if (obang1 >=lumang2) then goto 2;
            xdf2:=ydiff*obxdf1/obydf;
            goto 2;
          end;
    if (xmeaspoint >= xobend1) and (xmeaspoint <= xobend2) then
begin
            if (obang1 >= lumang1) and (obang2 >= lumang2) then
begin
              illuminance:=0;
              goto 1;
            end;
            if (lumang1 > obang1) then begin
              xdf2:=ydiff*obxdf1/obydf;
              afnotadd:=0;
              goto 2;
            end;
            if (lumang2 > obang2) then begin
              xdf1:=ydiff*obxdf2/obydf;
              afnotadd:=0;
              goto 2;
            end
          end;
          if (xmeaspoint > xobend2) then begin
            if (lumang1 <= obang2) then goto 2;
            xdf1:=ydiff*obxdf2/obydf;
            goto 2;
          end
        end;
        if (xmeaspoint > x2) then begin
      if (xmeaspoint >= xobend1) and (xmeaspoint <= xobend2) then
begin
            if (obang1 <= lumang2) then goto 2;
            if (obang1 >= lumang1) then begin
              illuminance:=0;
              goto 1;
            end;
            xdf2 =ydiff*obxdf1/obydf;
            goto 2,
          end;
          if (xmeaspoint > xobend2) then begin
            if (obang2 <= lumang2) and (obang1 >= lumang1) then
begin
              illuminance.=0;
              goto 1;
            end;
            if (obang2 <= lumang2) and (obang1 < lumang1) then begin
              if (lumang2 > obang1) then goto 2;
              xdf2:=ydiff*obxdf1/obydf;
              goto 2;
            end;
            if (obang1 > lumang1) and (obang2 > lumang2) then begin
              if (lumang1 <= obang2) then goto 2;
              xdf1:=ydiff*obxdf2/obydf;
              goto 2;
            end
          end
        end;
        if (xmeaspoint < x1) then begin
          if (xmeaspoint < xobend1) then begin
            if (obang1 <= lumang1) and (obang2 >= lumang2) then
begin
              illuminance:=0;
              goto 1;
            end;
            if (obang1 <= lumang1) and (obang2 < lumang2) then begin
              if (lumang1 >= obang2) then goto 2;
              xdf1:=ydiff*obxdf2/obydf;
              goto 2;
            end;
            if (obang2 > lumang2) and (obang1 > lumang1) then begin
              if (lumang2 <= obang1) then goto 2;
              xdf2:=ydiff*obxdf1/obydf;
              goto 2;
            end
          end;
  if (xmeaspoint >= xobend1) and (xmeaspoint <= xobend2) then
begin
          if (obang2 < lumang2) then begin
            if (lumang1 >= obang2) then goto 2;
            xdf1:=ydiff*obxdf2/obydf;
            goto 2;
          end;
          if (obang2 >= lumang2) then begin
            illuminance:=0;
                goto 1;
              end
            end
          end
        end{angob > anglum}
      end;{ycoord < ymeaspoint}
      2:illumcalc;
      1:parillum3:=illuminance;
      end;



Procedure Grid_Illuminance1;

   var totgrad,meangrad:real;

procedure New_Grid1;

var iii,jjj,ii,jj:integer;

begin
  illmin2:=3000;
  illmax2:=0;
  for jjj:=0 to 19 do begin
     jj:=jjj+1;
     for iii:=0 to 10 do begin
        ii:=iii+1;
        illumin1[iii,jjj]:=preillum1[ii,jj];
        if illumin1[iii,jjj] > illmax2 then begin
         illmax2:=illumin1[iii,jjj];
         ilmax2:=round(illmax2);
         end;
        if illumin1[iii,jjj] < illmin2 then begin
         illmin2:=illumin1[iii,jjj];
         ilmin2:=round(illmin2);
         if ilmin2=0 then ilmin2:=1;
         end;
       illumintot:=illumintot+illumin1[iii,jjj];
       end;
     end;
     illav2:=illumintot/(20*11);
     ilav2:=round(illav2);
     minav2:=ilmin2/ilav2;
     master2:=minav2;
     avmin2:=ilav2/ilmin2;
     imaster2:=avmin2;
     unif2:=ilmin2/ilmax2;
     pete2:=unif2;
     maxmin2:=ilmax2/ilmin2;
     ipete2:=maxmin2;
     maxav2:=ilmax2/ilav2;
     imaxter2:=maxav2;
     avmax2:=ilav2/ilmax2;
     idmaxter2:=avmax2;
WRITELN(G,'NEW MAXIMUM ILLUMINANCE = ',ilmax2:1);
WRITELN(G,'NEW AVERAGE ILLUMINANCE = ',ilav2:1);
WRITELN(G,'NEW MINIMUM ILLUMINANCE = ',ilmin2:1);
WRITELN(G,'NEW MIN / MAX  U.R      = ',pete2:3:2);
WRITELN(G,'NEW MAX / MIN  U.R      = ',ipete2:3:2);
WRITELN(G,'NEW MIN / AVG  U.R      = ',master2:3:2);
writeln(g,'NEW AVG / MIN  U.R      = ',imaster2:3:2);
writeln(g,'NEW MAX / AVG  U.R      = ',imaxter2:3:2);
writeln(g,'NEW AVG / MAX  U.R      = ',idmaxter2:3:2);
   end;



Procedure  Horzgrad;  { to calculate the gradient of illumnance }
               {along the x axis which is the width of task area}


 var i,j,ii,jj,s,p,n,m,xx,yy:integer;

 Begin
   writeln(g,'Gradient of illuminance in the x-direction  ( % )');
   for j:=0 to 19 do
   Begin
     yy:=j mod 3;
     if yy=0 then
     Begin
       jj:=round(j/3);
       for i:=1 to 10 do
       Begin
         xx:=i mod 3;
         if xx=1 then
         Begin
           ii:=round((i-1)/3);
           ee1[ii,jj]:=illumin1[i,j];
         End;
```

```
        End;
      End;
    End;
    for jj:=0 to 6 do
    Begin
      p:=jj;
      for ii:=0 to 3 do
      Begin
        if (ii>0) then
        Begin
          s:=ii-1;
          meanilum1[s,p]:=(ee1[ii,jj]+ee1[ii-1,jj])/2;
          diffilum1[s,p]:=(ee1[ii,jj]-ee1[ii-1,jj]);
          horizon1[s,p]:=(diffilum1[s,p]/meanilum1[s,p]);
          horgrad1[s,p]:=round(horizon1[s,p]*100);
          totgrad:=totgrad+abs(horgrad1[s,p]);
          write(g,horgrad1[s,p]:1,' ');
            if (s=2) then Begin
              writeln(g,' ');
              writeln(g,' ');
            End;
        End;
      End;{i counter}
    End;{j counter}
  End;{procedure horzgrad}


Procedure Vertgrad;{to calculate gradient of illuminance in}
           {the y direction from top to bottom}
 var i,j,ii,jj,s,p,n,m,xx,yy:integer;

 Begin
   writeln(g,'Gradient of illuminance in the y-direction  ( % )');
   for j:=0 to 19 do
   Begin
     yy:=j mod 3;
     if yy=0 then
     Begin
       jj:=round(j/3);
       for i:=1 to 10 do
       Begin
         xx:=i mod 3;
         if xx=1 then
         Begin
           ii:=round((i-1)/3);
           ev1[ii,jj]:=illumin1[i,j];
         End;
       End;
     End;
   End;
   for jj:=0 to 6 do
   Begin
     if (jj > 0) then
     Begin
       p:=jj-1;
       for ii:=0 to 3 do
       Begin
         s:=ii;
         meanilum2[s,p]:=(ev1[ii,jj]+ev1[ii,jj-1])/2;
         diffilum2[s,p]:=(ev1[ii,jj]-ev1[ii,jj-1]);
         vertical1[s,p]:=(diffilum2[s,p]/meanilum2[s,p]);
         vergrad1[s,p]:=round(vertical1[s,p]*100);
         totgrad:=totgrad+abs(vergrad1[s,p]);
         write(g,vergrad1[s,p]:1,' ');
         if (s=3) then Begin
         writeln(g,' ');
         writeln(g,' ');
         End;
       End;{ii counter}
     End;{if j > 0}
   End;{jj counter}
 End;{procedure vertgrad}


Procedure Mahler;
 var i,j:integer;
   STDTOT,STD,SU,stdratio:REAL;


 Begin
   writeln(g,'Mean and standard deviation in illuminance');
   stdtot:=0;
   for j:=0 to 19 do
   Begin
     for i:=0 to 10 do
     Begin
       STDROOT[I,J]:=SQR(ILLUMIN1[I,J]-ILLAV2);
       stdtot:=stdtot+stdroot[i,j];
     End;
   End;
   std:=sqrt(stdtot/points);
```

```
     stdratio:=std/illav2*100;
     writeln(g,'Standard deviation              : ',std:3:2);
   writeln(g,'ratio std/Eavg                   : ',stdratio:3:2,' %');
     SU:=(ILLAV2+STD)/(ILLAV2-STD);
     writeln(g,'Statistical uniformity          : ',su:3:2);
     writeln(g,' ');
     writeln(g,' ');
 End;



 PROCEDURE SQR_ADJACENT1;
  var a,b,xx,yy,n,m,count1,count2:integer;
     totalum,avgfour,minlav,maxlav,uratio,newratio:real;

 begin
  minlav:=2500;
  maxlav:=0;
  count2:=0;
  writeln(g,' ');
     FOR B:=0 TO 5 DO
      begin
       count1:=0;
       FOR A:=0 TO 2 DO
        begin
         for yy:=0 to 3 do
          begin
           m:=yy+count2;
           for xx:=0 to 3 do
            begin
             N:=XX+COUNT1+1;
             TOTALUM:=TOTALUM+ILLUMIN1[N,M];
            end;
          end;
         count1:=count1+3;
         avgfour:=totalum/16;
         if (avgfour > maxlav) then maxlav:=avgfour;
         if (avgfour < minlav) then minlav:=avgfour;
         totalum:=0;
        end;
       count2:=count2+3;
      end;
    uratio:=minlav/maxlav;
    newratio:=minlav/illav;
 writeln(g,'largest average illuminance (4X4)  : ',maxlav:4:1);
 writeln(g,'smallest average illuminance (4X4) : ',minlav:4:1);
 writeln(g,'Uniformity ratio Smallest/Largest  : ',uratio:3:2);
 writeln(g,'Uniformity ratio small. avg/Eavg   : ',newratio:3:2);
 writeln(g,' ');
 writeln(g,' ');
  end;





  Begin
   New_grid1;
   Mahler;
   SQR_ADJACENT1;
   Horzgrad;
   Vertgrad;
   meangrad:=totgrad/45;
   writeln(g,'Average gradient                 : ',meangrad:4:1);
  End;


Procedure Gd_Illu2;

  var totgrad,meangrad:real;

Procedure New_Grid2;

var iii,jjj,ii,jj:integer;


begin
 illmin2:=3000;
 illmax2:=0;
 for jjj:=0 to 10 do begin
    jj:=jjj+1;
    for iii:=0 to 19 do begin
       ii:=iii+1;
       illumin2[iii,jjj]:=preillum2[ii,jj];
       if illumin2[iii,jjj] > illmax2 then begin
        illmax2:=illumin2[iii,jjj];
        ilmax2:=round(illmax2);
       end;
```

```
      if illumin2[iii,jjj] < illmin2 then begin
       illmin2:=illumin2[iii,jjj];
       ilmin2:=round(illmin2);
       end;
     illumintot:=illumintot+illumin2[iii,jjj];
     end;
   end;
  illav2:=illumintot/(20*11);
  ilav2:=round(illav2);
  minav2:=ilmin2/ilav2;
  master2:=minav2;
  avmin2:=ilav2/ilmin2;
  imaster2:=avmin2;
  unif2:=ilmin2/ilmax2;
  pete2:=unif2;
  maxmin2:=ilmax2/ilmin2;
  ipete2:=maxmin2;
  maxav2:=ilmax2/ilav2;
  imaxter2:=maxav2;
  avmax2:=ilav2/ilmax2;
  idmaxter2:=avmax2;
WRITELN(G,'NEW MAXIMUM ILLUMINANCE = ',ilmax2:1);
WRITELN(G,'NEW AVERAGE ILLUMINANCE = ',ilav2:1);
WRITELN(G,'NEW MINIMUM ILLUMINANCE = ',ilmin2:1);
WRITELN(G,'NEW MIN / MAX  U.R     = ',pete2:3:2);
WRITELN(G,'NEW MAX / MIN  U.R     = ',ipete2:3:2);
WRITELN(G,'NEW MIN / AVG  U.R     = ',master2:3:2);
writeln(g,'NEW AVG / MIN  U.R     = ',imaster2:3:2);
writeln(g,'NEW MAX / AVG  U.R     = ',imaxter2:3:2);
writeln(g,'NEW AVG / MAX  U.R     = ',idmaxter2:3:2);
  end;


Procedure Horzgrad2; { to calculate the gradient of illumnance
              along the x axis which is the width of task area}

 var i,j,ii,jj,s,p,n,m,xx,yy:integer;

 Begin
   writeln(g,'Gradient of illuminance in the x-direction  ( % )');
   for j =1 to 10 do
   Begin
     yy:=j mod 3;
     if yy=1 then
     Begin
       jj:=round((j-1)/3);
       for i:=0 to 19 do
       Begin
         xx:=i mod 3;
         if xx=0 then
         Begin
           ii:=round(i/3);
           ee2[ii,jj]:=illumin2[i,j];
         End
       End;
     End
   End;
   for jj:=0 to 3 do
   Begin
     p:=jj;
     for ii:=0 to 6 do
     Begin
       if (ii>0) then
       Begin
         s:=ii-1;
         meanilum21[s,p]:=(ee2[ii,jj]+ee2[ii-1,jj])/2;
         diffilum21[s,p]:=(ee2[ii,jj]-ee2[ii-1,jj]);
         horizon2[s,p]:=(diffilum21[s,p]/meanilum21[s,p]);
         horgrad2[s,p]:=round(horizon2[s,p]*100);
         totgrad:=totgrad+abs(horgrad2[s,p]);
         write(g,horgrad2[s,p]:1,'  ');
           if (s=5) then Begin
             writeln(g,'  ');
             writeln(g,'  ');
           End;
       End;
     End;
   End;
End;


Procedure Vertgrad2;{to calculate gradient of illuminance in}
             {the y direction from top to bottom}
 var i,j,ii,jj,s,p,n,m,xx,yy:integer;

 Begin
   writeln(g,'Gradient of illuminance in the y-direction  ( % )');
   for j:=1 to 10 do
   Begin
     yy:=j mod 3;
     if yy=1 then
       Begin
         jj:=round((j-1)/3);
         for i:=0 to 19 do
           Begin
             xx:=i mod 3;
             if xx=0 then
             Begin
               ii:=round(i/3);
               ev2[ii,jj]:=illumin2[i,j];
             End;
           End;
         End;
     End;
   for jj:=0 to 3 do
   Begin
     if (jj > 0) then
     Begin
       p:=jj-1;
       for ii:=0 to 6 do
       Begin
         s:=ii;
         meanilum22[s,p]:=(ev2[ii,jj]+ev2[ii,jj-1])/2;
         diffilum22[s,p]:=(ev2[ii,jj]-ev2[ii,jj-1]);
         vertical2[s,p]:=(diffilum22[s,p]/meanilum22[s,p]);
         vergrad2[s,p]:=round(vertical2[s,p]*100);
         totgrad:=totgrad+abs(vergrad2[s,p]);
         write(g,vergrad2[s,p]:1,'  ');
         if (s=6) then Begin
         writeln(g,'  ');
         writeln(g,'  ');
         End;
       End;{ii counter}
     End;{if j > 0}
   End;{jj counter}
 End;{procedure vertgrad}


Procedure Mahler2;
 var i,j:integer;
    STDTOT,STD,SU,stdratio:REAL;


 Begin
   writeln(g,'Mean and standard deviation in illuminance');
   stdtot:=0;
   for j:=0 to 10 do
   Begin
     for i:=0 to 19 do
     Begin
       STDROOT2[I,J]:=SQR(ILLUMIN2[I,J]-ILLAV2);
       stdtot:=stdtot+stdroot2[i,j];
     End;
   End;
   std:=sqrt(stdtot/points);
   stdratio:=std/illav2*100;
   writeln(g,'Standard deviation          : ',std:3:2);
writeln(g,'ratio StD/Eavg              : ',stdratio:3:2);
   SU:=(ILLAV2+STD)/(ILLAV2-STD);
   writeln(g,'Statistical uniformity      : ',su:3:2);
   writeln(g,'  ');
   writeln(g,'  ');
End;


PROCEDURE SQR_ADJACENT2;
 var a,b,xx,yy,n,m,count1,count2:integer;
    totalum,avgfour,minlav,maxlav,uratio,newratio:real;

begin
 minlav:=2500;
 maxlav:=0;
 count2:=0;
    FOR B:=0 TO 2 DO
    begin
      count1:=0;
      FOR A:=0 TO 5 DO
       begin
        for yy:=0 to 3 do
         begin
          M:=YY+COUNT2+1;
```

```
        for xx:=0 to 3 do
         begin
          N:=XX+COUNT1+1;
          TOTALUM:=TOTALUM+ILLUMIN2[N,M];
         end;
        end;
       count1:=count1+3;
       avgfour:=totalum/16;
       if (avgfour > maxlav) then maxlav:=avgfour;
       if (avgfour < minlav) then minlav:=avgfour;
       totalum:=0;
      end;
      count2:=count2+3;
     end;
   uratio:=minlav/maxlav;
   newratio:=minlav/illav;
writeln(g,'largest average illuminance (4X4)  : ',maxlav:4:1);
writeln(g,'smallest average illuminance (4X4) : ',minlav:4:1);
writeln(g,'Uniformity ratio Smallest/Largest  : ',uratio:3:2);
writeln(g,'Uniformity ratio small. avg/Eavg   : ',newratio:3:2);
writeln(g,' ');
writeln(g,' ');
writeln(g,' ');
 end;




 Begin
   New_grid2;
   Mahler2;
   SQR_ADJACENT2;
   Horzgrad2;
   Vertgrad2;
   meangrad:=totgrad/45;
   writeln(g,'average gradient                : ',meangrad:5:1);
 End;


    PROCEDURE CONTROL;
LABEL 1,2;

VAR AA,BB REAL;
 SH,II,JJ,I,J,III,JJJ,WWW,TIMES:INTEGER;
CC,DD,EE,FF,ILMAXPTI,ILMAXPTJ,ILMINPTI,ILMINPTJ:REAL;
ANGOFMIN,ANGOFMAX,PTOFILMIN,PTOFILMAX,PTMINDIF,PTMAXDIF:REAL;
STORAGE1,STORAGE2,STORAGE3,STORAGE4:REAL;
    BEGIN
     XLABELS[1]:='1.0';
     XLABELS[2]:='1.5';
     XLABELS[3]:='2.0';
     XLABELS[4]:='2.5';
      YLABELS[1]:='0.0';
      YLABELS[2]:='0.1';
      YLABELS[3]:='0.2';
      YLABELS[4]:='0.3';
      YLABELS[5]:='0.4';
      YLABELS[6]:='0.5';
      YLABELS[7]:='0.6';
      YLABELS[8]:='0.7';
      YLABELS[9]:='0.8';
      YLABELS[10]:='0.9';
      YLABELS[11]:='1.0';
      YDISTLAB[1]:='0.0';
      YDISTLAB[2]:='0.2';
      YDISTLAB[3]:='0.4';
      YDISTLAB[4]:='0.6';
      YDISTLAB[5]:='0.8';
      YDISTLAB[6]:='1.0';
      YDISTLAB[7]:='1.2';
      YDISTLAB[8]:='1.4';
      YDISTLAB[9]:='1.6';
      YDISTLAB[10]:='1.8';
      YDISTLAB[11]:='2.0';
    HM:=1.80;
    BB:=0.10;
    AFNOTADD:=1;
    PREVSHSTO:=1;
    NOOBILTOT:=0;
    NOOBILMIN:=2500;
    NOOBILMAX:=0;
    FOR TIMES:=1 TO 2 DO BEGIN
    OCCASION:=TIMES;
    IF OCCASION=1 THEN BEGIN
     NPP:=21;
     NNP:=12;
     END;
      IF OCCASION=2 THEN BEGIN
       NPP:=12;
       NNP:=21;
       END;
IF (LUMLEN<0.91) THEN WWW:=0;
IF (LUMLEN>0.90) AND (LUMLEN<1.36) THEN WWW:=1;
IF (LUMLEN>1.35) AND (LUMLEN<1.81) THEN WWW:=2;
IF (LUMLEN>1.80) AND (LUMLEN<2.26) THEN WWW:=3;
IF (LUMLEN>2.25) AND (LUMLEN<2.71) THEN WWW:=4;
      FOR SH:=WWW TO 8 DO BEGIN
      SHSTO:=SH;
      SHR:=0.5+SH*0.25;
      PPP[SH]:=SHR;
      SHM:=SHR*HM;
      AA:=SHM/2;
      ILTOT:=0;
      ILLMIN:=2500;
      ILLMAX:=0;
if occasion=2 then begin
writeln(g,' ');
writeln(g,' ');
writeln(g,' ');
writeln(g,' ');
writeln(g,' ');
writeln(g,' ');
end;
      FOR III:=NPP DOWNTO 0 DO
      BEGIN
       J:=NPP-III;
       ISTO:=III;
      if occasion=1 then
       YMEASPOINT:=((III*BB)-(LGT/2))+(2*SHM)
       else
       ymeaspoint:=2*shm+(iii*bb);
      FOR JJJ:=0 TO NNP DO
      BEGIN
      I:=JJJ;
      JSTO:=JJJ;
     IF OCCASION=1 THEN
      XMEASPOINT:=(2*SHM)-((NNP-JJJ)*BB)
      ELSE
      XMEASPOINT:=((JJJ*BB)-(LGT/2))+(2*SHM);
      ILLUMATPT:=0;
      COUNT:=0;
      FOR II:=0 TO 3 DO
      BEGIN
      YCOORD:=AA+II*SHM;
      FOR JJ:=0 TO 3 DO
      BEGIN  (*EVERY LUMINAIRE*)
      STORAGE:=5000;
      XCOORD:=AA+JJ*SHM;
      YDIFF:=ABS(YMEASPOINT-YCOORD);
      IF YDIFF=0 THEN YDIFF:=0.001;
      AB:=SQRT(SQR(YDIFF)+SQR(HM)); (*DIAGONAL*)
      ANG:=ARCTAN(YDIFF/HM);
      ANGLED:=ANG*180/PI;
      X1:=XCOORD-LUMLEN/2;
      X2:=XCOORD+LUMLEN/2;  (*EACH END OF LUMINAIRE*);
      XDF1:=ABS(XMEASPOINT-X1);
      IF XDF1=0 THEN XDF1:=0.001;
      XDF2:=ABS(XMEASPOINT-X2);
      IF XDF2=0 THEN XDF2:=0.001;
      IF XDF1 < XDF2 THEN BEGIN
      XDF3:=XDF1;
      XDF4:=XDF2;
      END
      ELSE BEGIN
      XDF3:=XDF2;
      XDF4:=XDF1;
      END;
IF OCCASION=1 THEN BEGIN
  IF EMCASE=2 THEN BEGIN
    ILLUMCALC;
    GOTO 1
  END;
    PERPENDICULAR_RIGHT1;
    STORAGE1:=PERPILLUM1;
    PERPEND_RIGHT2;
    STORAGE2:=PERPILLUM2;
    PARALLEL_UP;
    STORAGE3:=PARILLUM1;
    parallel_down2;
    storage4:=parillum3;
IF STORAGE1 < STORAGE THEN
   STORAGE:=STORAGE1;
IF STORAGE2 < STORAGE THEN
   STORAGE:=STORAGE2;
IF STORAGE3 < STORAGE THEN
   STORAGE:=STORAGE3;
if storage4 < storage then
   storage:=storage4;
```

```
ILLUMINANCE:=STORAGE;
1:END;
IF OCCASION=2 THEN BEGIN
  IF EMCASE=2 THEN BEGIN
    ILLUMCALC;
    GOTO 2
  END;
    PARALLEL DOWN;
    STORAGE1:=PARILLUM2;
    PARALLEL DOWN2;
    STORAGE2:=PARILLUM3;
    PERPENDICULAR RIGHT1;
    STORAGE4:=PERPILLUM1;
    perpendicular left;
    storage3:=perpillum3;
  IF STORAGE1 < STORAGE THEN
    STORAGE:=STORAGE1;
  IF STORAGE2 < STORAGE THEN
    STORAGE:=STORAGE2;
  if storage4 < storage then
    storage:=storage4;
  IF STORAGE3 < STORAGE THEN
    STORAGE:=STORAGE3;
    ILLUMINANCE:=STORAGE;
2.END;
    ILLUMATPT:=ILLUMATPT+ILLUMINANCE;
    SMIL[JJ,II]:=ILLUMINANCE;
IF OCCASION=1 THEN
    PREILLUM1[I,J]:=PREILLUM1[I,J]+ILLUMINANCE;
 IF OCCASION=2 THEN
    PREILLUM2[I,J]:=PREILLUM2[I,J]+ILLUMINANCE;
    ILTOT:=ILTOT+ILLUMINANCE;
    end;{jj counter}
    end,{ii counter}
    IF OCCASION=1 THEN BEGIN
    ILLUMINI1[I,J]:=ROUND(PREILLUM1[I,J]);
IF (ILLUMINI1[I,J] < 1000 ) THEN WRITE(G,ILLUMINI1[I,J]:4,'
');
IF (ILLUMINI1[I,J] > 999) THEN WRITE(G,ILLUMINI1[I,J]:1,'
');
 IF I=NNP THEN BEGIN
WRITELN(G,' ');
WRITELN(G,' ');
WRITELN(G,' ');
END;
    IF PREILLUM1[I,J] > ILLMAX THEN BEGIN
    ILLMAX:=PREILLUM1[I,J],
    ILMAX:=ROUND(ILLMAX);
    ILMAXPTI:=I;
    ILMAXPTJ.=J;
    END;
    IF (PREILLUM1[I,J] < ILLMIN) AND (PREILLUM1[I,J] > 0)
THEN BEGIN
    ILLMIN:=PREILLUM1[I,J];
    ILMIN:=ROUND(ILLMIN);
    IF ILMIN=0 THEN ILMIN:=1;
    ILMINPTI:=I;
    ILMINPTJ:=J;
    END;
   END;
   IF OCCASION=2 THEN BEGIN
    ILLUMINI2[I,J]:=ROUND(PREILLUM2[I,J]);
   IF (ILLUMINI2[I,J] <1000) THEN
WRITE(G,ILLUMINI2[I,J]:4,' ');
   IF (ILLUMINI2[I,J] >999) THEN
WRITE(G,ILLUMINI2[I,J]:1,' ');
 IF I=NNP THEN BEGIN
   WRITELN(G,' ');
WRITELN(G,' ');
WRITELN(G,' ');
END;
if (j=npp) and (i=nnp) then begin
writeln(g,' ');
writeln(g,' ');
writeln(g,' ');
writeln(g,' ');
writeln(g,' ');
end;
     IF PREILLUM2[I,J] >ILLMAX THEN BEGIN
       ILLMAX:=PREILLUM2[I,J];
       ILMAX:=ROUND(ILLMAX);
       ILMAXPTI:=I;
       ILMAXPTJ:=J;
       END;
     IF (PREILLUM2[I,J] < ILLMIN) AND (PREILLUM2[I,J] >
0) THEN BEGIN
       ILLMIN:=PREILLUM2[I,J];
       ILMIN:=ROUND(ILLMIN);
       IF ILMIN=0 THEN ILMIN:=1;
       ILMINPTI:=I;
       ILMINPTJ:=J;
       END;
       END;

       END { J, X MEASPOINT DIRECTION}
       END; { I, Y MEASPOINT DIRECTION}
       ILLAV:=ILTOT/((NPP+1)*(NNP+1));
       ILAV:=ROUND(ILLAV);
       MINAV:=ILMIN/ILAV;
       AVMIN:=ILAV/ILMIN;
       MASTER[SH,TIMES]:=MINAV;
       IMASTER[SH,TIMES]:=AVMIN;
       UNIF:=ILMIN/ILMAX;
       PETE[SH,TIMES]:=UNIF;
       MAXMIN:=ILMAX/ILMIN;
       IPETE[SH,TIMES]:=MAXMIN;
       MAXAV:=ILMAX/ILAV;
       IMAXTER[SH,TIMES]:=MAXAV;
       AVMAX:=ILAV/ILMAX;
       IDMAXTER[SH,TIMES]:=AVMAX;

PTOFILMIN:=SQRT(SQR(ILMINPTI*BB)+SQR(ILMINPTJ*BB));

PTOFILMAX:=SQRT(SQR(ILMAXPTI*BB)+SQR(ILMAXPTJ*B
B));
     PTMINDIF:=ABS(PTOFILMIN-SQRT(SQR(AA)*2));
     PTMAXDIF:=PTOFILMAX;
     ANGOFMIN:=ARCTAN(ILMINPTJ*BB/HM);
     ANGOFMAX:=ARCTAN(ILMAXPTJ*BB/HM);
     IF PTMAXDIF=0 THEN PTMAXDIF:=0.0001;
     IF PTMINDIF=0 THEN PTMINDIF:=0.0001;
     CC:=ILMAXPTI*BB;
     IF CC=0 THEN CC:=0.001;
     DD:=ILMAXPTJ*BB;
     IF DD=0 THEN DD:=0.001;
     EE:=ILMINPTI*BB;
     IF EE=0 THEN EE:=0.001;
     FF:=ILMINPTJ*BB;
     IF FF=0 THEN FF:=0.001;
     ANGOFMIN:=ARCTAN(ILMINPTJ*BB/HM);
     ANGOFMAX:=ARCTAN(ILMAXPTJ*BB/HM);

     MINDISCREP[SH,TIMES]:=PTMINDIF;
     MAXDISCREP[SH,TIMES]:=PTMAXDIF;
writeln(g,' ');
WRITELN(G,'SPACING TO HEIGHT RATIO = ',SHR:3:2);
IF OCCASION=2 THEN WRITELN(G,' ');
WRITELN(G,'MAXIMUM ILLUMINANCE =',ilmax:1);
WRITELN(G,'AVERAGE ILLUMINANCE = ',ilav:1);
WRITELN(G,'MINIMUM ILLUMINANCE = ',ilmin:1);
WRITELN(G,'MIN / MAX  U.R     = ',pete[sh,times]:3:2);
WRITELN(G,'MAX / MIN  U.R     = ',ipete[sh,times]:3:2);
WRITELN(G,'MIN / AVG  U.R     = ',master[sh,times]:3.2);
writeln(g,'AVG / MIN  U.R     = ',imaster[sh,times]:3:2);
write(g,'MAX / AVG  U.R     = ',imaxter[sh,times]:3:2);
if occasion=1 then
writeln(g,'      human form and part.(2) perpend. to lumin. axis');
if occasion=2 then
writeln(g,'      human form and part.(2) parallel to lumin. axis');
write(g,'AVG / MAX  U.R     = ',idmaxter[sh,times]:3:2);
if occasion=1 then
writeln(g,'      partition (1) parallel to luminaires axis');
if occasion=2 then begin
writeln(g,'      partition (1) perpendicular to luminaires axis');
writeln(g,' ');
writeln(g,' ');
writeln(g,' ');
writeln(g,' ');
writeln(g,' ');
writeln(g,' ');
end;
IF OCCASION =1 THEN BEGIN
Grid_Illuminance1;
ILLUMINTOT:=0;
FOR J:=0 TO 19 DO BEGIN
FOR I:=0 TO 10 DO BEGIN
ILLUMIN1[I,J]:=0;
END;
END;
FOR J:=0 TO NPP DO BEGIN
FOR I:=0 TO NNP DO BEGIN
ILLUMINI1[I,J]:=0;
PREILLUM1[I,J]:=0;
END;
END;
END;
IF OCCASION=2 THEN BEGIN
Gd_Illu2;
ILLUMINTOT:=0;
FOR J:=0 TO 10 DO BEGIN
FOR I:=0 TO 19 DO BEGIN
ILLUMIN2[I,J]:=0;
END;
END;
```

```
FOR J:=0 TO NPP DO BEGIN
FOR I:=0 TO NNP DO BEGIN
ILLUMINI2[I,J]:=0;
PREILLUM2[I,J]:=0;
END;
END;
END;
END;{shr}
END;{TIMES}
END;{PROCEDURE CONTROL}


PROCEDURE MAST;
VAR STAN,K,I,BROK:INTEGER;
YVAL:REAL;
BEGIN
REWRITE(G);
RESET(LUMDATA);
READLN(LUMDATA,DUMMY1);
READLN(LUMDATA,DUMMY2,LUMTYPE);
READLN(LUMDATA,LUMLEN,LUMWIDTH,DUMMY3,DUMM
Y4,NUMLAMP);
    INDB;
    INDE;
    CONTROL;
END;

BEGIN
MAST;
    END.
```

Appendix C: Computer analysis program used in the illuminance simulation

This appendix includes the listing of the analysis program together with the execution and input files. The execution file contains some commands which link the user to some softwares which were necessary to access at the time when the program was run. For future use, the use of the commands in lines 2 to 9 should be checked with the computer laboratory advisory before running the program.

C1: Execution file for running the program.

```
&TRACE ON
CP LINK $SOFT 22D 500 RR
ACCESS 500 D
CP LINK $SOFT 2E7 501 RR
ACCESS 501 C
CP LINK $SOFT 23C 502 RR
ACCESS 502 F
CP LINK $SOFT 206 503 RR
ACCESS 503 E
EXEC VSPASCAL LIGHTING (MARGIN(1,100
GLOBAL TXTLIB PASCALVS VSF2FORT GINOFD GINSATTD GLIB
GLOBAL LOADLIB VSF2LOAD
FI OBINFO DISK OBSLH1H6 DATA
FI RMINFO DISK RINL6AH3 DATA
FI CEILINFO DISK CEILINFO DATA
FI LUMDATA DISK MOORCOMP LUMDATA
FI G DISK LH1H2503 TABLES
FI 8 DISK LH1H2503 CONTOUR
FI MANPOSLUM DISK MANUAL LUMPOSDA
FI MANLUM1 DISK MANP6MRL DATA
FI MANLUM2 DISK MANP6MRL DATA
LOAD LIGHTING (NOMAP CLEAR START
&EXIT
```

C2: Example of an obstruction file

```
48 0.5
0.60 0.60 1.25 2 0.70 0.90 0.3      1
0.48 0.40 1.05 2 2.11 0.60 0.4      2
0.16 0.20 1.23 2 2.27 0.70 0.3      3
0.03 1.50 2.00 2 3.40 0.90 0.6      4
0.60 0.60 1.25 2 4.70 0.90 0.3      5
0.48 0.40 1.05 2 6.11 0.60 0.4      6
0.16 0.20 1.23 2 6.27 0.70 0.3      7
0.03 1.50 2.00 2 7.40 0.90 0.6      8
0.60 0.60 1.25 2 8.70 0.90 0.3      9
0.48 0.40 1.05 2 10.11 0.60 0.4     10
0.16 0.20 1.23 2 10.27 0.70 0.3     11
0.03 1.50 2.00 2 11.40 0.90 0.6     12
0.60 0.60 1.25 2 12.70 0.90 0.3     13
0.48 0.40 1.05 2 14.11 0.60 0.4     14
0.16 0.20 1.23 2 14.27 0.70 0.3     15
0.03 1.50 2.00 2 15.40 0.90 0.6     16
0.60 0.60 1.25 2 0.70 3.90 0.3      17
0.48 0.40 1.05 2 2.11 3.60 0.4      18
0.16 0.20 1.23 2 2.27 3.70 0.3      19
0.03 1.50 2.00 2 3.40 3.90 0.6      20
0.60 0.60 1.25 2 4.70 3.90 0.3      21
0.48 0.40 1.05 2 6.11 3.60 0.4      22
0.16 0.20 1.23 2 6.27 3.70 0.3      23
0.03 1.50 2.00 2 7.40 3.90 0.6      24
0.60 0.60 1.25 2 8.70 3.90 0.3      25
0.48 0.40 1.05 2 10.11 3.60 0.4     26
0.16 0.20 1.23 2 10.27 3.70 0.3     27
0.03 1.50 2.00 2 11.40 3.90 0.6     28
0.60 0.60 1.25 2 12.70 3.90 0.3     29
0.48 0.40 1.05 2 14.11 3.60 0.4     30
0.16 0.20 1.23 2 14.27 3.70 0.3     31
0.03 1.50 2.00 2 15.40 3.90 0.6     32
0.60 0.60 1.25 2 0.70 6.90 0.3      33
0.48 0.40 1.05 2 2.11 6.60 0.4      34
0.16 0.20 1.23 2 2.27 6.70 0.3      35
0.03 1.50 2.00 2 3.40 6.90 0.6      36
0.60 0.60 1.25 2 4.70 6.90 0.3      37
0.48 0.40 1.05 2 6.11 6.60 0.4      38
0.16 0.20 1.23 2 6.27 6.70 0.3      39
0.03 1.50 2.00 2 7.40 6.90 0.6      40
0.60 0.60 1.25 2 8.70 6.90 0.3      41
0.48 0.40 1.05 2 10.11 6.60 0.4     42
0.16 0.20 1.23 2 10.27 6.70 0.3     43
0.03 1.50 2.00 2 11.40 6.90 0.6     44
0.60 0.60 1.25 2 12.70 6.90 0.3     45
0.48 0.40 1.05 2 14.11 6.60 0.4     46
0.16 0.20 1.23 2 14.27 6.70 0.3     47
0.03 1.50 2.00 2 15.40 6.90 0.6     48
0
```

Line 1: Number of obstructions in the room and discretization of obstruction surfaces.

Each subsequent line:

Obstruction length.

Obstruction width.

Obstruction height.

Position indicator; 1 for centre and 2 for lower left corner of obstruction.

Distance from origin in X direction.

Distance from origin in Y direction.

Reflection factor of obstruction.

Obstruction number.

Last line: Number of perimeter obstructions.

C3: Room data files

C3.a: general room data file

0.75 16 9 3.05 0.7 0.5 0.5 0.5 0.5 0.2 0.47 1.00 1.00 1.17 1.17 500 0.8
1 1 0 0 16 9 1 3

Order of above numbers:

Line 1:

1	: Working plane height
2	: Room length
3	: Room width
4	: Room height
5	: Ceiling reflectance
6 TO 9	: Wall reflection factors
10	: Floor reflection factor
11	: Utilisation factor
12	: SHRNOM for parallel orientation
13	: SHRNOM for perpendicular orientation
14	: SHRMAX for parallel orientation
15	: SHRMAX for perpendicular orientation
16	: Required average illuminance over the working plane
17	: Maintenance factor for the installation

Line 2:

1 : Discretization of the ceiling surface
2 : Discretization of the working plane
3 : Illuminance grid starting point in the X direction
4 : Illuminance grid starting point in the Y direction
5 : Illuminance grid end point in the X direction
6 : Illuminance grid end point in the Y direction
7 : Discretization of the room walls surfaces
8 : Number of isolux contours required for the graphic output

C3.b: Ceiling file

0.05 10 10

The first number: Distance from ceiling to luminaire.
Second and third: Number of points in each direction averaged to before the illuminance is calculated (range 2 - 20).

C3.c: Luminaire positioning file

1 1

Any number other than 1 means that the luminaires are automatically positioned.

C3.d: Luminaire number and position

```
12 6
0.66 0.75 2.00 0.75 3.33 0.75 4.66 0.75 6.00 0.75 7.33 0.75
8.66 0.75 10.00 0.75 11.33 0.75 12.66 0.75 14.00 0.75 15.33 0.75
0.66 2.25 2.00 2.25 3.33 2.25 4.66 2.25 6.00 2.25 7.33 2.25
8.66 2.25 10.00 2.25 11.33 2.25 12.66 2.25 14.00 2.25 15.33 2.25
0.66 3.75 2.00 3.75 3.33 3.75 4.66 3.75 6.00 3.75 7.33 3.75
8.66 3.75 10.00 3.75 11.33 3.75 12.66 3.75 14.00 3.75 15.33 3.75
0.66 5.25 2.00 5.25 3.33 5.25 4.66 5.25 6.00 5.25 7.33 5.25
8.66 5.25 10.00 5.25 11.33 5.25 12.66 5.25 14.00 5.25 15.33 5.25
0.66 6.75 2.00 6.75 3.33 6.75 4.66 6.75 6.00 6.75 7.33 6.75
8.66 6.75 10.00 6.75 11.33 6.75 12.66 6.75 14.00 6.75 15.33 6.75
0.66 8.25 2.00 8.25 3.33 8.25 4.66 8.25 6.00 8.25 7.33 8.25
8.66 8.25 10.00 8.25 11.33 8.25 12.66 8.25 14.00 8.25 15.33 8.25
```

Line 1: Number of luminaires in both X and Y directions respectively.
Subsequent lines: Pairs of (x,y) coordinates for each of the luminaires.

C4: Intensity distribution file

2650
1 1
0.38 0.38 3 3
135 135 132 128 123 118 113 108 101 94 88 83 76 68 62 56 48 39 31
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
135 135 131 127 122 116 113 109 105 101 96 91 84 77 67 58 51 44 34
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
135 135 130 126 122 118 113 108 104 100 95 90 84 77 68 60 51 42 33
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
135 135 131 127 121 114 111 107 102 97 93 88 82 76 68 61 51 42 32
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
135 135 130 126 122 118 113 108 104 100 95 90 84 77 68 60 51 42 33
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
135 135 131 127 122 116 113 109 105 101 96 91 84 77 67 58 51 44 34
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
135 135 132 128 123 118 113 108 101 94 88 83 76 68 62 56 48 39 31
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
135 135 131 127 122 116 113 109 105 101 96 91 84 77 67 58 51 44 34
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
135 135 130 126 122 118 113 108 104 100 95 90 84 77 68 60 51 42 33
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
135 135 131 127 121 114 111 107 102 97 93 88 82 76 68 61 51 42 32
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
135 135 130 126 122 118 113 108 104 100 95 90 84 77 68 60 51 42 33
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
135 135 131 127 121 114 111 107 102 97 93 88 82 76 68 61 51 42 32
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
0.508

C5: Listing of the program

```
PROGRAM
DESIGN(G,OBINFO,RMINFO,LUMDATA,MANPOSLUM,
        CEILINFO,MANLUM1,MANLUM2);

CONST PI=3.141592654;
 NBRLUMLEN=25; {*MAXIMUM NUMBER OF LUMINAIRES
IN LENGTH (X-DIR)*}
 NBRLUMWID=25; {*MAXIMUM NUMBER OF LUMINAIRES
IN WIDTH (Y-DIR)*}
 MAXSECT=10; {*MAXIMUM NUMBER OF SECTIONS
ALONG THE LUMINAIRE*}
 N=48; {*NUMBER OF OBSTRUCTIONS USED INSIDE THE
ROOM*}
LUMSECT=5;  {*ACTUAL NUMBER OF SECTIONS PER
LUMINAIRE USED*}
 LENGTHMAX=25; {*MAXIMUM LENGTH OF ROOM TO BE
USED IN PROGRAM*}
WIDTHMAX=25; {*MAXIMUM WIDTH OF ROOM TO BE
USED IN PROGRAM*}
XMAX=208;
 XXMAX=220;
XXLIMIT=16;
YYLIMIT=9;


TYPE  AA=ARRAY[1..N,1..5,1..3,1..3] OF REAL;

BAA=ARRAY[1..NBRLUMLEN,1..NBRLUMWID,0..MAXSECT,1
..N,1..3] OF INTEGER;
 BA=ARRAY[1..N,1..5,0..LENGTHMAX,0..WIDTHMAX] OF
REAL;
 BB=ARRAY[1 N,1..5,1..6] OF REAL;
 CC=ARRAY[1 .6,1..6] OF REAL;
CB=ARRAY[1..NBRLUMLEN,1..NBRLUMWID,1..2,0..MAXSEC
T] OF REAL;
BBC=ARRAY[1..XMAX,1..3,1..2] OF REAL;
BBBC=ARRAY[1..XMAX,1..3,1..2] OF REAL;
CCC=ARRAY[1..3] OF REAL;
VCCC=ARRAY[1..4] OF INTEGER;
OBREF=ARRAY[1..N] OF REAL;
DD=ARRAY[1..7,1..21,1..21] OF REAL;
TDD=ARRAY[3 .4,1..4,0..LENGTHMAX,0..WIDTHMAX] OF
REAL;
WTDD=ARRAY[1 .5,1..3,1..2] OF REAL;
YD=ARRAY[0..36,0..12] OF REAL;
 LLLL=ARRAY[0..36,0..3] OF REAL;
YYDD=ARRAY[0 .36,0..8] OF REAL;
PPPP=ARRAY[0..36] OF REAL;
YY=ARRAY[1..21] OF REAL;
 YYYY=ARRAY[1..N,1..5,1..2] OF REAL;
YYY=ARRAY[1..10,1..LENGTHMAX,1..WIDTHMAX] OF
REAL;
MYY=ARRAY[1..4,1..WIDTHMAX,1..LENGTHMAX] OF REAL;
 TTYY=ARRAY[0 .LENGTHMAX,0..WIDTHMAX] OF REAL;
TAA=ARRAY[1..6,1..2] OF REAL;
 VQCC=ARRAY[1..4] OF REAL;
CAA=ARRAY[1..XMAX] OF REAL;
CCAA=ARRAY[1..4,1..2] OF INTEGER;
TTY=ARRAY[1..XXMAX] OF REAL;


VAR A:AA; {THE ARRAY OF THE 3 POINTS PER SURFACE
OF THE OBSTRUCTION}
TURNEDIL:MYY; {THE TURNED WORKING PLANE
ILLUMINANCE VALUES}
REFLECT:TTY; {ARRAY OF THE REFLECTION FACTORS OF
THE INDIVIDUAL ELEMENTS
        UNDER CONSIDERATION}
RMSPLITINFO:CCAA; {HOLDS THE INFO ON HOW MANY
ELEMENTS/RMSURF}
ELEMITAV.CAA;
ENDIL:VQCC; {THE CEILING GRID LUMINAIRE
ILLUMINANCES}
ILQUAD:VQCC; {THE CEILING GRID LUMINAIRE
ILLUMINANCES}
GENINTELE:BBBC; {LIMITS OF EACH INTERREFLECTION
ELEMENT SURFACE }
BIGCEILGRID:TTYY; {THE ILLUMINANCES OVER WHOLE
CEILING}
ACRMSURFDISCRE:TAA; {THE DISCRETIZATION OF THE
ROOM SIDES}
{1..4 ARE THE WALLS , 5 IS THE WORKING PLANE, 6 IS
THE CEILING }
ACOBDISCRE:YYYY; {OBNUMBER,
SURACENUMBER,HORIZONTAL
 DISCRETIZATION, VERTICAL DISCRETIZATION }
OBREFLECT:OBREF;{REFLECTION FACTORS OF EACH
OBSTRUCTION}
OBILUM:BA; {1 TO 8 OBSTRUCTIONS WITH 5 SURFACES
EACH WITH A
 MAX ILLUMINANCE GRID OF 40 BY 40 OVER THEM}
DIRCOS:BB; { DIRECTION COSINES OF EVERY SURFACE
OF EVERY OBSTRUCTION}
LUMPOS:CB; {THE POSITION OF EACH LUMINAIRE
SECTION}
WALLILLUM:TDD;
RW:VQCC; {THE WALL REFLECTION FACTOR ARRAY}
OBLIMITS:BBC;
XNMPT:VCCC;  {NUMBER OF POINTS IN X DIRECTION
FOR WALLS 1..4}
YNMPT:VCCC;  {NUMBER OF POINTS IN Y DIRECTION
FOR WALLS 1..4}
RMDIRCOS:CC;
LNVCTCOS:CCC;
LUMOBDETAILS:BAA; {LUMOBDETAILS: LUMINAIRE
NUMBER IN X DIRECTION ;
LUMINAIRE NUMBER IN Y DIRECTION (WIDTH) ;
SECTION OF LUMINAIRE; OBSTRUCTION NUMBER ;
SIDENUMBER ABLE TO "SEE" }
TNTS:YD;
TTTS:LLLL;
INTS:YYDD;
IIIS:PPPP;
R:YY;
C:YY;
GDILUM:YYY; {GRID OF ILLUMINANCE CALC POINTS}
BGILMPLN:DD; {SURFACENUMBER 1 IS THE FLOOR, 2,3,4
& 5 ARE THE WALLS}
   {6 IS THE GENERAL CEILING ILLUMINANCES & 7
AROUND LUMINAIRES}
RMLIMITS:WTDD;
G,OBINFO,MANPOSLUM,RMINFO:TEXT;
CEILINFO,MANLUM1,MANLUM2:TEXT;
LUMDATA:TEXT; {THE LUMINAIRE INTENSITY
DISTRIBUTION}
{UTILFACT:TEXT; THE LUMINAIRES UTILISATION
FACTOR TABLE}
LUMINTTYPE,LAMPFIGGUIDE,II,JJ,RCFACT,RWFACT:INTEG
ER;
RC,RWW,RF, {SURFACE REFLECTION FACTORS}
XSTARTPT,YSTARTPT,HEIGHT,LENGTH,WIDTH,ACWIDTH,A
CLENGTH:REAL; {ROOM DIMENSIONS}
XENDPT,YENDPT,PROPOBDIS,STARTPTX,STARTPTY,
MULTFACT,CEILGRIDISCTIZATION,UF:REAL;
CEILDISCRE,XTOLOTOCOUNT,YTOLOTOCOUNT,XLUMCEN
T,YLUMCENT,WKPLNHT,
ILUMTOT,ILLUMREQ,XMEASPOINT,YMEASPOINT,SHRMAX
1,SHRNOM1,PTILUMTOT:REAL;
SHRMAX2,SHRNOM2,SHRNOM,SHRMAX,ST1:REAL;
NNPTAVCEIL,MMPTAVCEIL,CEILDIVISIONS,TOTELEMENT
NUM,NUMLAMP,TELLTALE,
OBNUM,CEILXNUMPT,CEILYNUMPT,XNUMPT,YNUMPT,NO
OBEFFECT,NCEILPT,MCEILPT,
NUMWRIT,STOBNUM,WRITNUM,DIRLUMLEN,PTORLINLUM
,STTOTELEMENTNUM,LUMSPLIT,TIMETHRU,
NOSEE,STRSIDENUMBER,I,J,RMSURFACE,WIDNUMALONG,
LENNUMALONG,LUMTYPE:INTEGER;
GOODPOINTS,CEILAV,LAMPOUTPUT,WALLDISCRE,EMITAR
EA,SMEMITAREA,LAREMITAREA,
DLOR,LUMWID,CEILONEQUADILUMTOT,LUMLEN,CEILTO
LUMHT,HM,PINTX,PINTY:REAL;
WKPLNDISCRE,XWKPLNDISCRE,YWKPLNDISCRE,SPECIALI
LMIN,SPECIALILMAX,SPECIALILAV:REAL;
BADCOUNT,BECAUSEDIRECTCASE,PERIMOBNUM,NUCONT,
NBLAMP,POSALL:INTEGER;
ON:STRING(2);
OFF:STRING(3);

PROCEDURE INITVS;FORTRAN;
PROCEDURE GINO;FORTRAN;
PROCEDURE DEVPAP(CONST Z1,Z2:REAL;
        CONST Z3:INTEGER);FORTRAN;
PROCEDURE WINDO2(CONST
XMIN,XMAX,YMIN,YMAX:REAL);FORTRAN;
PROCEDURE SAVDRA;FORTRAN;
PROCEDURE DEVEND;FORTRAN;
PROCEDURE PICCLE;FORTRAN;
PROCEDURE PICEND;FORTRAN;
PROCEDURE GINEND;FORTRAN;
PROCEDURE ENDVS;FORTRAN;

PROCEDURE DRAWOUTGRIDS;
VAR MINTOMAX,AVTOMIN,WLREF:REAL;


PROCEDURE SETFRA(CONST FR:INTEGER);FORTRAN;
PROCEDURE SETSCA(CONST XINC,YINC:REAL;VAR
DIFSCALE:STRING);FORTRAN;
PROCEDURE CHASIZ(CONST
WIDTH,HEIGHT:REAL);FORTRAN;
PROCEDURE AXIPOS(CONST IOR :INTEGER;
        CONST XXR,YYR,AXLEN :REAL;
        CONST XORY : INTEGER);FORTRAN;
PROCEDURE PICBEG(CONST BER:INTEGER);FORTRAN;
```

```
PROCEDURE CHAHOL(CONST STNG:STRING);FORTRAN;
PROCEDURE CHAFIX(VAR NUMBER:REAL;
        CONST WIDTH,PLACES:INTEGER);FORTRAN;
PROCEDURE MOVTO2(CONST SHR,MINAV:REAL);FORTRAN;
PROCEDURE MOVBY2(CONST X,Y:REAL);FORTRAN;
PROCEDURE LINTO2(CONST SHR,MINAV:REAL);FORTRAN;
PROCEDURE LINBY2(CONST X,Y:REAL);FORTRAN;
PROCEDURE CONSPA(CONST X,Y:REAL; VAR
XS,YS:REAL);FORTRAN;
PROCEDURE SPACON(CONST X,Y:REAL; VAR
XS,YS:REAL);FORTRAN;


PROCEDURE LUMDRAW1;

VAR II,JJ:INTEGER;
ACXS,ACYT,XX,YY,X,Y,XXS,YYS,XS,YS,S,T,SS,TT:REAL;
BEGIN
FOR II:=1 TO LENNUMALONG DO BEGIN    { FOR EVERY
LUMINAIRE }
FOR JJ:=1 TO WIDNUMALONG DO BEGIN   { IN THE ROOM
 }
{USE THE SECTION OF LUMINAIRE SET AS THE CENTRE
TO REPRESENT IT}
X:=LUMPOS[II,JJ,1,0];
Y:=LUMPOS[II,JJ,2,0];
X:=X+LUMLEN/2;
Y:=Y+LUMWID/2;  {HALF OF LUMINAIRE WIDTH}
CONSPA(X,Y,XS,YS);
MOVTO2(XS,YS);
X:=X-LUMLEN;
CONSPA(X,Y,XS,YS);
LINTO2(XS,YS);
Y:=Y-LUMWID;
CONSPA(X,Y,XS,YS);
LINTO2(XS,YS);
X:=X+LUMLEN;
CONSPA(X,Y,XS,YS);
LINTO2(XS,YS);
Y:=Y+LUMWID;
CONSPA(X,Y,XS,YS);
LINTO2(XS,YS);
Y:=Y-LUMWID/2;
CONSPA(X,Y,XS,YS);
MOVTO2(XS,YS);
X:=X-LUMLEN;
CONSPA(X,Y,XS,YS);
LINTO2(XS,YS);
END;  {NEXT LUMINAIRE CENTRE}
END;  {NEXT LUMINAIRE ROW. }
END;  {PROCEDURE LUMDRAW}


PROCEDURE LUMDRAW2;
VAR II,JJ:INTEGER;
ACXS,ACYT,XX,YY,X,Y,XXS,YYS,XS,YS,S,T,SS,TT:REAL;
BEGIN
FOR II:=1 TO LENNUMALONG DO BEGIN    { FOR EVERY
LUMINAIRE }
FOR JJ:=1 TO WIDNUMALONG DO BEGIN   { IN THE ROOM
}
{USE THE SECTION OF LUMINAIRE SET AS THE CENTRE
TO REPRESENT IT}
Y:=LUMPOS[II,JJ,1,0];  {NOTE THE CHANGE ROUND OF THE
X AND Y      }
X:=LUMPOS[II,JJ,2,0];  {DIRECTIONS SINCE ROOM IS
TURNED BACK ROUND }
Y:=Y+LUMLEN/2;
X:=X+LUMWID/2;  {HALF OF LUMINAIRE WIDTH}
CONSPA(X,Y,XS,YS);
MOVTO2(XS,YS);
Y:=Y-LUMLEN;
CONSPA(X,Y,XS,YS);
LINTO2(XS,YS);
X:=X-LUMWID;
CONSPA(X,Y,XS,YS);
LINTO2(XS,YS);
Y:=Y+LUMLEN;
CONSPA(X,Y,XS,YS);
LINTO2(XS,YS);
X:=X+LUMWID;
CONSPA(X,Y,XS,YS);
LINTO2(XS,YS);
X:=X-LUMWID/2;
CONSPA(X,Y,XS,YS);
MOVTO2(XS,YS);
Y:=Y-LUMLEN;
CONSPA(X,Y,XS,YS);
LINTO2(XS,YS);
END;  {NEXT LUMINAIRE CENTRE}
END;  {NEXT LUMINAIRE ROW. }
END;  {PROCEDURE LUMDRAW}



PROCEDURE OBDRAW;
VAR I,II:INTEGER;
HITE,XS,YS,X,Y:REAL;
BEGIN
FOR I:=1 TO OBNUM DO BEGIN
 II:=I MOD 3;
 IF II>0 THEN BEGIN
X:=OBLIMITS[I,1,1];
Y:=OBLIMITS[I,2,1];
CONSPA(X,Y,XS,YS);
MOVTO2(XS,YS);
X:=OBLIMITS[I,1,2];
Y:=OBLIMITS[I,2,1];
CONSPA(X,Y,XS,YS);
LINTO2(XS,YS);
X:=OBLIMITS[I,1,2];
Y:=OBLIMITS[I,2,2];
CONSPA(X,Y,XS,YS);
LINTO2(XS,YS);
X:=OBLIMITS[I,1,1];
Y:=OBLIMITS[I,2,2];
CONSPA(X,Y,XS,YS);
LINTO2(XS,YS);
X:=OBLIMITS[I,1,1];
Y:=OBLIMITS[I,2,1];
CONSPA(X,Y,XS,YS);
LINTO2(XS,YS);
X:=OBLIMITS[I,1,2];
Y:=OBLIMITS[I,2,2];
CONSPA(X,Y,XS,YS);
LINTO2(XS,YS);
X:=OBLIMITS[I,1,2];
Y:=OBLIMITS[I,2,1];
CONSPA(X,Y,XS,YS);
MOVTO2(XS,YS);
X:=OBLIMITS[I,1,1];
Y:=OBLIMITS[I,2,2];
CONSPA(X,Y,XS,YS);
LINTO2(XS,YS);
X:=(OBLIMITS[I,1,2]+OBLIMITS[I,1,1])/2;
Y:=(OBLIMITS[I,2,2]+OBLIMITS[I,2,1])/2;
CONSPA(X,Y,XS,YS);
MOVTO2(XS,YS-1);
HITE:=OBLIMITS[I,3,2];
CHAFIX(HITE,4,2);
{WRITES OUT THE HEIGHT OF THE OBSTRUCTION AT THE
OB CENTRE}
END;  {I COUNTER OBNUMBER. }
END   {II COUNTER}
END;  {PROCEDURE OBDRAW}


PROCEDURE XTRAINFO;
BEGIN
WINDO2(0,280.0,0,210.0);
MOVTO2(275.0,205.0);
LINTO2(2.0,205.0);
LINTO2(2.0,2.0);
LINTO2(275.0,2.0);
LINTO2(275.0,205.0);
MOVTO2(273.0,203.0);
LINTO2(4.0,203.0);
LINTO2(4.0,4.0);
LINTO2(273.0,4.0);
LINTO2(273.0,203.0);
CHASIZ(3.4,3.4);
MOVTO2(2.0,198.0);
CHAHOL('OBSTRUCTION AND LUMINAIRE LAYOUT
WITH*.');
MOVTO2(2.0,188.0);
CHAHOL('WORKING PLANE ILLUMINANCE CONTOURS*.');
CHASIZ(3.0,3.0);
MOVTO2(5.0,180.0);
IF (LENGTH > 10) AND (LENGTH < 12) AND (WIDTH > 11)
AND (WIDTH < 13) THEN
CHAHOL('BEDFORD HOUSE*.');


IF (LENGTH > 9) AND (LENGTH < 11) AND (WIDTH > 5) AND
(WIDTH < 7) THEN
CHAHOL('GEOLOGY BUILDING ROOM 309*.');


IF (LENGTH > 22) AND (LENGTH < 24) AND (WIDTH > 26)
AND (WIDTH < 28) THEN
CHAHOL('WYTHENSHAW BUILDING*.');
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IF (LENGTH > 30) AND (LENGTH < 32) AND (WIDTH > 5)
AND (WIDTH < 7) THEN
CHAHOL('SUNLIGHT HOUSE*.');
MOVTO2(5.0,152.0);
CHAHOL('ROOM LENGTH =*.');
MOVTO2(58.0,152.0);
CHAFIX(LENGTH,5,2);
MOVTO2(73.0,152.0);
CHAHOL('METRES*.');
MOVTO2(5.0,142.0);
CHAHOL('ROOM WIDTH =*.');
MOVTO2(58.0,142.0);
CHAFIX(WIDTH,5,2);
MOVTO2(73.0,142.0);
CHAHOL('METRES*.');
MOVTO2(5.0,132.0);
CHAHOL('ROOM HEIGHT =*.');
MOVTO2(58.0,132.0);
CHAFIX(HEIGHT,4,2);
MOVTO2(73.0,132.0);
CHAHOL('METRES*.');
MOVTO2(5.0,122.0);
CHAHOL('WORKING PLANE =*.');
MOVTO2(58.0,122.0);
CHAFIX(WKPLNHT,4,2);
MOVTO2(73.0,122.0);
CHAHOL('METRES*.');
MOVTO2(5.0,112.0);
CHAHOL('WALL REFLECTION FACTORS =*.');
WLREF:=RW[1];
MOVTO2(10.0,102.0);
CHAFIX(WLREF,4,2);
WLREF:=RW[2];
MOVTO2(30.0,102.0);
CHAFIX(WLREF,4,2);
WLREF:=RW[3];
MOVTO2(50.0,102.0);
CHAFIX(WLREF,4,2);
WLREF:=RW[4];
MOVTO2(70.0,102.0);
CHAFIX(WLREF,4,2);
MOVTO2(3.0,92.0);
CHAHOL('AVERAGE ILLUMINANCE =*.');
MOVTO2(74.0,92.0);
CHAFIX(SPECIALILAV,5,0);
MOVTO2(3.0,82.0);
CHAHOL('MINIMUM ILLUMINANCE =*.');
MOVTO2(74.0,82.0);
CHAFIX(SPECIALILMIN,5,0);
MOVTO2(3.0,72.0);
CHAHOL('MAXIMUM ILLUMINANCE =*.');
MOVTO2(74.0,72.0);
CHAFIX(SPECIALILMAX,5,0);
AVTOMIN:=SPECIALILMIN/SPECIALILAV;
MOVTO2(3.0,62.0);
CHAHOL('MIN TO AV UNIFORMITY =*.');
MOVTO2(78.0,62.0);
CHAFIX(AVTOMIN,4,2);
MINTOMAX:=SPECIALILMIN/SPECIALILMAX;
MOVTO2(3.0,52.0);
CHAHOL('MIN TO MAX UNIFORMITY =*.');
MOVTO2(78.0,52.0);
CHAFIX(MINTOMAX,4,2);
MOVTO2(3.0,42.0);
CHAHOL('CALCULATED VALUE CONTOURS*.');
MOVTO2(3.0,32.0);
CHAHOL('DESIGN ILLUMINANCE =*.');
MOVTO2(68.0,32.0);
CHAFIX(ILLUMREQ,5,0);
MOVTO2(77.0,32.0);
CHAHOL('LUX*.');
MOVTO2(3.0,22.0);
CHAHOL(' % POINTS ACCEPTABLE =*.');
MOVTO2(77.1,22.0);
CHAFIX(GOODPOINTS,5,1);
MOVTO2(5.0,172.0);
IF (PTORLINLUM = 1) THEN BEGIN
IF LUMTYPE=1 THEN CHAHOL('THORN SYMMETRIC POINT
VOL 1 P7.4 *.');
IF LUMTYPE=2 THEN CHAHOL('CIBSE TM5 SYMPT DATA
FILE*.');
IF LUMTYPE=4 THEN CHAHOL('THORN SYMMETRIC POINT
VOL 1 P8.8 *.');
IF (LUMTYPE < 1) OR (LUMTYPE > 4) THEN
CHAHOL('WHAT KIND OF DISTRIBUTION IS THIS THEN?*.');
END; {IF (PTORLINLUM = 1) }
IF (PTORLINLUM = 2) THEN BEGIN
IF LUMTYPE=1 THEN CHAHOL('THORN SYMMETRIC POINT
VOL 1 P7.4 *.');
IF LUMTYPE=2 THEN CHAHOL('CIBSE TM5 TYPE
LUMINAIRE*.')            ;
IF LUMTYPE=3 THEN CHAHOL('LINEAR BATWING
LUMINAIRE*.')            ;
IF LUMTYPE=4 THEN BEGIN
CHAHOL('OSRAM SPEEDPACK TWIN OPAL*.');
MOVTO2(5.0,162.0);
CHAHOL('PRISMATIC DIFFUSER OSSP260P*.');
END;
IF LUMTYPE=5 THEN CHAHOL('THORN FTRA 2675/FTRE
36*.');
IF LUMTYPE=6 THEN CHAHOL('MOORLIGHT 173B
13RT/W/N/1670*.')        ;
IF LUMTYPE=7 THEN CHAHOL('THORN FTP236
LUMINAIRE*.');
IF LUMTYPE=8 THEN CHAHOL('FO217/P CEILING MOUNT
PRISMATIC*.')            ;
IF (LUMTYPE < 1) OR (LUMTYPE > 8) THEN
CHAHOL('WHAT KIND OF DISTRIBUTION IS THIS THEN?*.');
END; {IF (PTORLINLUM = 2) }
END; {XTRAINFO}


PROCEDURE CONDRAW;

TYPE PY=ARRAY[1..YYLIMIT,1..XXLIMIT] OF REAL;
VAR I,J:INTEGER;
WKILUM:PY;
{THE ARRAY THAT HOLDS THE VALUES OF WORKING
PLANE ILLUMINANCE
TO BE CONTOUR PLOTTED}

PROCEDURE GRDCON(CONST NUMX:INTEGER;
    !       CONST XLOW,XHIGH:REAL;CONST
NUMY:INTEGER;
            CONST YLOW,YHIGH:REAL;VAR Z:PY;
            CONST CONT:INTEGER;
            VAR SMOOTH:STRING);FORTRAN;


BEGIN
FOR I:=1 TO XNUMPT DO BEGIN
FOR J:=1 TO YNUMPT DO BEGIN
WKILUM[J,I]:=GDILUM[10,I,J];
END;
END;
GRDCON(XNUMPT,XSTARTPT,XENDPT,YNUMPT,YSTARTPT,
YENDPT,WKILUM,NUCONT,ON);
 {NOTE VERY VERY CAREFULLY
THAT THE ARRAY WKILUM SPECIFIED ABOVE MUST ALSO
EXPECT THE FIRST NUMBER OF POINTS
FROM THE SECOND NUMBER TO THE THIRD NUMBER IN
TERMS OF DISTANCE OF THE ROOM.
THIS ALSO APPLIES TO THE FOURTH FIFTH AND SIXTH
NUMBERS.   !!!!!!!!!!!!!!!!!!!!}
END; {PROCEDURE CONDRAW1}


BEGIN
PICCLE;
PICBEG(TIMETHRU);
WINDO2(80,279.0,5,135.0);
CHASIZ(2.0,2.0);
SETFRA(1);
SETSCA(1,1,ON);
CONDRAW;
IF TIMETHRU=1 THEN LUMDRAW1;
IF TIMETHRU=2 THEN LUMDRAW2;
OBDRAW;
XTRAINFO;
PICEND;
END;   {PROCEDURE DRAWOUTGRIDS}




PROCEDURE ILGRIDWRIT;
{WRITES OUT THE GRID OF ILLUMINANCES OVER THE
WORKING PLANE}

VAR MM,Z,N,M,K,AA,BB,I,J,ZEROCOUNT:INTEGER;
ILMAX,ILMIN,ILAV,TOTILUM:REAL;
BEGIN
BADCOUNT:=0;
IF WRITNUM=1 THEN
WRITELN(G,'WORKING PLANE ILLUMINANCE GRID FOR
THE UNOBSTRUCTED DIRECT COMPONENT ONLY.');
IF WRITNUM=2 THEN
WRITELN(G,'WORKING PLANE ILLUMINANCE GRID FOR
THE OBSTRUCTED DIRECT COMPONENT ONLY.');
IF WRITNUM=3 THEN BEGIN
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WRITELN(G,'WORKING PLANE ILLUMINANCE GRID FOR
THE COMBINED DIRECT AND INDIRECT');
WRITELN(G,'COMPONENTS WITH NO OBSTRUCTIONS, ');
END;
IF WRITNUM=4 THEN BEGIN
WRITELN(G,'WORKING PLANE ILLUMINANCE GRID FOR
THE COMBINED DIRECT AND INDIRECT');
WRITELN(G,'COMPONENTS WITH THE OBSTRUCTIONS
DETAILED ABOVE. ');
END;
IF WRITNUM=5 THEN BEGIN
WRITELN(G,'DIFFERENCE BETWEEN OBSTRUCTED AND
UNOBSTRUCTED FOR ');
WRITELN(G,'DIRECT WORKING PLANE ILLUMINANCE.');
END;
IF WRITNUM=6 THEN BEGIN
WRITELN(G,'DIFFERENCE BETWEEN OBSTRUCTED AND
UNOBSTRUCTED');
WRITELN(G,'FOR TOTAL WORKING PLANE
ILLUMINANCE.');
END;
IF WRITNUM=7 THEN WRITELN(G,'THE INDIRECT
COMPONENT FOR THE UNOBSTRUCTED CASE. ');
IF WRITNUM=8 THEN WRITELN(G,'THE INDIRECT
COMPONENT FOR THE OBSTRUCTED CASE. ');
IF WRITNUM=9 THEN BEGIN
WRITELN(G,'THE SHORTFALL IF ANY IN THE TOTAL
ILLUMINANCE AT THE POINTS');
WRITELN(G,'ON THE WORKING PLANE GRID FROM THE
DESIGN ILLUMINANCE. ');
END;
IF WRITNUM=10 THEN WRITELN(G,'THE ILLUMINANCE
GRID PASSED TO THE DRAWING PROCEDURE.');
ILMIN:=9999;
ILMAX:=0;
ZEROCOUNT:=0;
TOTILUM:=0;
M:=XNUMPT;
N:=YNUMPT;
K:=1;
MM:=TRUNC(XNUMPT/19)+1;
FOR Z:=1 TO MM DO BEGIN
WRITELN(G);
WRITELN(G);
AA:=K;
BB:=K+19;
IF BB > XNUMPT THEN BB:=XNUMPT;
K:=BB+1;
FOR J:=N DOWNTO 1 DO
BEGIN
WRITELN(G);
FOR I:=AA TO BB DO BEGIN
WRITE(G,GDILUM[WRITNUM,I,J]:4:0,' ');
IF GDILUM[WRITNUM,I,J] > ILMAX THEN
ILMAX:=GDILUM[WRITNUM,I,J];
IF GDILUM[WRITNUM,I,J] < ILMIN THEN BEGIN
IF GDILUM[WRITNUM,I,J] > 0 THEN
ILMIN:=GDILUM[WRITNUM,I,J];
IF GDILUM[WRITNUM,I,J] = 0 THEN
ZEROCOUNT:=ZEROCOUNT+1;
END;
IF (WRITNUM=9) AND (GDILUM[WRITNUM,I,J] > 1) THEN
BADCOUNT:=BADCOUNT+1;
TOTILUM:=GDILUM[WRITNUM,I,J]+TOTILUM;
IF I=BB THEN WRITELN(G);
END {I COUNTER}
END {J COUNTER}
END; {OVERALL Z COUNTER}
ILAV:=TOTILUM/((XNUMPT*YNUMPT)-ZEROCOUNT);
WRITELN(G);
WRITELN(G);
WRITELN(G,'Y DIRECTION');
WRITELN(G,'1');
WRITELN(G,'1');
WRITELN(G,'1');
WRITELN(G,'------>X DIRECTION');
WRITELN(G);
IF WRITNUM=4 THEN BEGIN
SPECIALILAV:=ILAV;
SPECIALILMAX:=ILMAX;
SPECIALILMIN:=ILMIN;
END; {THESE SPECIAL VALUES ARE OUTPUT ON THE
CONTOUR PLOT}
IF (WRITNUM=9) THEN BEGIN
GOODPOINTS:=100-
((BADCOUNT*100)/(XNUMPT*YNUMPT));
WRITELN(G,'AVERAGE OBSTRUCTION CAUSED
REDUCTION FROM DESIGN ILLUMINANCE ',ILAV:4:0);
WRITELN(G);
WRITELN(G,'MINIMUM OBSTRUCTION CAUSED
REDUCTION FROM DESIGN ILLUMINANCE ',ILMIN:4:0);
WRITELN(G);
WRITELN(G,'MAXIMUM OBSTRUCTION CAUSED
REDUCTION FROM DESIGN ILLUMINANCE ',ILMAX:4:0);
WRITELN(G);
WRITELN(G,'THE PERCENTAGE OF CALCULATION POINTS
SATISFYING THE DESIGN');
WRITELN(G,'ILLUMINANCE OF ',ILLUMREQ:3:0,' LUX IS
',GOODPOINTS:3:2,' %');
WRITELN(G);
END
ELSE IF (WRITNUM=5) OR (WRITNUM=6) THEN BEGIN
WRITELN(G,'AVERAGE OBSTRUCTION CAUSED
REDUCTION IN ILLUMINANCE EQUALS ',ILAV:4:0);
WRITELN(G);
WRITELN(G,'MINIMUM OBSTRUCTION CAUSED
REDUCTION IN ILLUMINANCE EQUALS ',ILMIN:4:0);
WRITELN(G);
WRITELN(G,'MAXIMUM OBSTRUCTION CAUSED
REDUCTION IN ILLUMINANCE EQUALS ',ILMAX:4:0);
WRITELN(G);
END
ELSE BEGIN WRITELN(G);
WRITE(G,'AVERAGE ILLUMINANCE EQUALS ',ILAV:4:0);
WRITELN(G,' LUX');
WRITELN(G);
WRITE(G,'MINIMUM ILLUMINANCE EQUALS ',ILMIN:4:0);
WRITELN(G,' LUX');
WRITELN(G);
WRITE(G,'MAXIMUM ILLUMINANCE EQUALS ',ILMAX:4:0);
WRITELN(G,' LUX');
WRITELN(G);
WRITELN(G,'MIN TO AVERAGE UNIFORMITY
=',ILMIN/ILAV:4:3);
WRITELN(G);
WRITELN(G,'MIN TO MAX UNIFORMITY
=',ILMIN/ILMAX:4:3);
WRITELN(G);
END;
WRITELN(G);
WRITELN(G);
WRITELN(G);
WRITELN(G);
END; {PROCEDURE ILGRIDWRIT}


PROCEDURE OUTPUTURN;
VAR ACJ,K,I,J:INTEGER;

BEGIN
FOR K:=1 TO 4 DO BEGIN
FOR I:=1 TO XNUMPT DO BEGIN {NOTE THAT XNUMPT
AND YNUMPT ARE ALL READY TURNED}
WRITELN(G);
FOR J:=1 TO YNUMPT DO BEGIN
TURNEDIL[K,J,I]:=GDILUM[K,J,I]; {COPY THE GRID}
END {J COUNTER}
END; {I COUNTER}
ACJ:=YNUMPT;
FOR J:=1 TO YNUMPT DO BEGIN
FOR I:=1 TO XNUMPT DO BEGIN
GDILUM[K,I,J]:=TURNEDIL[K,ACJ,I];
END; {I COUNTER, XNUMPT}
ACJ:=ACJ-1;
END; {J COUNTER , YNUMPT }
END; {K COUNTER}
END; {PROCEDURE OUTPUTURN}


PROCEDURE QUICKWRITE;
VAR I,J,K:INTEGER;
BEGIN
WRITELN(G);
FOR K:=1 TO 10 DO BEGIN
WRITELN(G);
WRITELN(G);
WRITELN(G,'ILLUMINANCE GRID NUMBER ',K);
WRITELN(G);
FOR I:=1 TO XNUMPT DO BEGIN
WRITELN(G);
FOR J:=1 TO YNUMPT DO BEGIN
WRITE(G,GDILUM[K,I,J]:4:0,' ');
END; {J COUNTER}
WRITELN(G);
END {I COUNTER}
END {K COUNTER}
END; {PROCEDURE QUICKWRITE}


PROCEDURE WALLGRIDWRIT;
{WRITES OUT THE GRID OF THE ILLUMINANCES OVER
EACH OF THE FOUR ROOM
WALL SURFACES }
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VAR
RMSURFACE,MM,Z,K,AA,BB,I,J,N,M,ZEROCOUNT:INTEGER;
ILMAX,ILMIN,ILAV,TOTILUM:REAL;
BEGIN
FOR RMSURFACE:=1 TO 4 DO BEGIN
WRITELN(G);
WRITELN(G,'ROOM WALL NUMBER = ',RMSURFACE:2);
ILMIN:=9999;
ILMAX:=0;
ZEROCOUNT:=0;
TOTILUM:=0;
N:=XNMPT[RMSURFACE];
M:=YNMPT[RMSURFACE];
K:=0;
MM:=TRUNC(M/10)+1;
FOR Z:=1 TO MM DO BEGIN
WRITELN(G);
WRITELN(G);
AA:=K;
BB:=K+9;
IF BB > M THEN BB:=M;
K:=K+10;
FOR I:=0 TO N DO
BEGIN
WRITELN(G);
FOR J:=AA TO BB DO BEGIN
WRITE(G,WALLILLUM[WRITNUM,RMSURFACE,I,J]:4:0,' ');
IF (WALLILLUM[WRITNUM,RMSURFACE,I,J]>ILMAX) THEN
ILMAX:=WALLILLUM[WRITNUM,RMSURFACE,I,J];
IF WALLILLUM[WRITNUM,RMSURFACE,I,J] < ILMIN THEN
BEGIN
IF WALLILLUM[WRITNUM,RMSURFACE,I,J]>0 THEN
ILMIN:=WALLILLUM[WRITNUM,RMSURFACE,I,J];
IF WALLILLUM[WRITNUM,RMSURFACE,I,J] = 0 THEN
ZEROCOUNT:=ZEROCOUNT+1;
END;
TOTILUM:=WALLILLUM[WRITNUM,RMSURFACE,I,J]+TOTIL
UM;
IF J=BB THEN WRITELN(G);
END {J COUNTER}
END {I COUNTER}
END, {OVERALL Z COUNTER}
IF (TOTILUM > 0.1) THEN BEGIN
ILAV:=TOTILUM/(((N+1)*(M+1))-ZEROCOUNT);
END,
WRITELN(G);
WRITELN(G),
WRITELN(G,'AVERAGE ILLUMINANCE EQUALS ',ILAV:4:0);
WRITELN(G);
WRITELN(G,'MINIMUM ILLUMINANCE EQUALS
',ILMIN:4.0);
WRITELN(G);
WRITELN(G,'MAXIMUM ILLUMINANCE EQUALS
',ILMAX:4 0);
WRITELN(G);
IF (ILMIN < 0 001) OR (ILMAX < 0.001) OR (ILAV < 0.001)
THEN BEGIN
WRITELN(G,'MIN TO AVERAGE UNIFORMITY =',0);
WRITELN(G);
WRITELN(G,'MIN TO MAX UNIFORMITY =',0);
WRITELN(G);
END
ELSE BEGIN
WRITELN(G,'MIN TO AVERAGE UNIFORMITY
=',ILMIN/ILAV:4:3);
WRITELN(G);
WRITELN(G,'MIN TO MAX UNIFORMITY
=',ILMIN/ILMAX:4:3);
WRITELN(G);
END;
WRITELN(G);
END {EACH WALL SURFACE}
END; {PROCEDURE WALLGRIDWRIT}


PROCEDURE CEILGDWRITOUT;
{WRITES OUT THE GRID OF ILLUMINANCES OVER THE
CEILING PLANE}

VAR MM,Z,N,M,K,AA,BB,I,J,ZEROCOUNT:INTEGER;
ILMAX,ILMIN,ILAV,TOTILUM:REAL;
BEGIN
ILMIN:=9999;
ILMAX:=0;
ZEROCOUNT:=0;
TOTILUM:=0;
M:=CEILXNUMPT;
N:=CEILYNUMPT;
K:=1;
MM:=TRUNC(CEILXNUMPT/19)+1;
FOR Z:=1 TO MM DO BEGIN
{WRITELN(G);
WRITELN(G);}
AA:=K;
BB:=K+19;
IF BB > CEILXNUMPT THEN BB:=CEILXNUMPT;
K:=BB+1;
FOR J:=N DOWNTO 1 DO
BEGIN
{WRITELN(G); }
FOR I:=AA TO BB DO BEGIN
{WRITE(G,BIGCEILGRID[I,J]:4:0,' '); }
IF BIGCEILGRID[I,J] > ILMAX THEN
ILMAX:=BIGCEILGRID[I,J];
IF BIGCEILGRID[I,J] < ILMIN THEN BEGIN
IF BIGCEILGRID[I,J] > 0 THEN ILMIN:=BIGCEILGRID[I,J];
IF BIGCEILGRID[I,J] = 0 THEN
ZEROCOUNT:=ZEROCOUNT+1;
END;
TOTILUM:=BIGCEILGRID[I,J]+TOTILUM;
IF I=BB THEN WRITELN(G);
END {I COUNTER}
END {J COUNTER}
END; {OVERALL Z COUNTER}
ILAV:=TOTILUM/(((CEILXNUMPT)*(CEILYNUMPT))-
ZEROCOUNT);
{WRITELN(G);
WRITELN(G);
WRITELN(G,'Y DIRECTION');
WRITELN(G,'1');
WRITELN(G,'1');
WRITELN(G,'1');
WRITELN(G,'------>X DIRECTION');
WRITELN(G);
WRITELN(G);
WRITELN(G,'AVERAGE ILLUMINANCE EQUALS ',ILAV:4:0);
WRITELN(G);
WRITELN(G,'MINIMUM ILLUMINANCE EQUALS
',ILMIN:4:0);
WRITELN(G);
WRITELN(G,'MAXIMUM ILLUMINANCE EQUALS
',ILMAX:4:0);
WRITELN(G);
WRITELN(G,'MIN TO AVERAGE UNIFORMITY
=',ILMIN/ILAV:4:3);
WRITELN(G);
WRITELN(G,'MIN TO MAX UNIFORMITY
=',ILMIN/ILMAX:4:3);
WRITELN(G);
WRITELN(G); }
END; {PROCEDURE CEILGRIDWRIT}


PROCEDURE WKPLNSORT;
{CALCULATES THE OTHER WORKING PLANE
ILLUMINANCE GRIDS FROM THOSE
FOUR PREVIOUSLY CALCULATED}
VAR J,K:INTEGER;
BEGIN
FOR J:=1 TO XNUMPT DO BEGIN
FOR K:=1 TO YNUMPT DO BEGIN
GDILUM[5,J,K]:=GDILUM[1,J,K]-GDILUM[2,J,K];
IF GDILUM[2,J,K]=0 THEN GDILUM[5,J,K]:=0;
GDILUM[7,J,K]:=GDILUM[3,J,K]-GDILUM[1,J,K];
GDILUM[8,J,K]:=GDILUM[4,J,K]-GDILUM[2,J,K];
GDILUM[9,J,K]:=ILLUMREQ-GDILUM[4,J,K];
IF (GDILUM[9,J,K] < 0 ) THEN GDILUM[9,J,K]:=0;
GDILUM[10,J,K]:=GDILUM[4,J,K];
GDILUM[6,J,K]:=GDILUM[3,J,K]-GDILUM[4,J,K];
IF GDILUM[4,J,K]=0 THEN BEGIN
GDILUM[9,J,K]:=0;
GDILUM[10,J,K]:=(ILLUMREQ-200)-(ILLUMREQ*0.2); {YOU
WANT IT TO SHOW THAT
THERE IS AN OBSTRUCTION BUT YOU ALSO DO NOT
WANT THERE TO BE TOO MANY CONTOURS}
END;
END; {K, YNUMPT COUNTER}
END; {J, XNUMPT COUNTER}
END; {PROCEDURE WKPLNSORT }


PROCEDURE WKARAYTURN;  {TURNS THE WORKING
PLANE ARRAYS AROUND}
VAR ACI,I,J,K:INTEGER;
BEGIN
FOR K:=1 TO 10 DO BEGIN
ACI:=XNUMPT;
FOR I:=1 TO XNUMPT DO BEGIN
FOR J:=1 TO YNUMPT DO BEGIN
GDILUM[K,J,ACI]:=GDILUM[K,I,J];
END;
```

```
ACI:=ACI-1;
END;
END;
END; {PROCEDURE WKARAYTURN}


PROCEDURE WRITECONTROL; {THE PROCEDURE TO
CONTROL THE WORKING PLANE
GRID WRITEOUTS}
VAR I:INTEGER;
BEGIN
IF TIMETHRU=2 THEN OUTPUTURN;
{TURNS THE ARRAYS BACK TO THE SAME AS ORIGINAL
FOR CONSISTACY}
WKPLNSORT; {SORTS OUT THE INFO ABOUT THE
WORKING PLANE TO WRITTEN OUT}
FOR I:=1 TO 10 DO BEGIN
WRITNUM:=I;
ILGRIDWRIT; {WRITES OUT THE WORKING PLANE
ILLUMINANCE GRID}
END, {WRITTING OUT THE WORKING PLANE GRIDS}
{OUTPUTURN;
QUICKWRITE; }
END; { PROCEDURE WRITECONTROL }


PROCEDURE VECTCOSLINE;
{CALCULATES THE VECTOR COSINES OF THE LINE
BETWEEN LUMINAIRE AND
CALCULATION POINT}
{OR IN THE INTER-REFLECTION CASE USE THE LINE
BETWEEN THE CENTRE OF THE
TWO ELEMENTS WHICH ARE ABOUT TO BE CHECKED FOR
"SEE" OR "NO SEE" IN THE
FORM FACTOR CALCULATION PROCESS}
VAR DELTAX,DELTAY,DELTAZ,RDIST:REAL;
BEGIN
DELTAX:=XLUMCENT-XMEASPOINT;
DELTAY:=YLUMCENT-YMEASPOINT;
DELTAZ:=HEIGHT-WKPLNHT;
IF (DELTAZ < 0.001) THEN DELTAZ:=0.001;
{IF (DELTAX < 0.001) THEN DELTAX:=0.001;
IF (DELTAY < 0.001) THEN DELTAY:=0.001;    }
RDIST:=SQRT(SQR(DELTAX)+SQR(DELTAY)+SQR(DELTAZ));
LNVCTCOS[1]:=DELTAX/RDIST;
LNVCTCOS[2]:=DELTAY/RDIST;
LNVCTCOS[3]:=DELTAZ/RDIST;
END; {PROCEDURE VECTCOSLINE}


PROCEDURE THEINTERREFLECTION;

{RROOMM } {OOBB }
TYPE TYY=ARRAY[0..XXMAX,0..XXMAX] OF REAL;
VAR COEF:CAA; {ARRAY OF FINAL
EMMITANCES*REFLECT FACTS}
THIRARRAY:TTY; {ARRAY OF INITIAL
EMMITANCES*REFLECT FACTS}
FIRARRAY:TYY; {FORMFACTORS & INTERREFLECTION
ARRAYS}
STFORMFACT:TYY;
NUMWRIT:INTEGER;


PROCEDURE VECTOFELETOELELINE(II,JJ:INTEGER);
{THIS PROCEDURE CALCULATES THE POSITION IN X, Y &
Z COORDINATES OF THE
CENTRE OF EACH ELEMENT SO THAT PROCEDURE
VECTCOSLINE CAN BE USED TO FIND
THE VECTOR COSINE OF THE LINE BETWEEN THE
CENTRE OF THE TWO ELEMENTS
UNDER CONSIDERATION. THIS IS USED IN THE
FORMFACTOR CALCULATION.}

BEGIN
XLUMCENT:=(GENINTELE[JJ,1,2]+GENINTELE[JJ,1,1])/2;
YLUMCENT:=(GENINTELE[JJ,2,2]+GENINTELE[JJ,2,1])/2;
XMEASPOINT:=(GENINTELE[II,1,2]+GENINTELE[II,1,1])/2;
YMEASPOINT:=(GENINTELE[II,2,2]+GENINTELE[II,2,1])/2;
HEIGHT:=(GENINTELE[JJ,3,2]+GENINTELE[JJ,3,1])/2;
WKPLNHT:=(GENINTELE[II,3,2]+GENINTELE[II,3,1])/2;
END; {PROCEDURE VECTOFELETOELELINE}


PROCEDURE FNLCEILILUM(COMBCEIL:REAL);
VAR I,J,N,M:INTEGER;
BEGIN
N:=CEILXNUMPT;
M:=CEILYNUMPT;
FOR I:=0 TO N DO BEGIN
FOR J:=0 TO M DO BEGIN
BIGCEILGRID[I,J]:=COMBCEIL;
{ALL POINTS OF THE CEILING ARE THE SAME
ILLUMINANCE AND THEY ARE CALCULATED
FROM THE AVERAGE OF ALL POINTS DIRECT FROM
LUMINAIRES + THE AVERAGE
CONTRIBUTION FROM THE WALLS. }
END; {J, COUNTER}
END; {I, COUNTER}
END; {PROCEDURE FNLCEILILUM}


PROCEDURE CEILILUMFRMWALS;
{TO CALCULATE THE ILLUMINANCE FROM THE WALLS
RECEIVED ON THE CEILING}
TYPE CC=ARRAY[1..2] OF REAL;
TT=ARRAY[1..4] OF REAL;
VAR I,J,K,M,II,JJ,KK,MM,MULT:INTEGER;
COMBCEIL,
CEILINGAREA,END1,END2,DIST,WALLAREA,APPENAA,APP
ENAB,APPENAC,IFORMFACTOR:REAL;
ZBAR,CEILTOT,LHS,LHSTOT,XBAR,LHS1,LHS2,LHS3,LHS4,F1
2TOT,F12,LEN1,AREA1:REAL;
WALLAVILUM:TT;
V:CC;
Y:CC;
X:CC;
Z:CC;


PROCEDURE AVWALLILUM;

VAR RMSURFACE,I,J,N,M:INTEGER;
TOTILUM:REAL;
BEGIN
FOR RMSURFACE:=1 TO 4 DO BEGIN
TOTILUM:=0;
N:=XNMPT[RMSURFACE];
M:=YNMPT[RMSURFACE];
FOR I:=0 TO N DO
BEGIN
FOR J:=0 TO M DO BEGIN
TOTILUM:=WALLILLUM[3,RMSURFACE,I,J]+TOTILUM;
END {J COUNTER}
END; {I COUNTER}
WALLAVILUM[RMSURFACE]:=TOTILUM/((N+1)*(M+1));
END {EACH WALL SURFACE}
END; {PROCEDURE AVWALLILUM}

BEGIN
AVWALLILUM;
{TO FIND THE FORM FACTOR OF THE CEWILING FROM
EACH OF THE WALLS}
CEILTOT:=0;
CEILINGAREA:=LENGTH*WIDTH;
FOR II:= 1 TO 4 DO BEGIN {EACH WALL IN TURN}
LHSTOT:=0;
IF (II=1) OR (II=3) THEN JJ:=1 ELSE JJ:=2;
V[1]:=RMLIMITS[II,JJ,1];
V[2]:=RMLIMITS[II,JJ,2];
Y[1]:=RMLIMITS[II,JJ,1];
Y[2]:=RMLIMITS[II,JJ,2];
X[1]:=HM;
X[2]:=0;
IF (II=1) OR (II=3) THEN MM:=2 ELSE MM:=1;
Z[1]:=RMLIMITS[MM,MM,1];
Z[2]:=RMLIMITS[MM,MM,2];
XBAR:=HM;
IF (II=1) THEN ZBAR:=RMLIMITS[2,2,1]
ELSE IF (II=2) THEN ZBAR:=RMLIMITS[1,1,2]
ELSE IF (II=3) THEN ZBAR:=RMLIMITS[2,2,2]
ELSE IF (II=4) THEN ZBAR:=RMLIMITS[1,1,1];
FOR I:=1 TO 2 DO BEGIN
FOR J:=1 TO 2 DO BEGIN
FOR K:=1 TO 2 DO BEGIN
FOR M:=1 TO 2 DO BEGIN
APPENAA:=Y[M]-V[I];
APPENAB:=ZBAR-Z[J];
APPENAC:=X[K]-XBAR;
IF ((SQR(APPENAB)+SQR(APPENAC)) < 0.0000001) THEN
BEGIN
LHS1:=0;
END
ELSE BEGIN
LHS4:=APPENAA*(SQRT(SQR(APPENAB)+SQR(APPENAC)));
LHS3:=ARCTAN(APPENAA/SQRT(SQR(APPENAB)+SQR(APPE
NAC)));
LHS1:=LHS3*LHS4;
END;
IF ((SQR(APPENAA)+SQR(APPENAB)+SQR(APPENAC)) <
0.0000001) THEN BEGIN
```

```
LHS2:=0;
END
ELSE BEGIN
LHS4:=0.25*(SQR(APPENAA)-SQR(APPENAB)-
SQR(APPENAC));
LHS3:=LN(SQR(APPENAA)+SQR(APPENAB)+SQR(APPENAC))
;
LHS2:=LHS3*LHS4;
END;
LHS.=LHS1+LHS2;
IF (((I+J+K+M)/2) = TRUNC((I+J+K+M)/2)) THEN MULT:=1
ELSE MULT:=-1;
LHSTOT:=MULT*LHS+LHSTOT;
END {M COUNTER}
END {K COUNTER}
END {J COUNTER}
END; {I COUNTER}
LEN1:=ABS(Y[2]-Y[1]);
AREA1:=LEN1*HM;
IFORMFACTOR:=ABS((1/(2*PI*AREA1))*LHSTOT);
CEILTOT:=IFORMFACTOR*WALLAVILUM[II]+CEILTOT;
END; {II WALL COUNTER}
CEILTOT:=CEILTOT/(LENGTH*WIDTH);
COMBCEIL:=CEILTOT+CEILAV;
WRITELN(G,'THE TOTAL AVERAGE ILLUMINANCE OF THE
CEILING IS ',COMBCEIL:3:2);
WRITELN(G);
FNLCEILILUM(COMBCEIL);
END; {PROCEDURE CEILILUMFRMWALLS}


PROCEDURE FNLWALLILUMGRID;
{USING THE AVERAGE ILLUMINANCE OF THE ELEMENTS
BEFORE AND AFTER THE
INTER-REFLECTION PROCESS THIS PROCEDURE
CALCULATES THE FINAL ILLUMINANCE
AT EACH POINT OVER EACH ELEMENT CONTAINED IN
EACH WALL. IT IS SO
COMPLICATED BECAUSE OF THE SINGLE, DOUBLE AND
QUADRUPLE USE OF VARIOUS
FIGURES TO GRADUATE EMMITTANCES OVER THE TOTAL
ROOM VERTICAL SURFACES.}
LABEL 1;
TYPE WWR=ARRAY[1..4] OF REAL; {RECIPRICALS OF THE
WALL REFLECTION FACTORS.}
VAR
NHOWMANY,MHOWMANY,NARRAYNUM,MARRAYNUM,
II,JJ,I,J,RMSURFACE,N,M,TOTELEMENTNUM:INTEGER;
WR.WWR;
BEGIN
TOTELEMENTNUM:=0;
FOR RMSURFACE:=1 TO 4 DO BEGIN
WR[RMSURFACE]:=1/RW[RMSURFACE]; {TO RETURN TO
ILLUMINANCE AGAIN}
N:=XNMPT[RMSURFACE];
M:=YNMPT[RMSURFACE];
NHOWMANY:=RMSPLITINFO[RMSURFACE,1];
MHOWMANY:=RMSPLITINFO[RMSURFACE,2];
FOR I:=1 TO NHOWMANY DO BEGIN
FOR J:=1 TO MHOWMANY DO BEGIN
TOTELEMENTNUM:=TOTELEMENTNUM+1;
FOR II:=0 TO 3 DO BEGIN
FOR JJ:=0 TO 2 DO BEGIN
NARRAYNUM:=((I*3)-3)+II;
MARRAYNUM:=((J*2)-2)+JJ;
IF (II=1) OR (II=2) THEN BEGIN
IF (JJ=0) OR (JJ=2) THEN BEGIN
IF (JJ=2) AND (J=MHOWMANY) THEN BEGIN
WALLILLUM[WRITNUM,RMSURFACE,NARRAYNUM,MARRA
YNUM]:=
WR[RMSURFACE]*(RW[RMSURFACE]*WALLILLUM[WRITNU
M,RMSURFACE,NARRAYNUM,MARRAYNUM]
+COEF[TOTELEMENTNUM]-
(ELEMITAV[TOTELEMENTNUM]));
GOTO 1;
END; {JJ=2 & J=HOWMANY}
IF (JJ=0) AND (J=1) THEN BEGIN
WALLILLUM[WRITNUM,RMSURFACE,NARRAYNUM,MARRA
YNUM]:=
WR[RMSURFACE]*(RW[RMSURFACE]*WALLILLUM[WRITNU
M,RMSURFACE,NARRAYNUM,MARRAYNUM]
+COEF[TOTELEMENTNUM]-
(ELEMITAV[TOTELEMENTNUM]));
GOTO 1;
END; {JJ=0 & J=1 }
WALLILLUM[WRITNUM,RMSURFACE,NARRAYNUM,MARRA
YNUM]:=
WR[RMSURFACE]*(RW[RMSURFACE]*WALLILLUM[WRITNU
M,RMSURFACE,NARRAYNUM,MARRAYNUM]
+0.5*(COEF[TOTELEMENTNUM])-
0.5*((ELEMITAV[TOTELEMENTNUM])));
GOTO 1;
END; {JJ=2 & JJ=0 }
WALLILLUM[WRITNUM,RMSURFACE,NARRAYNUM,MARRA
YNUM]:=
WR[RMSURFACE]*(RW[RMSURFACE]*WALLILLUM[WRITNU
M,RMSURFACE,NARRAYNUM,MARRAYNUM]
+COEF[TOTELEMENTNUM]-
(ELEMITAV[TOTELEMENTNUM]));
GOTO 1;
END; {II=2 & II=1 }


IF (II=0) THEN BEGIN
IF (JJ=0) OR (JJ=2) THEN BEGIN
IF (JJ=2) AND (J=MHOWMANY) THEN BEGIN
IF (I=1) THEN BEGIN
WALLILLUM[WRITNUM,RMSURFACE,NARRAYNUM,MARRA
YNUM]:=
WR[RMSURFACE]*(RW[RMSURFACE]*WALLILLUM[WRITNU
M,RMSURFACE,NARRAYNUM,MARRAYNUM]
+COEF[TOTELEMENTNUM]-
(ELEMITAV[TOTELEMENTNUM]));
GOTO 1;
END; {I=1 }
WALLILLUM[WRITNUM,RMSURFACE,NARRAYNUM,MARRA
YNUM]:=
WR[RMSURFACE]*(RW[RMSURFACE]*WALLILLUM[WRITNU
M,RMSURFACE,NARRAYNUM,MARRAYNUM]
+0.5*(COEF[TOTELEMENTNUM])-
0.5*((ELEMITAV[TOTELEMENTNUM])));
GOTO 1;
END; {JJ=2 & J=MHOWMANY }
IF (I=1) THEN BEGIN
IF (JJ=0) AND (J=1) THEN BEGIN
WALLILLUM[WRITNUM,RMSURFACE,NARRAYNUM,MARRA
YNUM]:=
WR[RMSURFACE]*(RW[RMSURFACE]*WALLILLUM[WRITNU
M,RMSURFACE,NARRAYNUM,MARRAYNUM]
+COEF[TOTELEMENTNUM]-
(ELEMITAV[TOTELEMENTNUM]));
GOTO 1;
END; {JJ=0 AND J=1}
WALLILLUM[WRITNUM,RMSURFACE,NARRAYNUM,MARRA
YNUM]:=
WR[RMSURFACE]*(RW[RMSURFACE]*WALLILLUM[WRITNU
M,RMSURFACE,NARRAYNUM,MARRAYNUM]
+0.5*(COEF[TOTELEMENTNUM])-
0.5*((ELEMITAV[TOTELEMENTNUM])));
GOTO 1;
END; {I=1 }
IF (JJ=0) AND(J=1) THEN BEGIN
WALLILLUM[WRITNUM,RMSURFACE,NARRAYNUM,MARRA
YNUM]:=
WR[RMSURFACE]*(RW[RMSURFACE]*WALLILLUM[WRITNU
M,RMSURFACE,NARRAYNUM,MARRAYNUM]
+0.5*(COEF[TOTELEMENTNUM])-
0.5*((ELEMITAV[TOTELEMENTNUM])));
GOTO 1;
END; {    }
WALLILLUM[WRITNUM,RMSURFACE,NARRAYNUM,MARRA
YNUM]:=
WR[RMSURFACE]*(RW[RMSURFACE]*WALLILLUM[WRITNU
M,RMSURFACE,NARRAYNUM,MARRAYNUM]
+0.25*(COEF[TOTELEMENTNUM])-
0.25*((ELEMITAV[TOTELEMENTNUM])));
GOTO 1;
END; {          }
IF (I=1) AND (JJ=1) THEN BEGIN
WALLILLUM[WRITNUM,RMSURFACE,NARRAYNUM,MARRA
YNUM]:=
WR[RMSURFACE]*(RW[RMSURFACE]*WALLILLUM[WRITNU
M,RMSURFACE,NARRAYNUM,MARRAYNUM]
+COEF[TOTELEMENTNUM]-
(ELEMITAV[TOTELEMENTNUM]));
GOTO 1;
END; {I=1 & JJ=1}


WALLILLUM[WRITNUM,RMSURFACE,NARRAYNUM,MARRA
YNUM]:=
WR[RMSURFACE]*(RW[RMSURFACE]*WALLILLUM[WRITNU
M,RMSURFACE,NARRAYNUM,MARRAYNUM]
+0.5*(COEF[TOTELEMENTNUM])-
0.5*((ELEMITAV[TOTELEMENTNUM])));
GOTO 1;
END; {II=0}

IF (II=3) THEN BEGIN
IF (I=NHOWMANY) THEN BEGIN
IF (JJ=2) THEN BEGIN
IF (J=MHOWMANY) THEN BEGIN
WALLILLUM[WRITNUM,RMSURFACE,NARRAYNUM,MARRA
YNUM]:=
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WR[RMSURFACE]*(RW[RMSURFACE]*WALLILLUM[WRITNU
M,RMSURFACE,NARRAYNUM,MARRAYNUM]
+COEF[TOTELEMENTNUM]-
(ELEMITAV[TOTELEMENTNUM]));
GOTO 1;
END;  {J=MHOWMANY}
WALLILLUM[WRITNUM,RMSURFACE,NARRAYNUM,MARRA
YNUM]:=
WR[RMSURFACE]*(RW[RMSURFACE]*WALLILLUM[WRITNU
M,RMSURFACE,NARRAYNUM,MARRAYNUM]
+0.5*(COEF[TOTELEMENTNUM])-
0.5*((ELEMITAV[TOTELEMENTNUM])));
GOTO 1;
END;  {JJ=2  }
IF (JJ=0) THEN BEGIN
IF (J=1) THEN BEGIN
WALLILLUM[WRITNUM,RMSURFACE,NARRAYNUM,MARRA
YNUM]:=
WR[RMSURFACE]*(RW[RMSURFACE]*WALLILLUM[WRITNU
M,RMSURFACE,NARRAYNUM,MARRAYNUM]
+COEF[TOTELEMENTNUM]-
(ELEMITAV[TOTELEMENTNUM]));
GOTO 1;
END;  {J=1   }
WALLILLUM[WRITNUM,RMSURFACE,NARRAYNUM,MARRA
YNUM]:=
WR[RMSURFACE]*(RW[RMSURFACE]*WALLILLUM[WRITNU
M,RMSURFACE,NARRAYNUM,MARRAYNUM]
+0.5*(COEF[TOTELEMENTNUM])-
0.5*((ELEMITAV[TOTELEMENTNUM])));
GOTO 1;
END;  {JJ=0  }

WALLILLUM[WRITNUM,RMSURFACE,NARRAYNUM,MARRA
YNUM]:=
WR[RMSURFACE]*(RW[RMSURFACE]*WALLILLUM[WRITNU
M,RMSURFACE,NARRAYNUM,MARRAYNUM]
+COEF[TOTELEMENTNUM]-
(ELEMITAV[TOTELEMENTNUM]));
GOTO 1;
END;  {I=NHOWMANY}

IF (JJ=2) THEN BEGIN
IF (J=MHOWMANY) THEN BEGIN
WALLILLUM[WRITNUM,RMSURFACE,NARRAYNUM,MARRA
YNUM]:=
WR[RMSURFACE]*(RW[RMSURFACE]*WALLILLUM[WRITNU
M,RMSURFACE,NARRAYNUM,MARRAYNUM]
+0.5*(COEF[TOTELEMENTNUM])-
0.5*((ELEMITAV[TOTELEMENTNUM])));
GOTO 1;
END;  {J=HOWMANY}
WALLILLUM[WRITNUM,RMSURFACE,NARRAYNUM,MARRA
YNUM]:=
WR[RMSURFACE]*(RW[RMSURFACE]*WALLILLUM[WRITNU
M,RMSURFACE,NARRAYNUM,MARRAYNUM]
+0.25*(COEF[TOTELEMENTNUM])-
0.25*((ELEMITAV[TOTELEMENTNUM])));
GOTO 1;
END;  { JJ=2  }
IF (JJ=0) THEN BEGIN
IF (J=1) THEN BEGIN
WALLILLUM[WRITNUM,RMSURFACE,NARRAYNUM,MARRA
YNUM]:=
WR[RMSURFACE]*(RW[RMSURFACE]*WALLILLUM[WRITNU
M,RMSURFACE,NARRAYNUM,MARRAYNUM]
+0.5*(COEF[TOTELEMENTNUM])-
0.5*((ELEMITAV[TOTELEMENTNUM])));
GOTO 1;
END;  {J=1   }
WALLILLUM[WRITNUM,RMSURFACE,NARRAYNUM,MARRA
YNUM]:=
WR[RMSURFACE]*(RW[RMSURFACE]*WALLILLUM[WRITNU
M,RMSURFACE,NARRAYNUM,MARRAYNUM]
+0.25*(COEF[TOTELEMENTNUM])-
0.25*((ELEMITAV[TOTELEMENTNUM])));
GOTO 1;
END;  { JJ=0  }

WALLILLUM[WRITNUM,RMSURFACE,NARRAYNUM,MARRA
YNUM]:=
WR[RMSURFACE]*(RW[RMSURFACE]*WALLILLUM[WRITNU
M,RMSURFACE,NARRAYNUM,MARRAYNUM]
+0.5*(COEF[TOTELEMENTNUM])-
0.5*((ELEMITAV[TOTELEMENTNUM])));
GOTO 1;
END;  {II=3  }
1:END  {JJ COUNTER}
END; {II COUNTER}
END; {J COUNTER}
END; {I COUNTER}
END; {RMSURFACE  COUNTER}
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END; {PROCEDURE FNLWALLILUMGRID}


PROCEDURE FNLOBSURFILUMGRID;
{CALCULATES THE FINAL ILLUMINANCES OVER THE
OBSTRUCTION VERTICAL SURFACES}

VAR I,J,N,M,SIDENUMBER,OBNUMBER:INTEGER;
PARTC,PARTB,PARTA,WR,ACXDISC,ACYDISC:REAL;
BEGIN
FOR OBNUMBER:=1 TO OBNUM DO BEGIN
WR:=1/OBREFLECT[OBNUMBER]; {TO RETURN TO
ILLUMINANCE AGAIN}
FOR SIDENUMBER:=1 TO 4 DO BEGIN
ACXDISC:=ACOBDISCRE[OBNUMBER,SIDENUMBER,1];
ACYDISC:=ACOBDISCRE[OBNUMBER,SIDENUMBER,2];
IF (SIDENUMBER=1) OR (SIDENUMBER=3) THEN
N:=ROUND((OBLIMITS[OBNUMBER,1,2]-
OBLIMITS[OBNUMBER,1,1])/ACXDISC);
IF (SIDENUMBER=2) OR (SIDENUMBER=4) THEN
N:=ROUND((OBLIMITS[OBNUMBER,2,2]-
OBLIMITS[OBNUMBER,2,1])/ACXDISC);
M:=ROUND((OBLIMITS[OBNUMBER,3,2]-
WKPLNHT)/ACYDISC);
FOR I:=0 TO N DO BEGIN
FOR J:=0 TO M DO BEGIN
PARTA:=WR*(OBREFLECT[OBNUMBER]*OBILUM[OBNUMBE
R,SIDENUMBER,I,J]);
PARTB:=WR*(COEF[((OBNUMBER*4)-
4)+SIDENUMBER+STTOTELEMENTNUM]);
PARTC:=WR*(ELEMITAV[((OBNUMBER*4)-
4)+SIDENUMBER+STTOTELEMENTNUM]);
OBILUM[OBNUMBER,SIDENUMBER,I,J]:=PARTA+PARTB-
PARTC;
END; {J COUNTER}
END; {I COUNTER}
END; {SIDENUMBER COUNTER}
END; {OBNUMBER COUNTER}
END; {PROCEDURE FNLOBSURFILUMGRID}



PROCEDURE GAUSS;
(*MATRIX SOLUTION  BY GAUSSIAN ELIMINATION*)
(*FROM P78 "PASCAL PROGS. FOR SCI. & ENGRS."*)
{THE FINAL EMMITTANCE OF EACH ELEMENT IS IN THE
COEF ARRAY}
VAR I,J,K,II,L,N:INTEGER;
ZZZ,HOLD,SUM,T,AB,BIG,ZIZITOP:REAL;
IROW,ICOL:INTEGER;
BEGIN
  FOR I:= 1 TO (TOTELEMENTNUM-1) DO
  BEGIN
   BIG:= ABS(FIRARRAY[I,I]);
   L:= I;
   II:= I + 1;
   FOR J:= II TO TOTELEMENTNUM DO
   BEGIN  (*SEARCH FOR LARGEST ELEMENT*)
    AB:= ABS(FIRARRAY[J,I]);
    IF AB>BIG THEN
    BEGIN
     BIG:= AB;
     L:= J
    END
   END;
   BEGIN
    IF L<>I THEN
    BEGIN
     (*INTERCHANGE ROWS TO PUT LARGEST ELEMENT
ON DIAGONAL*)
     FOR J:= 1 TO TOTELEMENTNUM DO
     BEGIN
      HOLD:= FIRARRAY[L,J];
      FIRARRAY[L,J]:= FIRARRAY[I,J];
      FIRARRAY[I,J]:= HOLD;
     END;
     HOLD:= THIRARRAY[L];
     THIRARRAY[L]:= THIRARRAY[I];
     THIRARRAY[I]:= HOLD;
    END; (*IF L<>I*)
    FOR J:= II TO TOTELEMENTNUM DO
    BEGIN
     T:= FIRARRAY[J,I]/FIRARRAY[I,I];
     FOR K:= II TO TOTELEMENTNUM DO
     FIRARRAY[J,K]:= FIRARRAY[J,K] -
(T*(FIRARRAY[I,K]));
     THIRARRAY[J]:= THIRARRAY[J] - (T*(THIRARRAY[I]));
    END  (*JLOOP*)
   END  (*IF BIG*)
  END;  (*I LOOP*)
  FOR I:= (TOTELEMENTNUM - 1) DOWNTO 1 DO
  (*BACK SUBSTITUTION*)
```

```
    BEGIN
     SUM:= 0.0;
     FOR J:= I + 1 TO TOTELEMENTNUM DO BEGIN
       COEF[J]:=0;
       COEF[J]:=THIRARRAY[J]/FIRARRAY[J,J];
       SUM:= SUM + ((FIRARRAY[I,J])*(COEF[J]));
     END;{J LOOP}
     COEF[I]:= (THIRARRAY[I]-SUM)/FIRARRAY[I,I];
     END; {I LOOP}
   END; (*GAUSS*)

PROCEDURE ELEMENTARRAY;
{FOR THIS PROGRAM LET IT BE NOTICED THAT WE HAVE
DISCARDED THE TOP }
{IE THE HORIZONTAL SURFACE NUMBER 5 OF ANY
OBSTRUCTION FROM THE INTER-REFLCTION PROCESS.}
{THE NUMBER OF ELEMENTS FROM THE 4 WALLS MUST
ALWAYS ADD UP TO AN EVEN NUMBER}
{THIS PROCEDURE CALCULATES THE OBSTRUCTION
ELEMENT LIMITS TO BE
CONSIDERED IN THE CALCULATION. }

VAR AFIX,I,J,K:INTEGER;
ELEBALAN,OBCOUNT:INTEGER;
BEGIN
OBCOUNT:=0;
FOR I:= (STTOTELEMENTNUM+1) TO
((4*OBNUM)+STTOTELEMENTNUM) DO BEGIN
AFIX:=I MOD 4;
ELEBALAN:=STTOTELEMENTNUM MOD 4;
IF (ABS(((I-1-ELEBALAN)/4)-TRUNC((I-1-ELEBALAN)/4)) <
0.01) THEN OBCOUNT:=OBCOUNT+1;
{IE NEXT OBSTRUCTION SINCE COUNTER IS UP 4}
TOTELEMENTNUM:=TOTELEMENTNUM+1;
FOR J:= 1 TO 3 DO BEGIN
FOR K:= 1 TO 2 DO BEGIN
GENINTELE[I,J,K]:=OBLIMITS[OBCOUNT,J,K];
END  {K COUNTER}
END; {J COUNTER}
{IF (ABS(I/2-TRUNC(I/2)) < 0.0001) THEN
GENINTELE[I,1,1]:=GENINTELE[I,1,2]     }
{IE I IS EVEN }
{ELSE GENINTELE[I,2,1]:=GENINTELE[I,2,2];  }
IF AFIX=1 THEN GENINTELE[I,2,1]:=GENINTELE[I,2,2];
IF AFIX=2 THEN GENINTELE[I,1,2]:=GENINTELE[I,1,1];
IF AFIX=3 THEN GENINTELE[I,2,2]:=GENINTELE[I,2,1];
IF AFIX=0 THEN GENINTELE[I,1,1]:=GENINTELE[I,1,2];
END; {I COUNTER}
END; {PROCEDURE ELEMENTARRAY }


PROCEDURE ELEOBTEST(IELEOBNUMB,TEST1:INTEGER;
VAR NOSEE:INTEGER);
{THIS PROCEDURE TESTS IF THERE IS ANY EFFECT OF
ANY OBSTRUCTION SITUATED
IN THE ROOM BLOCKING THE VIEW OF THE TWO
ELEMENTS UNDER CONSIDERATION
IN THE FORMFACTOR CALCULATION PROCEDURE.}

LABEL 1,2,3;
VAR IJI,OBNUMBER,SURFACENUM:INTEGER;
XINTERSECT,YINTERSECT,ZINTERSECT,DISTINTERSECT,
INTSECT1,INTSECT2,INTSECT3,INTSECT4,TOPLINE,SUM,TO
TSUM:REAL;
BEGIN
FOR OBNUMBER:=1 TO OBNUM DO BEGIN
IF (ABS(IELEOBNUMB-OBNUMBER) < 0.01) THEN GOTO 2;
FOR SURFACENUM:=1 TO 4 DO BEGIN
IF (ABS(TEST1-SURFACENUM) < 0.01) THEN GOTO 3;
INTSECT1:=DIRCOS[OBNUMBER,SURFACENUM,6];
INTSECT2:=(XMEASPOINT*DIRCOS[OBNUMBER,SURFACEN
UM,3]);
INTSECT3:=(YMEASPOINT*DIRCOS[OBNUMBER,SURFACEN
UM,4]);
INTSECT4:=(WKPLNHT*DIRCOS[OBNUMBER,SURFACENUM,
5]);
TOPLINE:=INTSECT1-(INTSECT2+INTSECT3+INTSECT4);
TOTSUM:=0;
FOR IJI:=1 TO 3 DO BEGIN
SUM:=LNVCTCOS[IJI]*DIRCOS[OBNUMBER,SURFACENUM,IJI
+2];
TOTSUM:=SUM+TOTSUM;
END;
IF TOTSUM=0 THEN GOTO 3; {LINE BETWEEN THE TWO
CONSIDERED
ELEMENTS AND THE LINE DOWN THE SURFACE OF THE
OBSTRUCTION ARE PARALLEL}
{THIS HAS BEEN FULLY CHECKED IT WORKS PERFECTLY}
DISTINTERSECT:=TOPLINE/TOTSUM;
{NOW TO FIND COORDINATES OF THE INTERSECTION
USING EQUATION 1 TREGENZA}
XINTERSECT:=XMEASPOINT+(DISTINTERSECT*LNVCTCOS[
1]);
YINTERSECT:=YMEASPOINT+(DISTINTERSECT*LNVCTCOS[
2]);
ZINTERSECT:=WKPLNHT+(DISTINTERSECT*LNVCTCOS[3]);
IF (XINTERSECT < 0) OR (YINTERSECT < 0)
OR (ZINTERSECT < WKPLNHT) THEN GOTO 3;
{NOW CHECK THAT X INTERSECT LIES WITHIN THE X
DIRECTION}
{LIMITATIONS OF SURFACE UNDER CONSIDERATION ALSO
Y AND Z}
IF (SURFACENUM=2) OR (SURFACENUM=4) THEN BEGIN
{THE NEXT 0.15 COMPARISON IS JUST TO CHECK IT IS THIS
OB SURFACENUM}
IF (ABS(XINTERSECT-OBLIMITS[OBNUMBER,1,1]) < 0.15) OR
(ABS(XINTERSECT-OBLIMITS[OBNUMBER,1,2]) < 0.15) THEN
IF (ABS(ZINTERSECT-OBLIMITS[OBNUMBER,3,1]) < 0.0001)
OR
(ZINTERSECT > OBLIMITS[OBNUMBER,3,1]) THEN BEGIN
IF (ABS(ZINTERSECT-OBLIMITS[OBNUMBER,3,2]) < 0.0001)
OR
(OBLIMITS[OBNUMBER,3,2] > ZINTERSECT) THEN BEGIN
IF (ABS(YINTERSECT-OBLIMITS[OBNUMBER,2,2]) < 0.0001)
OR
(OBLIMITS[OBNUMBER,2,2] > YINTERSECT) THEN BEGIN
IF (ABS(YINTERSECT-OBLIMITS[OBNUMBER,2,1]) < 0.0001)
OR
(YINTERSECT > OBLIMITS[OBNUMBER,2,1]) THEN BEGIN
NOSEE:=1;
GOTO 1;
END {IF THIS SURFACE IS CLOSER THAN ANY OTHER}
END
END
END
END;
IF (SURFACENUM=1) OR (SURFACENUM=3) THEN BEGIN
{THE NEXT 0.15 COMPARISON IS JUST TO CHECK IT IS THIS
OB SURFACENUM}
IF (ABS(YINTERSECT-OBLIMITS[OBNUMBER,2,1]) < 0.15) OR
(ABS(YINTERSECT-OBLIMITS[OBNUMBER,2,2]) < 0.15) THEN
IF (ABS(ZINTERSECT-OBLIMITS[OBNUMBER,3,1]) < 0.0001)
OR
(ZINTERSECT > OBLIMITS[OBNUMBER,3,1]) THEN BEGIN
IF (ABS(ZINTERSECT-OBLIMITS[OBNUMBER,3,2]) < 0.0001)
OR
(OBLIMITS[OBNUMBER,3,2] > ZINTERSECT) THEN BEGIN
IF (ABS(XINTERSECT-OBLIMITS[OBNUMBER,1,2]) < 0.0001)
OR
(OBLIMITS[OBNUMBER,1,2] > XINTERSECT) THEN BEGIN
IF (ABS(XINTERSECT-OBLIMITS[OBNUMBER,1,1]) < 0.0001)
OR
(XINTERSECT > OBLIMITS[OBNUMBER,1,1]) THEN BEGIN
NOSEE:=1;
GOTO 1;
END {IF THIS SURFACE IS CLOSER THAN ANY OTHER}
END
END
END
END;
3:END; {NUMSURFACE}
2:END; {OBNUMBER}
1:END; {PROCEDURE} {PROCEDURE ELEOBTEST}


PROCEDURE INTREFL1;
{THE MASTER PROCEDURE FOR THE CALCULATION OF
FORMFACTORS FOR EITHER
PARALLEL OR PERPENDICULAR ELEMENTS.     }

LABEL 1;
VAR Z,LHS3,A,B,C,LHS1,LHS2,LHS,F12,AREA1,XBAR,
IFORMFACTOR,JFORMFACTOR,LEN3,LEN4,AREA2,
BDDELE,ADDELE,STHEIGHT,STWKPLNHT,
DISTBTSURF,LEN1,LEN2,YBAR,ZBAR,F12TOT,LHSTOT:REA
L;
IRMSURFACE,JRMSURFACE,DIFMOD,ACOMPARE,TEST1,TES
T2,II,JJ,MULT,
IELEOBNUM,STA,STB,STC:INTEGER;
Y:AA;

PROCEDURE PARFORMF(II,III:INTEGER);
{THE SURFACE IN TERMS OF 1..4 IN DIRECTION OF
FACING,
THE ELELENT NUMBER}
LABEL 1;
TYPE STT=ARRAY[1..2,1..3,1..2] OF REAL;
VAR MULT,LL,I,J,K,M:INTEGER;
ST:STT;
A,B:REAL;
BEGIN
{THE NEXT IS A TEST TO DETERMINE IF THE TWO SIDES
ARE FACING PARALLEL }
{ TO THE LENGTH OR PERPENDICULAR TO IT}
```

```
{CALCULATES FRACTION OF FLUX LEAVING SURF 1
WHICH IS INCIDENT ON SURF 2}
FOR I:=1 TO 3 DO BEGIN
FOR J:=1 TO 2 DO BEGIN
ST[1,I,J]:=GENINTELE[III,I,J];
END; {J COUNTER}
END; {I COUNTER}
FOR I:=1 TO 3 DO BEGIN
FOR J:=1 TO 2 DO BEGIN
ST[2,I,J]:=GENINTELE[JJ,I,J];
END; {J COUNTER}
END; {I COUNTER}
{THIS READING THE ARRAYS INTO A STORAGE ARRAY
SAVES CONVERTING BACK TO
 THE SMALLER ORIGINAL ELEMENTS IF THERE HAS BEEN
A CHANGE. }
IF (TRUNC(II/2)=II/2) THEN BEGIN
{IE THE SIDES ARE EVEN NUMBERED}
STA:=1;  {STA IS THE DISTANCE BETWEEN THE SURFACES
}
STB:=3;  {STB & STC ARE THE DIRECTIONS OF
MOVEMENT }
STC:=2;  {OVER EACH OF THE SURFACES              }
END
ELSE BEGIN
STA:=2;  {STA IS THE DISTANCE BETWEEN THE SURFACES
}
STB:=1;  {STB & STC ARE THE DIRECTIONS OF
MOVEMENT }
STC:=3;  {OVER EACH OF THE SURFACES              }
END;
DISTBTSURF:=ABS(ST[1,STA,1]-ST[2,STA,2]);

IF (DISTBTSURF<0.1) THEN BEGIN
{IF THE TWO SIDES ARE CLOSER TOGETHER THAN 0.1
THEN NO FORMFACTOR IS
CALCULATED SINCE JUST TOO INACCURATE AND
THEREFORE POINTLESS}
{WRITELN('DISTBTSURF < 0.1');}
IFORMFACTOR:=0;
JFORMFACTOR:=0;
GOTO 1,
END,
IF (DISTBTSURF<1.0) THEN BEGIN
MULT:=TRUNC(1/DISTBTSURF)+1;
IF (TRUNC(II/2)=II/2) THEN BEGIN  {EVEN NUMBERED
SURFACES}
FOR LL:=2 TO 3 DO BEGIN {MAKE THE SURFACES AND
THE DISTANCES BETWEEN
THEM CORRESPONDINGLY BIGGER TO ALLOW THE FORM
FACTOR EQUATION TO BE
CARRIED OUT ACCURATELY}
ST[1,LL,2]:=ST[1,LL,2]*MULT;
ST[2,LL,2]:=ST[2,LL,2]*MULT;
END; {LL COUNTER}
ST[2,1,2]:=ST[2,1,2]*MULT;
END
ELSE BEGIN {ODD NUMBERED SURFACES }
{MAKE THE SURFACES AND THE DISTANCES BETWEEN
THEM CORRESPONDINGLY
BIGGER TO ALLOW THE FORMFACTOR EQUATION TO BE
CARRIED OUT ACCURATELY}
ST[1,1,2]:=ST[1,1,2]*MULT;
ST[1,3,2]:=ST[1,3,2]*MULT;
ST[2,1,2]:=ST[2,1,2]*MULT;
ST[2,2,2]:=ST[2,2,2]*MULT;
ST[2,3,2]:=ST[2,3,2]*MULT;
END
END; {IF DISTBTSURF < 1.0 }
FOR I:=1 TO 2 DO BEGIN
FOR J:=1 TO 2 DO BEGIN
FOR K:=1 TO 2 DO BEGIN
FOR M:=1 TO 2 DO BEGIN
B:=(1/DISTBTSURF)*(ST[2,STB,M]-ST[1,STB,J]);
A:=(1/DISTBTSURF)*(ST[2,STC,K]-ST[1,STC,I]);
LHS1:=B*(SQRT(SQR(A)+1))*ARCTAN(B/SQRT(SQR(A)+1));
LHS2:=A*(SQRT(SQR(B)+1))*ARCTAN(A/SQRT(SQR(B)+1));
LHS3:=0.5*LN(SQR(A)+SQR(B)+1);
LHS:=LHS1+LHS2-LHS3;
IF (((I+J+K+M)/2) = TRUNC((I+J+K+M)/2)) THEN MULT:=1
ELSE MULT:=-1;
LHSTOT:=MULT*LHS+LHSTOT;
END {M COUNTER}
END {K COUNTER}
END {J COUNTER}
END; {I COUNTER}
LEN1:=ST[1,STB,2]-ST[1,STB,1];
LEN2:=ST[1,STC,2]-ST[1,STC,1];
AREA1:=LEN1*LEN2;
IFORMFACTOR:=ABS((DISTBTSURF/(2*PI*AREA1))*LHSTOT)
;
LEN3:=ST[2,STB,2]-ST[2,STB,1];
LEN4:=ST[2,STC,2]-ST[2,STC,1];
AREA2:=LEN3*LEN4;
JFORMFACTOR:=ABS((DISTBTSURF/(2*PI*AREA2))*LHSTOT)
;
1:STFORMFACT[III,JJ]:=IFORMFACTOR;
STFORMFACT[JJ,III]:=JFORMFACTOR;
END; {PROCEDURE PARFORMF}



PROCEDURE PERPFMFA(II,III:INTEGER);
{THE SURFACE IN TERMS OF 1..4 IN DIRECTION OF
FACING,
THE ELELENT NUMBER}
VAR A,B,C:REAL;
I,J,K,M:INTEGER;
BEGIN
{THE NEXT IS A TEST TO DETERMINE IF THE TWO SIDES
ARE FACING PARALLEL }
{ TO THE LENGTH OR PERPENDICULAR TO IT}
IF (TRUNC(II/2)=II/2) THEN BEGIN {SIDE IS EVEN}
STA:=2;  {STA IS THE DIRECTION WHICH IS CONSTANT  }
STB:=3;  {STB & STC ARE THE DIRECTIONS OF
MOVEMENT }
STC:=1;  {OVER EACH OF THE SURFACES              }
END
ELSE BEGIN
STA:=1;  {STA IS THE DIRECTION WHICH IS CONSTANT  }
STB:=3;  {STB & STC ARE THE DIRECTIONS OF
MOVEMENT }
STC:=2;  {OVER EACH OF THE SURFACES              }
END;
ZBAR:=GENINTELE[III,STC,1];
XBAR:=GENINTELE[JJ,STA,2];
FOR I:=1 TO 2 DO BEGIN
FOR J:=1 TO 2 DO BEGIN
FOR K:=1 TO 2 DO BEGIN
FOR M:=1 TO 2 DO BEGIN
C:=(GENINTELE[III,STA,K]-XBAR);
B:=(ZBAR-GENINTELE[JJ,STC,J]);
A:=(GENINTELE[III,STB,M]-GENINTELE[JJ,STB,I]);
IF ((SQR(B)+SQR(C)) < 0.0000001) THEN BEGIN
LHS1:=0;
END
ELSE
LHS1:=A*(SQRT(SQR(B)+SQR(C)))*ARCTAN(A/SQRT(SQR(B)+
SQR(C)));
IF ((SQR(A)+SQR(B)+SQR(C)) < 0.0000001) THEN BEGIN
LHS2:=0;
END
ELSE LHS2:=0.25*(SQR(A)-SQR(B)-
SQR(C))*LN(SQR(A)+SQR(B)+SQR(C));
LHS:=LHS1+LHS2;
IF (((I+J+K+M)/2) = TRUNC((I+J+K+M)/2)) THEN MULT:=1
ELSE MULT:=-1;
LHSTOT:=MULT*LHS+LHSTOT;
END {M COUNTER}
END {K COUNTER}
END {J COUNTER}
END; {I COUNTER}
LEN1:=GENINTELE[III,STA,2]-GENINTELE[III,STA,1];
LEN2:=GENINTELE[III,STB,2]-GENINTELE[III,STB,1];
AREA1:=LEN1*LEN2;
IFORMFACTOR:=ABS((1/(2*PI*AREA1))*LHSTOT);
LEN3:=GENINTELE[JJ,STC,2]-GENINTELE[JJ,STC,1];
LEN4:=GENINTELE[JJ,STB,2]-GENINTELE[JJ,STB,1];
AREA2:=LEN3*LEN4;
JFORMFACTOR:=ABS((1/(2*PI*AREA2))*LHSTOT);
STFORMFACT[III,JJ]:=IFORMFACTOR;
STFORMFACT[JJ,III]:=JFORMFACTOR;
END; {PROCEDURE PERPFMFA}

BEGIN
STHEIGHT:=HEIGHT;
STWKPLNHT:=WKPLNHT;
FOR II:=TOTELEMENTNUM DOWNTO 2 DO BEGIN
FOR JJ:=1 TO II-1 DO BEGIN
IF (JJ=1) AND (II > (STTOTELEMENTNUM+0.5)) THEN
BEGIN
IELEOBNUM:=(TRUNC(((II-1)-STTOTELEMENTNUM)/4))+1;
{TELLS WHICH OBSTRUCTION THE ELEMENT IS ON}
REFLECT[II]:=OBREFLECT[IELEOBNUM];
END;
LHSTOT:=0;
IF (II>(STTOTELEMENTNUM+0.5)) AND
(JJ>(STTOTELEMENTNUM+0.5)) THEN BEGIN
{BOTH ELEMENTS ARE ON OBSTRUCTION SURFACES}
TEST1:=II MOD 4;
TEST2:=JJ MOD 4;
DIFMOD:=TEST1-TEST2;
IF ABS(DIFMOD) < 0.001 THEN BEGIN {SURFACES FACE
THE SAME DIRECTION}
```

```
STFORMFACT[II,JJ]:=0;
STFORMFACT[JJ,II]:=0;
GOTO 1;
END;
IF (TEST1=0) THEN ACOMPARE:=4
ELSE ACOMPARE:=TEST1;
IF ((II-JJ) < ACOMPARE) THEN BEGIN {SURFACES ARE ON
THE SAME OBSTRUC}
STFORMFACT[II,JJ]:=0;
STFORMFACT[JJ,II]:=0;
GOTO 1;
END;
IF ACOMPARE=1 THEN
IF (GENINTELE[II,2,1] >
((GENINTELE[JJ,2,1]+GENINTELE[JJ,2,2])/2)) THEN
BEGIN
STFORMFACT[II,JJ]:=0;
STFORMFACT[JJ,II]:=0;
GOTO 1;
END;

IF ACOMPARE=2 THEN
IF (GENINTELE[II,1,1] <
((GENINTELE[JJ,1,1]+GENINTELE[JJ,1,2])/2)) THEN
BEGIN
STFORMFACT[II,JJ]:=0;
STFORMFACT[JJ,II]:=0;
GOTO 1;
END;
IF ACOMPARE=3 THEN
IF (GENINTELE[II,2,1] <
((GENINTELE[JJ,2,1]+GENINTELE[JJ,2,2])/2)) THEN
BEGIN
STFORMFACT[II,JJ]:=0;
STFORMFACT[JJ,II].=0;
GOTO 1;
END;
IF ACOMPARE=4 THEN
IF (GENINTELE[II,1,1] >
((GENINTELE[JJ,1,1]+GENINTELE[JJ,1,2])/2)) THEN
BEGIN
STFORMFACT[II,JJ]·=0;
STFORMFACT[JJ,II].=0;
GOTO 1;
END;

VECTOFELETOELELINE(II,JJ);  {THE TEST FOR SIGHT
BETWEEN CENTRES OF ELEMENTS}
VECTCOSLINE;
IELEOBNUM·=(TRUNC(((II-1)-STTOTELEMENTNUM)/4))+1;
{TELLS WHICH OBSTRUCTION THE ELEMENT IS ON}
{GIVES THE REFLECTION FACTOR OF THE OBSTRUCTION
WHICH IS READ IN IN
PROCEDURE OBDIRCOSIN TO THE ELEMENT REFLECTION
HOLDER PROCEDURE}
NOSEE =0;
ELEOBTEST(IELEOBNUM,TEST1,NOSEE); {OBSTRUCTION
NUMBER, SURFACENUMBER}
IF (ABS(1-NOSEE) < 0.001) THEN BEGIN
STFORMFACT[II,JJ]:=0;
STFORMFACT[JJ,II]:=0;
GOTO 1;
END;

TEST1:=II MOD 2;
TEST2·=JJ MOD 2;
IF (ABS(TEST1-TEST2) < 0.0001) THEN BEGIN
{TEST1 AND TEST2 CAN ONLY BE 1 OR 0 AND IF THEY
ARE THE SAME THEN THE
SIDES ARE PARALLEL}
{THE ELEMENTS ARE PARALLEL}
PARFORMF(II,II);
END
ELSE BEGIN
{THE ELEMENTS ARE PERPENDICULAR}
PERPFMFA(II,II);
END;
GOTO 1;
END; {BOTH ELEMENTS ARE ON OBSTRUCTION
SURFACES}

IF JJ=1 THEN BEGIN {NEW II HAS BEEN CLOCKED}
ADDELE:=(RMSPLITINFO[1,1]*RMSPLITINFO[1,2])+0.5;
IF (II < (STTOTELEMENTNUM+0.5)) THEN BEGIN {IS A
ROOM SURFACE}
{NOW TO FIND OUT WHICH ROOMSURFACE THE ELEMENT
MIGHT BE ON}
IF (II > 0) AND (II < ADDELE) THEN IRMSURFACE:=1;
BDDELE:=ADDELE;
ADDELE:=(RMSPLITINFO[2,1]*RMSPLITINFO[2,2])+ADDELE;
IF (II > BDDELE) AND (II < ADDELE) THEN
IRMSURFACE:=2;
BDDELE:=ADDELE;
ADDELE:=(RMSPLITINFO[3,1]*RMSPLITINFO[3,2])+ADDELE;
IF (II > BDDELE) AND (II < ADDELE) THEN
IRMSURFACE:=3;
BDDELE:=ADDELE;
ADDELE:=(RMSPLITINFO[4,1]*RMSPLITINFO[4,2])+ADDELE;
IF (II > BDDELE) AND (II < ADDELE) THEN
IRMSURFACE:=4;
BDDELE:=ADDELE;
REFLECT[II]:=RW[IRMSURFACE];
{GIVES THE REFLECTION FACTOR OF THE ROOM SURFACE
TO THE ELEMENT II}
END; {ROOM SURFACENUMBER DELEGATION FOR II}
END; {NEW II HAS BEEN CLOCKED}

IF (JJ < (STTOTELEMENTNUM+0.5)) THEN BEGIN {IS A
ROOM SURFACE}
{NOW TO FIND OUT WHICH ROOMSURFACE THE ELEMENT
MIGHT BE ON}
ADDELE:=(RMSPLITINFO[1,1]*RMSPLITINFO[1,2])+0.5;
IF (JJ > 0) AND (JJ < ADDELE) THEN JRMSURFACE:=1;
BDDELE:=ADDELE;
ADDELE:=(RMSPLITINFO[2,1]*RMSPLITINFO[2,2])+ADDELE;
IF (JJ > BDDELE) AND (JJ < ADDELE) THEN
JRMSURFACE:=2;
BDDELE:=ADDELE;
ADDELE:=(RMSPLITINFO[3,1]*RMSPLITINFO[3,2])+ADDELE;
IF (JJ > BDDELE) AND (JJ < ADDELE) THEN
JRMSURFACE:=3;
BDDELE:=ADDELE;
ADDELE:=(RMSPLITINFO[4,1]*RMSPLITINFO[4,2])+ADDELE;
IF (JJ > BDDELE) AND (JJ < ADDELE) THEN
JRMSURFACE:=4;
BDDELE:=ADDELE;
END; {ROOM SURFACENUMBER DELEGATION FOR JJ}

IF (II>(STTOTELEMENTNUM+0.5)) AND
(JJ<(STTOTELEMENTNUM+0.5)) THEN BEGIN
{II ELEMENT IS ON AN OBSTRUCTION SURFACE AND JJ IS
ON A ROOM SURFACE}
TEST1:=(II-STTOTELEMENTNUM) MOD 4;
IF TEST1=0 THEN TEST1:=4;
DIFMOD:=TEST1-JRMSURFACE;
IF ABS(DIFMOD) < 0.001 THEN BEGIN {SURFACES FACE
THE SAME DIRECTION}
STFORMFACT[II,JJ]:=0;
STFORMFACT[JJ,II]:=0;
GOTO 1;
END;
IF TEST1=1 THEN
IF (GENINTELE[II,2,1] >
((GENINTELE[JJ,2,1]+GENINTELE[JJ,2,2])/2)) THEN

BEGIN
STFORMFACT[II,JJ]:=0;
STFORMFACT[JJ,II]:=0;
GOTO 1;
END;
IF TEST1=2 THEN
IF (GENINTELE[II,1,1] <
((GENINTELE[JJ,1,1]+GENINTELE[JJ,1,2])/2)) THEN
BEGIN
STFORMFACT[II,JJ]:=0;
STFORMFACT[JJ,II]:=0;
GOTO 1;
END;
IF TEST1=3 THEN
IF (GENINTELE[II,2,1] <
((GENINTELE[JJ,2,1]+GENINTELE[JJ,2,2])/2)) THEN
BEGIN
STFORMFACT[II,JJ]:=0;
STFORMFACT[JJ,II]:=0;
GOTO 1;
END;
IF TEST1=4 THEN
IF (GENINTELE[II,1,1] >
((GENINTELE[JJ,1,1]+GENINTELE[JJ,1,2])/2)) THEN
BEGIN
STFORMFACT[II,JJ]:=0;
STFORMFACT[JJ,II]:=0;
GOTO 1;
END;
```

```
VECTOFELETOELELINE(II,JJ);
VECTCOSLINE;
IELEOBNUM:=(TRUNC(((II-1)-STTOTELEMENTNUM)/4))+1;
{TELLS WHICH OBSTRUCTION THE ELEMENT IS ON}
NOSEE:=0;
ELEOBTEST(IELEOBNUM,TEST1,NOSEE); {OBSTRUCTIONS
NUMBER, SURFACE NUM}
IF (ABS(1-NOSEE) < 0.001) THEN BEGIN
STFORMFACT[II,JJ]:=0;
STFORMFACT[JJ,II]:=0;
GOTO 1;
END;

TEST1:=II MOD 2;
TEST2:=JRMSURFACE MOD 2;
IF (ABS(TEST1-TEST2) < 0.0001) THEN BEGIN
{TEST1 AND TEST2 CAN ONLY BE 1 OR 0 AND IF THEY
ARE THE SAME THEN THE
SIDES ARE PARALLEL}
{THE ELEMENTS ARE PARALLEL}
PARFORMF(II,II);
END
ELSE BEGIN
{THE ELEMENTS ARE PERPENDICULAR}
PERPFMFA(II,II);
END;
END;{II ELEMENT IS ON AN OBSTRUCTION SURFACE AND
JJ IS ON A ROOM SURFACE}

IF (II<(STTOTELEMENTNUM+0.5)) AND
(JJ<(STTOTELEMENTNUM+0.5)) THEN BEGIN
{ ELEMENT II AND JJ ARE ON A ROOM SURFACE}
IF (ABS(IRMSURFACE-JRMSURFACE) < 0.001) THEN BEGIN
{CANTSEE EACH OTHER AS ARE ON SAME SURFACE}
STFORMFACT[II,JJ]:=0;
STFORMFACT[JJ,II]:=0;
GOTO 1;
END;
VECTOFELETOELELINE(II,JJ);
VECTCOSLINE;
{IN HERE GOES THE TEST FOR SIGHT BETWEEN CENTRES
OF ELEMENTS}
{TELLS WHICH OBSTRUCTION THE ELEMENT IS ON}
NOSEE:=0;
ELEOBTEST(0,IRMSURFACE,NOSEE); {OBSTRUCTIONS
WHICH DONT COUNT ARE
 SET TO ZERO , THE DIRECTION OF THE EMMITTTING
ELEMENT}
IF (ABS(1-NOSEE) < 0.001) THEN BEGIN
STFORMFACT[II,JJ]:=0;
STFORMFACT[JJ,II]:=0;
GOTO 1;
END;
TEST1:=IRMSURFACE MOD 2;
TEST2:=JRMSURFACE MOD 2;
IF (ABS(TEST1-TEST2) < 0.0001) THEN BEGIN
{TEST1 AND TEST2 CAN ONLY BE 1 OR 0 AND IF THEY
ARE THE SAME THEN THE
SIDES ARE PARALLEL}
{THE ELEMENTS ARE PARALLEL}
PARFORMF(IRMSURFACE,II);
END
ELSE BEGIN
{THE ELEMENTS ARE PERPENDICULAR}
PERPFMFA(IRMSURFACE,II);
END,
END, { ELEMENT II AND JJ ARE ON A ROOM SURFACE}
1.END {JJ COUNTER }
END;  {II COUNTER }
HEIGHT:=STHEIGHT;
WKPLNHT:=STWKPLNHT;
END;  {PROCEDURE INTREFL1}


PROCEDURE INREFSETUPARRAY;
{THIS PROCEDURE SETS UP THE TWO ARRAYS AS IN THE
BRACKETTS PAPER PAGE 4}
{FIRARRAY IS THE FORMFACTOR * REFLECTION FACTOR
FOR EACH ELEMENT}
{THIRARRAY IS THE INITIAL AVERAGE ILLUMINANCE OF
THE ELEMENT * ITS}
{REFLECTION FACTOR}
VAR I,J:INTEGER;
BEGIN
FOR I:= 1 TO TOTELEMENTNUM DO BEGIN
FOR J:= 1 TO TOTELEMENTNUM DO BEGIN
IF (I = J) THEN FIRARRAY[I,J]:=-1
ELSE FIRARRAY[I,J]:=REFLECT[I]*STFORMFACT[I,J];
END;  {J COUNTER}
THIRARRAY[I]:=-1*ELEMITAV[I];
{NOTE NO NEED TO MULTIPLY BY THE ELEMENT
REFLECTION FACTOR SINCE ELEMITAV
IS ALREADY THE ILLUMINANCE*REFLECTION FACTOR}
END;  {I COUNTER}
{IF (TIMETHRU=1) AND (WRITNUM=4) THEN BEGIN
  WRITELN(S,'STAGE 1 CHECKING IN INREFSETUPARRAY');
  WRITELN(S,'_______________________________');
  WRITELN(S);
  WRITELN(S,'TABLE OF REFLECTION FACTORS OF
ELEMENTS');
  FOR I:= 1 TO TOTELEMENTNUM DO BEGIN
    WRITELN(S,'REFLECT[',I:1,'] = ',REFLECT[I]:3:1);
  END;
  WRITELN(S,'_______________________________');
  WRITELN(S);
  WRITELN(S,'TABLE OF FORM FACTOR OF ELEMENTS');
  FOR I:= 1 TO TOTELEMENTNUM DO BEGIN
    FOR J:= 1 TO TOTELEMENTNUM DO BEGIN
      WRITE(S,STFORMFACT[I,J]:3:1,' ');
      IF (J=TOTELEMENTNUM) THEN BEGIN
        WRITELN(S);
        WRITELN(S);
        WRITELN(S);
      END;
    END
  END;
  WRITELN(S,'_______________________________');
  WRITELN(S);
  WRITELN(S,'TABLE OF FORM FACT. * REFL. FACT. OF
ELEMENTS');
  FOR I:= 1 TO TOTELEMENTNUM DO BEGIN
    FOR J:= 1 TO TOTELEMENTNUM DO BEGIN
      WRITE(S,FIRARRAY[I,J]:3:1,' ');
      IF (J=TOTELEMENTNUM) THEN BEGIN
        WRITELN(S);
        WRITELN(S);
        WRITELN(S);
      END;
    END
  END;
  WRITELN(S,'_______________________________');
  WRITELN(S);
  WRITELN(S,'TABLE OF INITIAL AVEG. EMITTANCE');
  FOR I:= 1 TO TOTELEMENTNUM DO BEGIN
    WRITELN(S,'THIRARRAY[',I:1,'] = ',THIRARRAY[I]:5:1);
  END;
  WRITELN(S,'_______________________________');
  WRITELN(S);
END;}
END;    {PROCEDURE INREFSETUPARRAY }
```

```
BEGIN
ELEMENTARRAY;{READS ALL OBSTRUCTION LIMITS INTO
THE ONE ARRAY FOR INTREFL1}
STOBNUM:=OBNUM;
FOR NUMWRIT:=3 TO 4 DO BEGIN
WRITNUM:=NUMWRIT;
IF WRITNUM=3 THEN BEGIN
TOTELEMENTNUM:=TOTELEMENTNUM-(OBNUM*4);
OBNUM:=0;
END; {WRITNUM=3 CASE}
IF WRITNUM=4 THEN BEGIN
OBNUM:=STOBNUM;
TOTELEMENTNUM:=TOTELEMENTNUM+(OBNUM*4);
END; {WRITNUM=4 CASE}
INTREFL1;  {CALCULATES THE FORM FACTORS FOR PAR
& PERP SURFACES}
INREFSETUPARRAY; {SETS UP THE INITIAL EMITANCE &
FORMFACT ARRAYS
          FOR THE INTER- REFLECTION CALCULATIONS }
GAUSS; {CALCULATES THE FINAL EMMITANCES OF THE
ELEMENTS
          USING GAUSS MATRIX INVERSION TECHNIQUES}
IF WRITNUM=4 THEN
FNLOBSURFILUMGRID; {THESE TWO CALCULATE THE
FINAL ILLUMINANCES      }
FNLWALLILUMGRID;  {OVER THE ROOM AND
OBSTRUCTION VERTICAL SURFACES }
{WALLGRIDWRIT; }

END; { NUMWRIT COUNTER }
CEILILUMFRMWALS;
END; {PROCEDURE THEINTERREFLECTION}


PROCEDURE SEILEMITCAL(STSURFACENUM:INTEGER;
            XINTERSECT,YINTERSECT:REAL;
            VAR EMITANCE:REAL);
{CALCULATES THE EMMITANCE FROM THE SECTION OF
CEILING
 WHICH THE SECTION OF THE HEMISPHERE CAN "SEE"}
```

```
VAR N,M:INTEGER;
ILLUMIN,DELTAX,DELTAY,HORIDIST,VERTDIST,ACHORDIS
CRE,ACVERTDISCRE:REAL;
BEGIN
HORIDIST:=ABS(RMLIMITS[STSURFACENUM,1,1]-
XINTERSECT);
VERTDIST:=ABS(RMLIMITS[STSURFACENUM,2,1]-
YINTERSECT);
ACHORDISCRE:=ACRMSURFDISCRE[6,1];
ACVERTDISCRE:=ACRMSURFDISCRE[6,2];
N:=TRUNC(HORIDIST/ACHORDISCRE);
M:=TRUNC(VERTDIST/ACVERTDISCRE);
DELTAX:=HORIDIST-(N*ACHORDISCRE);
DELTAY:=VERTDIST-(M*ACVERTDISCRE);
ILLUMIN:=BIGCEILGRID[N+1,M+1]*(DELTAX*DELTAY)
+BIGCEILGRID[N,M+1]*((ACHORDISCRE-
DELTAX)*(DELTAY))
+BIGCEILGRID[N,M]*((ACHORDISCRE-
DELTAX)*(ACVERTDISCRE-DELTAY))
+BIGCEILGRID[N+1,M]*(DELTAX*(ACVERTDISCRE-
DELTAY));
EMITANCE:=RC*ILLUMIN;
IF EMITANCE > 100 THEN BEGIN
{10* AVERAGE CEILING EMMITANCE}

{THE SECTION OF HEMISPHERE CAN SEE EITHER THE
LUMINAIRE OR THE PATCH
OF HIGH ILLUMINANCE WHICH SURROUNDS IT.
THEREFORE WE MUST USE WHAT WE
LEARNT IN THE THREE CEILING PROGRAMS AND WROTE
ABOUT IN THE PAPER.
ALSO MUST INTRODUCE A TEST WHICH STOPS THIS
LUMINAIRE BEING COUNTED
TWICE AS AN AREA OF HIGH LUMINANCE IE STOP THE N
OR M BEING ROUNDED
THE NEXT TIME TO SEE THE SAME PATCH OF HIGH
ILLUMINANCE AGAIN WHICH
WOULD CAUSE ONE LUMINAIRES HIGH LUMINANCE TO
BE COUNTED TWICE.}
END.
END. {PROCEDURE SIELEMITCALC}


PROCEDURE
RMEMITCAL(STSURFACENUM,LIMITKIND.INTEGER;
        STXYINTERSECT,STZINTERSECT:REAL;
        VAR EMITANCE.REAL);
{CALCULATES THE EMMITANCE FROM THE SECTION OF
ROOM WALL SURFACE,
 WHICH THE SECTION OF THE HEMISPHERE CAN "SEE"}
{THE CALCULATIONS INVOLVED IN THIS PROCEDURE ARE
OF COURSE CLOSELY
RELATED TO THE INITIAL CALCULATION OF THE
ILLUMINANCE OVER THE WALLS
PERFORMED BY PROCEDURE WALLPTGRID . IE THE
HORIDIST & VERTDIST TERMS
CALCULATE FROM THE LOW LOW CORNER NOT THE HIGH
HIGH }
{BY CHANGING THE VERTDIST TO BE FROM HEIGHT NOT
WKPLNHT THE CORRECT
VALUE OF M IS GENERATED TO READ THE
WALLILLUMINANCE GRID CORRECTLY}


VAR N,M:INTEGER;
HORIDIST,VERTDIST,ILLUMIN,DELTAX,DELTAY,ACHORDIS
CRE,ACVERTDISCRE:REAL;
BEGIN
HORIDIST:=ABS(RMLIMITS[STSURFACENUM,LIMITKIND,1]-
STXYINTERSECT);
VERTDIST:=ABS(HEIGHT-STZINTERSECT);
ACHORDISCRE:=ACRMSURFDISCRE[STSURFACENUM,1];
ACVERTDISCRE:=ACRMSURFDISCRE[STSURFACENUM,2];
N:=TRUNC(HORIDIST/ACHORDISCRE);
M:=TRUNC(VERTDIST/ACVERTDISCRE);
DELTAX:=HORIDIST-(N*ACHORDISCRE);
DELTAY:=VERTDIST-(M*ACVERTDISCRE);
ILLUMIN:=WALLILLUM[WRITNUM,STSURFACENUM,N+1,M
+1]*(DELTAX*DELTAY)
+WALLILLUM[WRITNUM,STSURFACENUM,N,M+1]*((ACHOR
DISCRE-DELTAX)*(DELTAY))
+WALLILLUM[WRITNUM,STSURFACENUM,N,M]*((ACHORDI
SCRE-DELTAX)*(ACVERTDISCRE-DELTAY))
+WALLILLUM[WRITNUM,STSURFACENUM,N+1,M]*(DELTA
X*(ACVERTDISCRE-DELTAY));
EMITANCE:=RW[STSURFACENUM]*ILLUMIN;
(*ITELN('EMITANCE :=',EMITANCE:3:2,' RW[
',STSURFACENUM,RW[STSURFACENUM]); *)
END; {PROCEDURE RMEMITCAL}
```

```
PROCEDURE
SFEMITCAL(STOBNUMBER,STSURFACENUM,LIMITKIND:IN
TEGER;
        STXYINTERSECT,STZINTERSECT:REAL;
        VAR EMITANCE:REAL);
{CALCULATES THE EMMITANCE FROM THE SECTION OF
OBSTRUCTION SURFACE, WHICH THE SECTION OF THE
HEMISPHERE CAN "SEE"}

VAR INTEREST,N,M:INTEGER;
HORIDIST,VERTDIST,ILLUMIN,DELTAX,DELTAY,ACHORDIS
CRE,ACVERTDISCRE:REAL;
BEGIN
HORIDIST:=ABS(OBLIMITS[STOBNUMBER,LIMITKIND,2]-
STXYINTERSECT);
VERTDIST:=ABS(OBLIMITS[STOBNUMBER,3,2]-
STZINTERSECT);
ACHORDISCRE:=ACOBDISCRE[STOBNUMBER,STSURFACEN
UM,1];
ACVERTDISCRE:=ACOBDISCRE[STOBNUMBER,STSURFACEN
UM,2];
N:=TRUNC(HORIDIST/ACHORDISCRE);
M:=TRUNC(VERTDIST/ACVERTDISCRE);
DELTAX:=HORIDIST-(N*ACHORDISCRE);
DELTAY:=VERTDIST-(M*ACVERTDISCRE);
ILLUMIN:=OBILUM[STOBNUMBER,STSURFACENUM,N+1,M+
1]*(DELTAX*DELTAY)
+OBILUM[STOBNUMBER,STSURFACENUM,N,M+1]*((ACHOR
DISCRE-DELTAX)*(DELTAY))
+OBILUM[STOBNUMBER,STSURFACENUM,N,M]*((ACHORDI
SCRE-DELTAX)*(ACVERTDISCRE-DELTAY))
+OBILUM[STOBNUMBER,STSURFACENUM,N+1,M]*(DELTAX
*(ACVERTDISCRE-DELTAY));
INTEREST:=(STOBNUMBER*4)+STSURFACENUM;
EMITANCE:=REFLECT[STTOTELEMENTNUM+INTEREST]*I
LLUMIN;
END; {PROCEDURE SFEMITCALC}


PROCEDURE INDIRILUMCALC;
{CALCULATES THE INDIRECT ILLUMINANCE OVER THE
WORKING PLANE
SETS UP THE HEMISPHERE ABOVE EACH WORKING PLANE
CALCULATION POINT.
DETERMINES WHICH SURFACE, EITHER ROOM OR
OBSTRUCTION, WHICH THE LINE
PASSING THROUGH THE CENTRE OF THE HEMISPHERE
ACTUALLY SEES AND THEN
CALCULATES THE TOTAL ILLUM RECEIVED FROM ALL
SURFACES AT THE POINT.}

TYPE SN=ARRAY[0..2] OF INTEGER;
VAR
INTSECT1,INTSECT2,INTSECT3,INTSECT4,DISTINTERSECT:
REAL;
SURNUM:SN;
STOBNUMBER,STSURFACENUM,SURFACENUM,
LIMITKIND,II,OBNUMBER,NUMSURFACE,I,J:INTEGER;
ALPHA1,ALPHA2,ACALPHA,STDISTINTERSECT,BETA,
ADSTILLUM,ORIDISTINTERSECT,TOTSUM,SUM,TOPLINE,
STWKPLNHT,EMITANCE,STILLUM,XINTERSECT,YINTERSE
CT,ZINTERSECT:REAL;
STXINTERSECT,STXYINTERSECT,STYINTERSECT,STZINTER
SECT:REAL;


PROCEDURE ALPHASET;
{THIS PROCEDURE SETS THE ANGLE LIMITS OF ALPHA
DIRECTION OF HEMIS-PHERE}

BEGIN

IF J=1 THEN BEGIN
ALPHA1:=0;
ALPHA2:=PI/6;
END
ELSE IF J=2 THEN BEGIN
ALPHA1:=PI/6;
ALPHA2:=PI/4;
END
ELSE IF J=3 THEN BEGIN
ALPHA1:=PI/4;
ALPHA2:=PI/3;
END
ELSE IF J=4 THEN BEGIN
ALPHA1:=PI/3;
ALPHA2:=PI/2;
END;
END; {PROCEDURE ALPHASET}
```

```
PROCEDURE SURNUMSET;
{THIS PROCEDURE SETS THE ARRAY VALUES IN SURNUM}

{THESE NEXT I = 1 TO 12 TELL WHICH SURFACE NUMBER
THE LINE IN THE
THIS DIRECTION CAN INTERSECT WITH IE WHICH
SURFACE NUMBERS MAY
BE SEEN FROM THE POINT IN QUESTION}
BEGIN
IF (I=1) OR (I=2) THEN BEGIN
SURNUM[1]:=2;
SURNUM[2]:=3;
END;
IF (I=3) THEN BEGIN
SURNUM[1]:=3;
SURNUM[2]:=0;
END;
IF (I=4) OR (I=5) THEN BEGIN
SURNUM[1]:=3;
SURNUM[2]:=4;
END,
IF (I=6) THEN BEGIN
SURNUM[1]:=4;
SURNUM[2]:=0;
END;
IF (I=7) OR (I=8) THEN BEGIN
SURNUM[1]:=1;
SURNUM[2]:=4;
END;
IF (I=9) THEN BEGIN
SURNUM[1]:=1;
SURNUM[2].=0;
END,
IF (I=10) OR (I=11) THEN BEGIN
SURNUM[1]:=1;
SURNUM[2]:=2;
END,
IF (I=12) THEN BEGIN
SURNUM[1]:=2;
SURNUM[2]:=0;
END,
END, {PROCEDURE SURNUMSET}


PROCEDURE EMITFROMOBCHECK;
{THIS PROCEDURE DETERMINES IF THE VECTOR OR LINE
PROJECTED FROM THE
CALCULATION POINT IS ABLE TO INTERSECT THE
SURFACE OF ANY OBSTRUCTION
SURFACE IF THIS IS POSSIBLE THEN IT DETERMINES HOW
MUCH "ILLUMINANCE"
IT WILL RECEIVE FROM THE SURFACE THAT IT
INTERSECTS BY INTERPOLATING
AMONGST THE ILLUMINANCE VALUES CLOSEST TO THE
POINT OF INTERSECTION
ON THE SURFACE IN QUESTION}
LABEL 2,3;
VAR OBNUMBER,NUMSURFACE,II:INTEGER;
BEGIN
STDISTINTERSECT:=SQRT(SQR(LENGTH)+SQR(WIDTH)+SQR
(HEIGHT));
ORIDISTINTERSECT:=STDISTINTERSECT;
FOR OBNUMBER:=1 TO OBNUM DO BEGIN
FOR NUMSURFACE:=1 TO 2 DO BEGIN
SURFACENUM:=SURNUM[NUMSURFACE];
IF SURFACENUM=0 THEN GOTO 2;
INTSECT1:=DIRCOS[OBNUMBER,SURFACENUM,6];
INTSECT2:=(XMEASPOINT*DIRCOS[OBNUMBER,SURFACEN
UM,3]);
INTSECT3:=(YMEASPOINT*DIRCOS[OBNUMBER,SURFACEN
UM,4]);
INTSECT4:=(STWKPLNHT*DIRCOS[OBNUMBER,SURFACENU
M,5]);
TOPLINE:=INTSECT1-(INTSECT2+INTSECT3+INTSECT4);
TOTSUM:=0;
FOR II:=1 TO 3 DO BEGIN
SUM.=LNVCTCOS[II]*DIRCOS[OBNUMBER,SURFACENUM,II+
2];
TOTSUM:=SUM+TOTSUM;
END;
IF TOTSUM=0 THEN WRITELN(G,' TOTSUM:=0 ');
DISTINTERSECT:=TOPLINE/TOTSUM;
{THE COORDINATES OF THE INTERSECTION USING
EQUATION 1 TREGENZA IE THE
VECTOR COSINES METHOD. }
XINTERSECT:=XMEASPOINT+(DISTINTERSECT*LNVCTCOS[
1]);
YINTERSECT:=YMEASPOINT+(DISTINTERSECT*LNVCTCOS[
2]);
ZINTERSECT:=STWKPLNHT+(DISTINTERSECT*LNVCTCOS[3
]);
IF (XINTERSECT < 0) OR (YINTERSECT < 0)
OR (ZINTERSECT < STWKPLNHT) THEN GOTO 3; { POINT
IN QUESTION
IS OUT OF ORDER BEING LESS THAN THE X OR Y
INTERSECT OR BELOW
WORKING PLANE HEIGHT }

{NOW CHECK THAT X INTERSECT LIES WITHIN THE X
DIRECTION
LIMITATIONS OF SURFACE UNDER CONSIDERATION AND
SAME FOR Y AND Z}
IF (SURFACENUM=2) OR (SURFACENUM=4) THEN BEGIN
{THE NEXT 0.15 COMPARISON IS JUST TO CHECK IT IS THIS
OB SURFACENUM}
IF (ABS(XINTERSECT-OBLIMITS[OBNUMBER,1,1]) < 0.15) OR
(ABS(XINTERSECT-OBLIMITS[OBNUMBER,1,2]) < 0.15) THEN
IF (ABS(ZINTERSECT-OBLIMITS[OBNUMBER,3,1]) < 0.0001)
OR
(ZINTERSECT > OBLIMITS[OBNUMBER,3,1]) THEN BEGIN
IF (ABS(ZINTERSECT-OBLIMITS[OBNUMBER,3,2]) < 0.0001)
OR
(OBLIMITS[OBNUMBER,3,2] > ZINTERSECT) THEN BEGIN
IF (ABS(YINTERSECT-OBLIMITS[OBNUMBER,2,2]) < 0.0001)
OR
(OBLIMITS[OBNUMBER,2,2] > YINTERSECT) THEN BEGIN
IF (ABS(YINTERSECT-OBLIMITS[OBNUMBER,2,1]) < 0.0001)
OR
(YINTERSECT > OBLIMITS[OBNUMBER,2,1]) THEN BEGIN
IF ABS(DISTINTERSECT) < STDISTINTERSECT THEN BEGIN
{STORE THE RELEVANT INFO ABOUT THIS SURFACE}
{NO NEED TO STORE X COORDINATE SINCE IT IS
CONSTANT}
STOBNUMBER:=OBNUMBER;
STSURFACENUM:=SURFACENUM;
STDISTINTERSECT:=ABS(DISTINTERSECT);
LIMITKIND:=2;
STXYINTERSECT:=YINTERSECT;
STZINTERSECT:=ZINTERSECT;
END {IF THIS SURFACE IS CLOSER THAN ANY OTHER}
END
ELSE GOTO 3;
END
END
END
END; { OBSTRUCTION (SURFACENUM=2) OR
(SURFACENUM=4) }
IF (SURFACENUM=1) OR (SURFACENUM=3) THEN BEGIN
{THE NEXT 0.15 COMPARISON IS JUST TO CHECK IT IS THIS
OB SURFACENUM}
IF (ABS(YINTERSECT-OBLIMITS[OBNUMBER,2,1]) < 0.15) OR
(ABS(YINTERSECT-OBLIMITS[OBNUMBER,2,2]) < 0.15) THEN
IF (ABS(ZINTERSECT-OBLIMITS[OBNUMBER,3,1]) < 0.0001)
OR
(ZINTERSECT > OBLIMITS[OBNUMBER,3,1]) THEN BEGIN
IF (ABS(ZINTERSECT-OBLIMITS[OBNUMBER,3,2]) < 0.0001)
OR
(OBLIMITS[OBNUMBER,3,2] > ZINTERSECT) THEN BEGIN
IF (ABS(XINTERSECT-OBLIMITS[OBNUMBER,1,2]) < 0.0001)
OR
(OBLIMITS[OBNUMBER,1,2] > XINTERSECT) THEN BEGIN
IF (ABS(XINTERSECT-OBLIMITS[OBNUMBER,1,1]) < 0.0001)
OR
(XINTERSECT > OBLIMITS[OBNUMBER,1,1]) THEN BEGIN
IF ABS(DISTINTERSECT) < STDISTINTERSECT THEN BEGIN
{STORE THE RELEVANT INFO ABOUT THIS SURFACE}
{NO NEED TO STORE Y COORDINATE SINCE IT IS
CONSTANT}
STOBNUMBER:=OBNUMBER;
STSURFACENUM:=SURFACENUM;
STDISTINTERSECT:=ABS(DISTINTERSECT);
STXYINTERSECT:=XINTERSECT;
LIMITKIND:=1;
STZINTERSECT:=ZINTERSECT;
END {IF THIS SURFACE IS CLOSER THAN ANY OTHER}
END
ELSE GOTO 3;
END
END
END
END; { OBSTRUCTION (SURFACENUM=1) OR
(SURFACENUM=3) }
3:END; {NUMSURFACE COUNTER}
2:END; {OBNUMBER COUNTER.}

IF STDISTINTERSECT < ORIDISTINTERSECT THEN BEGIN
SFEMITCAL(STOBNUMBER,STSURFACENUM,LIMITKIND,
STXYINTERSECT,STZINTERSECT,EMITANCE); {TO OBTAIN
THE EMITANCE RECEIVED
FROM THE POINT ON THE SIDE OF THE OBSTRUCTION
WHICH IS INTERSECTED. }

IF (STDISTINTERSECT < 0.01) THEN STILLUM:=0   {THE
```

```
VERY UNLIKELY CASE
OF A POINT OF CALCULATION BEING SO CLOSE TO THE
OBSTRUCTION SURFACE
THAT IT WOULD MAKE A MESS OF THE CALCULATIONS
TO COUNT THE ILLUMINANCE
FROM IT. }

ELSE STILLUM:=EMITANCE;
END  { STDISTINTERSECT < ORIDISTINTERSECT }
ELSE STILLUM:=0;
END; {PROCEDURE EMITFROMOBCHECK  }


PROCEDURE EMITFRMWALLS;
{THIS PROCEDURE CALCULATES HOW MUCH EMITTANCE
IS RECEIVED FROM THE
WALLS IF NONE IS RECEIVED FROM ANY OBSTRUCTION
FOR THIS SECTION OF
HEMISPHERE. }
LABEL 1,4;
VAR NUMSURFACE,II:INTEGER;
BEGIN
SURNUM[0]:=5;
FOR NUMSURFACE:=0 TO 2 DO BEGIN
SURFACENUM:=SURNUM[NUMSURFACE];
{WRITELN('SURFACENUM= ',SURFACENUM:3);}
INTSECT1:=RMDIRCOS[SURFACENUM,6];
INTSECT2:=(XMEASPOINT*RMDIRCOS[SURFACENUM,3]);
INTSECT3:=(YMEASPOINT*RMDIRCOS[SURFACENUM,4]);
INTSECT4:=(STWKPLNHT*RMDIRCOS[SURFACENUM,5]);
TOPLINE:=INTSECT1-(INTSECT2+INTSECT3+INTSECT4);
TOTSUM:=0;
FOR II:=1 TO 3 DO BEGIN
SUM:=LNVCTCOS[II]*RMDIRCOS[SURFACENUM,II+2];
TOTSUM:=SUM+TOTSUM;
END;
IF TOTSUM=0 THEN WRITELN(G,' TOTSUM:=0 ');
DISTINTERSECT:=TOPLINE/TOTSUM;
{NOW TO FIND COORDINATES OF THE INTERSECTION
USING EQUATION 1 TREGENZA}
XINTERSECT:=XMEASPOINT+(DISTINTERSECT*LNVCTCOS[
1]);
YINTERSECT:=YMEASPOINT+(DISTINTERSECT*LNVCTCOS[
2]);
ZINTERSECT:=STWKPLNHT+(DISTINTERSECT*LNVCTCOS[3
]);
IF (XINTERSECT < 0) OR (YINTERSECT < 0)
OR (ZINTERSECT < STWKPLNHT) THEN GOTO 1;
{NOW CHECK THAT X INTERSECT LIES WITHIN THE X
DIRECTION}
{LIMITATIONS OF SURFACE UNDER CONSIDERATION ALSO
Y AND Z}
IF SURFACENUM=5 THEN BEGIN
IF (ABS(RMLIMITS[SURFACENUM,1,1]-XINTERSECT) <
0.0001) OR
(XINTERSECT > RMLIMITS[SURFACENUM,1,1]) THEN BEGIN
IF (ABS(RMLIMITS[SURFACENUM,1,2]-XINTERSECT) <
0.0001) OR
(RMLIMITS[SURFACENUM,1,2] > XINTERSECT) THEN BEGIN
IF (ABS(RMLIMITS[SURFACENUM,2,2]-YINTERSECT) <
0.0001) OR
(RMLIMITS[SURFACENUM,2,2] > YINTERSECT) THEN BEGIN
IF (ABS(RMLIMITS[SURFACENUM,2,1]-YINTERSECT) <
0.0001) OR
(YINTERSECT > RMLIMITS[SURFACENUM,2,1]) THEN BEGIN
SEILEMITCAL(SURFACENUM,XINTERSECT,YINTERSECT,E
MITANCE);
GOTO 4;
END
ELSE GOTO 1;
END
END
END
END;  { WALL (SURFACENUM=5) WHICH IS OF COURSE
THE CEILING}
IF (SURFACENUM=2) OR (SURFACENUM=4) THEN BEGIN
IF (ABS(RMLIMITS[SURFACENUM,3,1]-ZINTERSECT) <
0.0001) OR
(ZINTERSECT > RMLIMITS[SURFACENUM,3,1]) THEN BEGIN
IF (ABS(RMLIMITS[SURFACENUM,3,2]-ZINTERSECT) <
0.0001) OR
(RMLIMITS[SURFACENUM,3,2] > ZINTERSECT) THEN BEGIN
IF (ABS(RMLIMITS[SURFACENUM,2,2]-YINTERSECT) <
0.0001) OR
(RMLIMITS[SURFACENUM,2,2] > YINTERSECT) THEN BEGIN
IF (ABS(RMLIMITS[SURFACENUM,2,1]-YINTERSECT) <
0.0001) OR
(YINTERSECT > RMLIMITS[SURFACENUM,2,1]) THEN BEGIN
LIMITKIND:=2;
RMEMITCAL(SURFACENUM,LIMITKIND,YINTERSECT,ZINT
ERSECT,EMITANCE);
GOTO 4;
```

```
END
ELSE GOTO 1;
END
END
END
END;  { WALL (SURFACENUM=2) OR (SURFACENUM=4) }
IF (SURFACENUM=1) OR (SURFACENUM=3) THEN BEGIN
IF (ABS(RMLIMITS[SURFACENUM,3,1]-ZINTERSECT) <
0.0001) OR
(ZINTERSECT > RMLIMITS[SURFACENUM,3,1]) THEN BEGIN
IF (ABS(RMLIMITS[SURFACENUM,3,2]-ZINTERSECT) <
0.0001) OR
(RMLIMITS[SURFACENUM,3,2] > ZINTERSECT) THEN BEGIN
IF (ABS(RMLIMITS[SURFACENUM,1,2]-XINTERSECT) <
0.0001) OR
(RMLIMITS[SURFACENUM,1,2] > XINTERSECT) THEN BEGIN
IF (ABS(RMLIMITS[SURFACENUM,1,1]-XINTERSECT) <
0.0001) OR
(XINTERSECT > RMLIMITS[SURFACENUM,1,1]) THEN BEGIN
LIMITKIND:=1;
RMEMITCAL(SURFACENUM,LIMITKIND,XINTERSECT,ZINT
ERSECT,EMITANCE);
GOTO 4;
END
ELSE GOTO 1;
END
END
END
END;  { WALL (SURFACENUM=2) OR (SURFACENUM=4) }
1:END;  {NUMSURFACE COUNTER }
4:STILLUM:=EMITANCE;
{4:STILLUM:=(EMITANCE*COS((PI/2)-
ACALPHA))/(PI*(SQR(DISTINTERSECT)));}
END;   {PROCEDURE EMITFRMWALLS}


BEGIN
{THE DEFINITION OF ALL AXES AND ANGLES IS IN
ACCORDACE WITH THE
TREGENZA PAPER FIGURE 3 P165}
STWKPLNHT:=WKPLNHT;
ADSTILLUM:=0;
FOR I:=1 TO 12 DO BEGIN
FOR J:=1 TO 4 DO BEGIN
STILLUM:=0;
BETA:=I*PI/6; {ANGLE IN PLAN IE AZIMUTH}
ALPHASET;   {TO OBTAIN THE ALPHA1 AND ALPHA2
VALUES}
ACALPHA:=(ALPHA1+ALPHA2)/2;  {ANGLE OF ELEVATION}
LNVCTCOS[1]:=SIN(ACALPHA)*COS(BETA);
LNVCTCOS[2]:=SIN(ACALPHA)*SIN(BETA);
LNVCTCOS[3]:=COS(ACALPHA);
{THIS IS THE DIRECTIONAL COSINES OF THE LINE FROM
THE CENTRE OF THE
HEMISPHERE WHICH WE WILL COMPARE WITH ALL
SURFACES IN ROOM TO DETERMINE
WHERE THERE IS AN INTERSECTION}
SURNUMSET;  {GIVES VALUES TO THE ARRAY SURNUM }

EMITFROMOBCHECK;  {TO CALCULATE IF THE LINE FROM
THE CALCULATION POINT
PASSES THROUGH AN OBSTRUCTION SURFACE AND IF SO
WHAT EMITANCE IS
RECEIVED FROM IT. }
IF (STILLUM < 0.001) THEN
{IF NO OBSTRUCTION SURFACE INTERSECTS THE LINE
THEN COMPARE
 WITH ALL WALL SURFACES SINCE ONE SURFACE MUST
INTERSECT IT}
EMITFRMWALLS;
ADSTILLUM:=ADSTILLUM+STILLUM;

END  {J COUNTER }
END; {I COUNTER }
PTILUMTOT:=ADSTILLUM/48;
END;  {PROCEDURE INDIRILUMCALC}


PROCEDURE INDIRILUMPTGRID;
LABEL 1;
VAR OBNUMBER,I,J,N,M:INTEGER;
XWKPLNDISCRE,YWKPLNDISCRE:REAL;
BEGIN
N:=XNUMPT;
M:=YNUMPT;
XWKPLNDISCRE:=ACRMSURFDISCRE[5,1];
YWKPLNDISCRE:=ACRMSURFDISCRE[5,2];
FOR I:=1 TO N DO BEGIN    (*FOR EVERY POINT IN THE X
DIRECTION*)
FOR J:=1 TO M DO BEGIN    (*FOR EVERY POINT IN THE Y
DIRECTION*)
```

```
XMEASPOINT:=I*XWKPLNDISCRE-
XWKPLNDISCRE/2+XSTARTPT;
YMEASPOINT:=J*YWKPLNDISCRE-
YWKPLNDISCRE/2+YSTARTPT;
{GOTO TO CALCULATION OF INDIRECT ILLUMINANCE
PROCEDURE}
IF XMEASPOINT=0 THEN XMEASPOINT:=0.01;
IF YMEASPOINT=0 THEN YMEASPOINT:=0.01;
{THE CALCULATION OF VECTOR COSINES DOESNT WORK
WHEN 0,0 IS USED
SINCE INFINITY , DIVIDE BY ZERO ETC}
FOR OBNUMBER:=(PERIMOBNUM+1) TO OBNUM DO BEGIN
{ONLY NON-PERIMETER OBSTRUCTIONS CAN BLOCK THE
ILLUMINANCE
OF A POINT BY BEING ON IT}
{THIS IS THE CHECK TO SEE IF THE CALCULATION POINT
IS ACTUALLY
UNDER AN OBSTRUCTION. }
IF (ABS(XMEASPOINT-OBLIMITS[OBNUMBER,1,1]) < 0.0001)
OR
(XMEASPOINT > OBLIMITS[OBNUMBER,1,1]) THEN BEGIN
IF (ABS(XMEASPOINT-OBLIMITS[OBNUMBER,1,2]) < 0.0001)
OR
(OBLIMITS[OBNUMBER,1,2] > XMEASPOINT) THEN BEGIN
IF (ABS(YMEASPOINT-OBLIMITS[OBNUMBER,2,2]) < 0.0001)
OR
(OBLIMITS[OBNUMBER,2,2] > YMEASPOINT) THEN BEGIN
IF (ABS(YMEASPOINT-OBLIMITS[OBNUMBER,2,1]) < 0.0001)
OR
(YMEASPOINT > OBLIMITS[OBNUMBER,2,1]) THEN BEGIN
GOTO 1;
END
END
END
END
END; {OBNUMBER COUNTER }
INDIRILUMCALC;
GDILUM[WRITNUM,I,J]:=PTILUMTOT+GDILUM[WRITNUM-
2,I,J];


1 END {J COUNTER }
END. { I COUNTER }
END;


PROCEDURE ILINTSETUP(T:INTEGER;
VAR INDEX:INTEGER);
{A PROCEDURE USED AS AN INDEX GIVEN IN THE UDIP
INTERPOLATION PROCESS}

BEGIN
INDEX:=T-30;
IF (T>=1) AND (T<=20) THEN INDEX:=1;
IF (T>=21) AND (T<=26) THEN INDEX:=2;
IF (T>=27) AND (T<=30) THEN INDEX:=3;
IF (T>=31) AND (T<=33) THEN INDEX:=4;
IF (T=34) OR (T=35) THEN INDEX:=5;
IF (T>=46) AND (T<=47) THEN INDEX:=16;
IF (T>=48) AND (T<=50) THEN INDEX:=17;
IF (T>=51) AND (T<=54) THEN INDEX:=18;
IF (T>=55) AND (T<=60) THEN INDEX:=19;
IF (T>=61) AND (T<=81) THEN INDEX:=20;
IF T>81 THEN BEGIN WRITELN(G,'T IS IN ERROR');
WRITELN(G,'T = ',T);
END
END; {PROCEDURE ILINTSETUP}


PROCEDURE WALLINTERP(RMSURFACE: INTEGER;
PINTX,PINTY,PINTZ:REAL;VAR ILLUMATPT:REAL);
{CALLED BY THE PROCEDURES WHICH ARE
CALCULATING THE ILLUMINANCE
AT THE POINTS OVER THE VERTICAL SURFACES THIS
INTERPOLATES AMONGST
THE UDIP ILLUMINANCES FOR THE RELEVANT SURFACES
TO OBTAIN THE
ILLUMINANCE AT THE POINT UNDER CONSIDERATION}

LABEL 1;
VAR DELTAX,DELTAY:REAL;
KINDEX,MINDEX,IINDEX,JINDEX:INTEGER;
BEGIN
IF (PINTZ < 0.001) THEN BEGIN
ILLUMATPT:=0;
GOTO 1;
END;
IF (ABS(PINTX/PINTZ) > 10) OR (ABS(PINTY/PINTZ) > 10)
THEN BEGIN
ILLUMATPT:=0;
GOTO 1;
END;
KINDEX:=TRUNC(4*PINTY/ABS(PINTZ)+41);
ILINTSETUP(KINDEX,IINDEX);
MINDEX:=TRUNC(4*PINTX/ABS(PINTZ)+41);
ILINTSETUP(MINDEX,JINDEX);
DELTAX:=((PINTX/PINTZ)-C[JINDEX])/(C[JINDEX+1]-
C[JINDEX]);
DELTAY:=((PINTY/PINTZ)-R[IINDEX])/(R[IINDEX+1]-
R[IINDEX]);
ILLUMATPT:=(BGILMPLN[RMSURFACE+1,IINDEX,JINDEX])*
((1-DELTAX)*(1-DELTAY))
 +(BGILMPLN[RMSURFACE+1,IINDEX+1,JINDEX])*((1-
DELTAX)*(DELTAY))

+(BGILMPLN[RMSURFACE+1,IINDEX,JINDEX+1])*((DELTAX
)*(1-DELTAY))

+(BGILMPLN[RMSURFACE+1,IINDEX+1,JINDEX+1])*(DELTA
X*DELTAY);
1:END; {PROCEDURE WALLINTERP}


PROCEDURE FIRSTCHEK(OBNUMBER:INTEGER);
{PRODUCES NOOBEFFECT=0 IF OBSTRUCTION HAS NO
EFFECT ON ILLUMINANCE}
{FROM THIS LUMINAIRE TO THIS MEASURING POINT}
BEGIN
NOOBEFFECT:=2; {SET TO A KNOWN VALUE FOR WHICH
NOTHING HAPPENS}
IF (XMEASPOINT < OBLIMITS[OBNUMBER,1,1]) AND
 (XLUMCENT < OBLIMITS[OBNUMBER,1,1]) OR
(XMEASPOINT > OBLIMITS[OBNUMBER,1,2]) AND
 (XLUMCENT > OBLIMITS[OBNUMBER,1,2]) THEN BEGIN
 NOOBEFFECT:=0;
END;
IF (YMEASPOINT < OBLIMITS[OBNUMBER,2,1]) AND
 (YLUMCENT < OBLIMITS[OBNUMBER,2,1]) OR
(YMEASPOINT > OBLIMITS[OBNUMBER,2,2]) AND
 (YLUMCENT > OBLIMITS[OBNUMBER,2,2]) THEN BEGIN
 NOOBEFFECT:=0;
END;
END; {PROCEDURE FIRSTCHEK }


PROCEDURE LNPLNINTSECT(II,JJ,K:INTEGER);
{CALCULATES IF THERE, IS AND IF SO WHERE, THE
INTERSECTION OF THE LINE
BETWEEN LUMINAIRE AND CALCULATION POINT IS FOR
ALL SURFACES OF ALL
OBSTRUCTIONS}

{PRODUCES NOOBEFFECT=1 IF AN OBSTRUCTION HAS AN
EFFECT ON}
{THE ILLUMINANCE FROM THIS LUMINAIRE TO THIS
MEASURING POINT}
LABEL 1,2,3;
VAR
INTSECT1,INTSECT2,INTSECT3,INTSECT4,DISTINTERSECT,
TOTSUM,SUM,TOPLINE,
XINTERSECT,YINTERSECT,ZINTERSECT:REAL;
SURFACENUM,NUMSURFACE,OBNUMBER,I:INTEGER;
BEGIN
VECTCOSLINE; {TO CALCULATE THE VECTOR COSINES
OF THE LINE}
         {CONNECTING MEASURING POINT AND
LUMINAIRE CENTRE}
FOR OBNUMBER:=1 TO OBNUM DO BEGIN
FIRSTCHEK(OBNUMBER); {TO SEE IF OBSTRUCTION AT
OTHER SIDE OF ROOM}
            {THAN THE CALCULATION POINT FROM
LUMINAIRE}
IF (OBNUMBER < PERIMOBNUM+0.5) AND
(BECAUSEDIRECTCASE = 1) THEN GOTO 2;
 {NO EFFECT POSSIBLE FROM THIS OB}
IF NOOBEFFECT=0 THEN GOTO 2; {NO EFFECT POSSIBLE
FROM THIS OB}
FOR NUMSURFACE:=1 TO 3 DO BEGIN
SURFACENUM:=LUMOBDETAILS[II,JJ,K,OBNUMBER,NUMSU
RFACE];
IF (SURFACENUM = STRSIDENUMBER) THEN GOTO 3;
IF SURFACENUM=0 THEN GOTO 2;
INTSECT1:=DIRCOS[OBNUMBER,SURFACENUM,6];
INTSECT2:=(XLUMCENT*DIRCOS[OBNUMBER,SURFACENU
M,3]);
INTSECT3:=(YLUMCENT*DIRCOS[OBNUMBER,SURFACENU
M,4]);
INTSECT4:=(HEIGHT*DIRCOS[OBNUMBER,SURFACENUM,5])
;
TOPLINE:=INTSECT1-(INTSECT2+INTSECT3+INTSECT4);
TOTSUM:=0;
FOR I:=1 TO 3 DO BEGIN
SUM:=LNVCTCOS[I]*DIRCOS[OBNUMBER,SURFACENUM,I+2]
;
```

```
TOTSUM:=SUM+TOTSUM;
END;
IF TOTSUM=0 THEN WRITELN(G,' TOTSUM:=0 ');
DISTINTERSECT:=TOPLINE/TOTSUM;
{NOW TO FIND COORDINATES OF THE INTERSECTION
USING EQUATION 1 TREGENZA}
XINTERSECT:=XLUMCENT+(DISTINTERSECT*LNVCTCOS[1]
);
YINTERSECT:=YLUMCENT+(DISTINTERSECT*LNVCTCOS[2]
);
ZINTERSECT:=HEIGHT+(DISTINTERSECT*LNVCTCOS[3]);
{NOW CHECK THAT X INTERSECT LIES WITHIN THE X
DIRECTION}
{LIMITATIONS OF SURFACE UNDER CONSIDERATION ALSO
Y AND Z}
IF SURFACENUM=5 THEN BEGIN
IF (ABS(XINTERSECT-OBLIMITS[OBNUMBER,1,1]) < 0.0001)
OR
(XINTERSECT > OBLIMITS[OBNUMBER,1,1]) THEN BEGIN
IF (ABS(XINTERSECT-OBLIMITS[OBNUMBER,1,2]) < 0.0001)
OR
(OBLIMITS[OBNUMBER,1,2] > XINTERSECT) THEN BEGIN
IF (ABS(YINTERSECT-OBLIMITS[OBNUMBER,2,2]) < 0.0001)
OR
(OBLIMITS[OBNUMBER,2,2] > YINTERSECT) THEN BEGIN
IF (ABS(YINTERSECT-OBLIMITS[OBNUMBER,2,1]) < 0.0001)
OR
(YINTERSECT > OBLIMITS[OBNUMBER,2,1]) THEN BEGIN
NOOBEFFECT:=1;
GOTO 1;
END
ELSE GOTO 3;
END
END
END
END;
IF (SURFACENUM=2) OR (SURFACENUM=4) THEN BEGIN
IF (ABS(ZINTERSECT-OBLIMITS[OBNUMBER,3,1]) < 0.0001)
OR
(ZINTERSECT > OBLIMITS[OBNUMBER,3,1]) THEN BEGIN
IF (ABS(ZINTERSECT-OBLIMITS[OBNUMBER,3,2]) < 0.0001)
OR
(OBLIMITS[OBNUMBER,3,2] > ZINTERSECT) THEN BEGIN
IF (ABS(YINTERSECT-OBLIMITS[OBNUMBER,2,2]) < 0.0001)
OR
(OBLIMITS[OBNUMBER,2,2] > YINTERSECT) THEN BEGIN
IF (ABS(YINTERSECT-OBLIMITS[OBNUMBER,2,1]) < 0.0001)
OR
(YINTERSECT > OBLIMITS[OBNUMBER,2,1]) THEN BEGIN
NOOBEFFECT.=1;
GOTO 1;
END
ELSE GOTO 3;
END
END
END
END,
IF (SURFACENUM=1) OR (SURFACENUM=3) THEN BEGIN
IF (ABS(ZINTERSECT-OBLIMITS[OBNUMBER,3,1]) < 0.0001)
OR
(ZINTERSECT > OBLIMITS[OBNUMBER,3,1]) THEN BEGIN
IF (ABS(ZINTERSECT-OBLIMITS[OBNUMBER,3,2]) < 0.0001)
OR
(OBLIMITS[OBNUMBER,3,2] > ZINTERSECT) THEN BEGIN
IF (ABS(XINTERSECT-OBLIMITS[OBNUMBER,1,2]) < 0.0001)
OR
(OBLIMITS[OBNUMBER,1,2] > XINTERSECT) THEN BEGIN
IF (ABS(XINTERSECT-OBLIMITS[OBNUMBER,1,1]) < 0.0001)
OR
(XINTERSECT > OBLIMITS[OBNUMBER,1,1]) THEN BEGIN
NOOBEFFECT:=1;
GOTO 1;
END
ELSE GOTO 3;
END
END
END
END;
3:END; {NUMSURFACE}
2:END; {OBNUMBER}
1:END; {PROCEDURE LNPLNINTSECT}


PROCEDURE DIRECTCOMPONENT;
{THIS MASTER PROCEDURE CALCULATES THE DIRECT
ILLUMINANCE OVER ALL OF
THE SURFACES IN THE ROOM INCLUDING THE WALLS
AND THE OBSTRUCTIONS.}
{OOBB }
TYPE AAA=ARRAY[1..N,0..5] OF REAL; {AVERAGE
ILLUMINANCES OVER OB SIDES }
```

```
VAR SIDEILUMAV:AAA; {AVERAGE ILLUMINANCES
OVER OB SIDES}


PROCEDURE OBILUMGRID;
{BY CALLING THE RELEVANT UDIP INTERPOLATION
PROCEDURES THIS PROCEDURE
CALCULATES THE DIRECT ILLUMINANCE OVER EVERY
POINT OVER EVERY SURFACE
OF EVERY OBSTRUCTION. CALLS THE RELEVANT UDIP
INTERPOLATION PROCEDURES}

LABEL 1,2,3,4;
VAR
SIDENUMBER,OBNUMBER,XBITS,YBITS,ZBITS,XMOV,YMO
V,ZMOV:INTEGER;
STOREA,STOREB,K,XLUMNUMBER,YLUMNUMBER:INTEGE
R;
SIDEAV,SIDEILUMTOT,ACXDISC,ACYDISC,
ACZDISC,STWKPLNHT,PINTZ,ILLUMATPT:REAL;
BEGIN
STWKPLNHT:=WKPLNHT;
FOR OBNUMBER:=1 TO OBNUM DO BEGIN
FOR SIDENUMBER:=1 TO 5 DO BEGIN
SIDEILUMTOT:=0;
STRSIDENUMBER:=SIDENUMBER;
IF (SIDENUMBER=1) OR (SIDENUMBER=3) THEN BEGIN
XBITS:=ROUND((OBLIMITS[OBNUMBER,1,2]-
OBLIMITS[OBNUMBER,1,1])/PROPOBDIS);
ZBITS:=ROUND((OBLIMITS[OBNUMBER,3,2]-
STWKPLNHT)/PROPOBDIS);
IF (XBITS < 0.1) THEN XBITS:=1;
IF (ZBITS < 0.1) THEN ZBITS:=1;
ACXDISC:=(OBLIMITS[OBNUMBER,1,2]-
OBLIMITS[OBNUMBER,1,1])/XBITS;
ACZDISC:=(OBLIMITS[OBNUMBER,3,2]-STWKPLNHT)/ZBITS;
ACOBDISCRE[OBNUMBER,SIDENUMBER,1]:=ACXDISC;
ACOBDISCRE[OBNUMBER,SIDENUMBER,2]:=ACZDISC;
FOR XMOV:=0 TO XBITS DO BEGIN
XMEASPOINT:=(OBLIMITS[OBNUMBER,1,2])-
XMOV*ACXDISC;
IF (ABS(XMOV - 0) < 0.01) THEN
XMEASPOINT:=(OBLIMITS[OBNUMBER,1,2])-0.01;
IF (XMOV = XBITS) THEN
XMEASPOINT:=(OBLIMITS[OBNUMBER,1,1])+0.01;
FOR ZMOV:=0 TO ZBITS DO BEGIN
PTILUMTOT:=0;
WKPLNHT:=OBLIMITS[OBNUMBER,3,2]-(ZMOV*ACZDISC);
IF (ABS(WKPLNHT-OBLIMITS[OBNUMBER,3,2]) < 0.01) THEN
WKPLNHT:=OBLIMITS[OBNUMBER,3,2]-0.01;
IF (ZMOV = ZBITS) THEN
WKPLNHT:=STWKPLNHT+0.01;
IF (SIDENUMBER=3) THEN
YMEASPOINT:=OBLIMITS[OBNUMBER,2,1];
IF (SIDENUMBER=1) THEN
YMEASPOINT:=OBLIMITS[OBNUMBER,2,2];
FOR XLUMNUMBER:=1 TO LENNUMALONG DO BEGIN
{LUMINAIRES IN X DIRECTION}
FOR YLUMNUMBER:=1 TO WIDNUMALONG DO BEGIN
{LUMINAIRES IN Y DIRECTION}
{IF (PTORLINLUM=1) THEN BEGIN
K:=LUMSPLIT;
IF
((LUMOBDETAILS[XLUMNUMBER,YLUMNUMBER,K,OBNU
MBER,1])=SIDENUMBER) OR
((LUMOBDETAILS[XLUMNUMBER,YLUMNUMBER,K,OBNU
MBER,2])=SIDENUMBER) OR
((LUMOBDETAILS[XLUMNUMBER,YLUMNUMBER,K,OBNU
MBER,3])=SIDENUMBER) THEN BEGIN
XLUMCENT:=LUMPOS[XLUMNUMBER,YLUMNUMBER,1,K];
YLUMCENT:=LUMPOS[XLUMNUMBER,YLUMNUMBER,2,1];
LNPLNINTSECT(XLUMNUMBER,YLUMNUMBER,K);
IF NOOBEFFECT=1 THEN GOTO 5;
PINTX:=XLUMCENT-XMEASPOINT;
PINTZ:=ABS(YLUMCENT-YMEASPOINT);
PINTY:=HEIGHT-WKPLNHT;
WALLINTERP(SIDENUMBER,PINTX,PINTY,PINTZ,ILLUMAT
PT);
ILLUMATPT:=(1/SQR(PINTZ))*ILLUMATPT;
PTILUMTOT:=PTILUMTOT+ILLUMATPT;
END;
5:END;
IF (PTORLINLUM=2) THEN BEGIN}
FOR K:=1 TO LUMSPLIT DO BEGIN
IF
((LUMOBDETAILS[XLUMNUMBER,YLUMNUMBER,K,OBNU
MBER,1])=SIDENUMBER) OR
((LUMOBDETAILS[XLUMNUMBER,YLUMNUMBER,K,OBNU
MBER,2])=SIDENUMBER) OR
((LUMOBDETAILS[XLUMNUMBER,YLUMNUMBER,K,OBNU
MBER,3])=SIDENUMBER) THEN BEGIN
XLUMCENT:=LUMPOS[XLUMNUMBER,YLUMNUMBER,1,K];
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YLUMCENT:=LUMPOS[XLUMNUMBER,YLUMNUMBER,2,1];
LNPLNINTSECT(XLUMNUMBER,YLUMNUMBER,K);
IF NOOBEFFECT=1 THEN GOTO 1;
PINTX:=XLUMCENT-XMEASPOINT;
PINTZ:=ABS(YLUMCENT-YMEASPOINT);
PINTY:=HEIGHT-WKPLNHT;
WALLINTERP(SIDENUMBER,PINTX,PINTY,PINTZ,ILLUMAT
PT);
ILLUMATPT:=(1/SQR(PINTZ))*ILLUMATPT;
PTILUMTOT:=PTILUMTOT+ILLUMATPT;
END;
1:END;
{END; }
END;
END;
OBILUM[OBNUMBER,SIDENUMBER,XMOV,ZMOV]:=PTILUM
TOT;
SIDEILUMTOT:=PTILUMTOT+SIDEILUMTOT;
END;
END;
SIDEAV:=SIDEILUMTOT/(ZBITS*XBITS);
SIDEILUMAV[OBNUMBER,SIDENUMBER]:=SIDEAV;
STOREA:=((OBNUMBER*4)-
4)+SIDENUMBER+STTOTELEMENTNUM;
ELEMITAV[STOREA]:=SIDEAV*REFLECT[STOREA];
END;
IF (SIDENUMBER=2) OR (SIDENUMBER=4) THEN BEGIN
YBITS:=ROUND((OBLIMITS[OBNUMBER,2,2]-
OBLIMITS[OBNUMBER,2,1])/PROPOBDIS);
ZBITS:=ROUND((OBLIMITS[OBNUMBER,3,2]-
STWKPLNHT)/PROPOBDIS);
IF (YBITS < 0.1) THEN YBITS:=1;
IF (ZBITS < 0.1) THEN ZBITS:=1;
ACYDISC:=(OBLIMITS[OBNUMBER,2,2]-
OBLIMITS[OBNUMBER,2,1])/YBITS;
ACZDISC:=(OBLIMITS[OBNUMBER,3,2]-STWKPLNHT)/ZBITS;
ACOBDISCRE[OBNUMBER,SIDENUMBER,1]:=ACYDISC;
ACOBDISCRE[OBNUMBER,SIDENUMBER,2]:=ACZDISC;
FOR YMOV:=0 TO YBITS DO BEGIN
YMEASPOINT:=(OBLIMITS[OBNUMBER,2,2])-
YMOV*ACYDISC;
IF (ABS(YMOV - 0) < 0.01) THEN
YMEASPOINT:=(OBLIMITS[OBNUMBER,2,2])-0.01;
IF (YMOV = YBITS) THEN
YMEASPOINT:=(OBLIMITS[OBNUMBER,2,1])+0.01;
FOR ZMOV:=0 TO ZBITS DO BEGIN
PTILUMTOT:=0;
WKPLNHT:=OBLIMITS[OBNUMBER,3,2]-(ZMOV*ACZDISC);
IF (ABS(WKPLNHT-OBLIMITS[OBNUMBER,3,2]) < 0.01) THEN
WKPLNHT:=OBLIMITS[OBNUMBER,3,2]-0.01;
IF (ZMOV = ZBITS) THEN
WKPLNHT:=STWKPLNHT+0.01;
IF (SIDENUMBER=2) THEN
XMEASPOINT:=OBLIMITS[OBNUMBER,1,1];
IF (SIDENUMBER=4) THEN
XMEASPOINT:=OBLIMITS[OBNUMBER,1,2];
FOR XLUMNUMBER:=1 TO LENNUMALONG DO BEGIN
FOR YLUMNUMBER:=1 TO WIDNUMALONG DO BEGIN
{IF (PTORLINLUM=1) THEN BEGIN
K:=LUMSPLIT;
IF
((LUMOBDETAILS[XLUMNUMBER,YLUMNUMBER,K,OBNU
MBER,1])=SIDENUMBER) OR
((LUMOBDETAILS[XLUMNUMBER,YLUMNUMBER,K,OBNU
MBER,2])=SIDENUMBER) OR
((LUMOBDETAILS[XLUMNUMBER,YLUMNUMBER,K,OBNU
MBER,3])=SIDENUMBER) THEN BEGIN
XLUMCENT:=LUMPOS[XLUMNUMBER,YLUMNUMBER,1,K];
YLUMCENT:=LUMPOS[XLUMNUMBER,YLUMNUMBER,2,1];
LNPLNINTSECT(XLUMNUMBER,YLUMNUMBER,K);
IF NOOBEFFECT=1 THEN GOTO 6;
PINTZ:=ABS(XLUMCENT-XMEASPOINT);
PINTX:=(YLUMCENT-YMEASPOINT);
PINTY:=HEIGHT-WKPLNHT;
WALLINTERP(SIDENUMBER,PINTX,PINTY,PINTZ,ILLUMAT
PT);
ILLUMATPT:=(1/SQR(PINTZ))*ILLUMATPT;
PTILUMTOT:=PTILUMTOT+ILLUMATPT;
END;
6:END;
IF (PTORLINLUM=2) THEN BEGIN }
FOR K:=1 TO LUMSPLIT DO BEGIN
IF
((LUMOBDETAILS[XLUMNUMBER,YLUMNUMBER,K,OBNU
MBER,1])=SIDENUMBER) OR
((LUMOBDETAILS[XLUMNUMBER,YLUMNUMBER,K,OBNU
MBER,2])=SIDENUMBER) OR
((LUMOBDETAILS[XLUMNUMBER,YLUMNUMBER,K,OBNU
MBER,3])=SIDENUMBER) THEN BEGIN
XLUMCENT:=LUMPOS[XLUMNUMBER,YLUMNUMBER,1,K];
YLUMCENT:=LUMPOS[XLUMNUMBER,YLUMNUMBER,2,1];
LNPLNINTSECT(XLUMNUMBER,YLUMNUMBER,K);
IF NOOBEFFECT=1 THEN GOTO 2;
PINTZ:=ABS(XLUMCENT-XMEASPOINT);
PINTX:=(YLUMCENT-YMEASPOINT);
PINTY:=HEIGHT-WKPLNHT;
WALLINTERP(SIDENUMBER,PINTX,PINTY,PINTZ,ILLUMAT
PT);
ILLUMATPT:=(1/SQR(PINTZ))*ILLUMATPT;
PTILUMTOT:=PTILUMTOT+ILLUMATPT;
END;
2:END;
{END; }
END;
END;
OBILUM[OBNUMBER,SIDENUMBER,YMOV,ZMOV]:=PTILUM
TOT;
SIDEILUMTOT:=PTILUMTOT+SIDEILUMTOT;
END;
END;
SIDEAV:=SIDEILUMTOT/(ZBITS*YBITS);
SIDEILUMAV[OBNUMBER,SIDENUMBER]:=SIDEAV;
STOREB:=((OBNUMBER*4)-
4)+SIDENUMBER+STTOTELEMENTNUM;
ELEMITAV[STOREB]:=SIDEAV*REFLECT[STOREB];
END;
IF (SIDENUMBER=5) THEN BEGIN
YBITS:=ROUND((OBLIMITS[OBNUMBER,2,2]-
OBLIMITS[OBNUMBER,2,1])/PROPOBDIS);
XBITS:=ROUND((OBLIMITS[OBNUMBER,1,2]-
OBLIMITS[OBNUMBER,1,1])/PROPOBDIS);
IF (YBITS < 0.1) THEN YBITS:=1;
IF (XBITS < 0.1) THEN XBITS:=1;
ACYDISC:=(OBLIMITS[OBNUMBER,2,2]-
OBLIMITS[OBNUMBER,2,1])/YBITS;
ACXDISC:=(OBLIMITS[OBNUMBER,1,2]-
OBLIMITS[OBNUMBER,1,1])/XBITS;
ACOBDISCRE[OBNUMBER,SIDENUMBER,1]:=ACXDISC;
ACOBDISCRE[OBNUMBER,SIDENUMBER,2]:=ACYDISC;
PINTZ:=HEIGHT-OBLIMITS[OBNUMBER,3,2];
FOR YMOV:=0 TO YBITS DO BEGIN
YMEASPOINT:=(OBLIMITS[OBNUMBER,2,2])-
YMOV*ACYDISC;
IF (ABS(YMOV - 0) < 0.01) THEN
YMEASPOINT:=(OBLIMITS[OBNUMBER,2,2])-0.01;
IF (YMOV = YBITS) THEN
YMEASPOINT:=(OBLIMITS[OBNUMBER,2,1])+0.01;
FOR XMOV:=0 TO XBITS DO BEGIN
PTILUMTOT:=0;
XMEASPOINT:=(OBLIMITS[OBNUMBER,1,2])-
(XMOV*ACXDISC);
IF (ABS(XMOV - 0) < 0.01) THEN
XMEASPOINT:=(OBLIMITS[OBNUMBER,1,2])-0.01;
IF (XMOV = XBITS) THEN
XMEASPOINT:=(OBLIMITS[OBNUMBER,1,1])+0.01;
IF (PINTZ < 0.001) THEN BEGIN PTILUMTOT:=0; GOTO 4;
END;
WKPLNHT:=(OBLIMITS[OBNUMBER,3,2]);
FOR XLUMNUMBER:=1 TO LENNUMALONG DO BEGIN
FOR YLUMNUMBER:=1 TO WIDNUMALONG DO BEGIN
{IF (PTORLINLUM=1) THEN BEGIN
K:=LUMSPLIT;
IF
((LUMOBDETAILS[XLUMNUMBER,YLUMNUMBER,K,OBNU
MBER,1])=SIDENUMBER) OR
((LUMOBDETAILS[XLUMNUMBER,YLUMNUMBER,K,OBNU
MBER,2])=SIDENUMBER) OR
((LUMOBDETAILS[XLUMNUMBER,YLUMNUMBER,K,OBNU
MBER,3])=SIDENUMBER) THEN BEGIN
XLUMCENT:=LUMPOS[XLUMNUMBER,YLUMNUMBER,1,K];
YLUMCENT:=LUMPOS[XLUMNUMBER,YLUMNUMBER,2,1];
LNPLNINTSECT(XLUMNUMBER,YLUMNUMBER,K);
IF NOOBEFFECT=1 THEN GOTO 7;
PINTX:=XLUMCENT-XMEASPOINT;
PINTY:=YLUMCENT-YMEASPOINT;
WALLINTERP(0,PINTX,PINTY,PINTZ,ILLUMATPT);
ILLUMATPT:=(1/SQR(PINTZ))*ILLUMATPT;
PTILUMTOT:=PTILUMTOT+ILLUMATPT;
END;
7:END;
IF (PTORLINLUM=2) THEN BEGIN}
FOR K:=1 TO LUMSPLIT DO BEGIN
IF
((LUMOBDETAILS[XLUMNUMBER,YLUMNUMBER,K,OBNU
MBER,1])=SIDENUMBER) OR
((LUMOBDETAILS[XLUMNUMBER,YLUMNUMBER,K,OBNU
MBER,2])=SIDENUMBER) OR
((LUMOBDETAILS[XLUMNUMBER,YLUMNUMBER,K,OBNU
MBER,3])=SIDENUMBER) THEN BEGIN
XLUMCENT:=LUMPOS[XLUMNUMBER,YLUMNUMBER,1,K];
YLUMCENT:=LUMPOS[XLUMNUMBER,YLUMNUMBER,2,1];
LNPLNINTSECT(XLUMNUMBER,YLUMNUMBER,K);
IF NOOBEFFECT=1 THEN GOTO 3;
PINTX:=XLUMCENT-XMEASPOINT;
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```
PINTY:=YLUMCENT-YMEASPOINT;
WALLINTERP(0,PINTX,PINTY,PINTZ,ILLUMATPT);
ILLUMATPT:=(1/SQR(PINTZ))*ILLUMATPT;
PTILUMTOT:=PTILUMTOT+ILLUMATPT;
END;
3:END;
{END;}
END;
END;
4:OBILUM[OBNUMBER,SIDENUMBER,XMOV,YMOV]:=PTILU
MTOT;
SIDEILUMTOT:=PTILUMTOT+SIDEILUMTOT;
END;
END;
SIDEAV:=SIDEILUMTOT/(YBITS*XBITS);
SIDEILUMAV[OBNUMBER,SIDENUMBER]:=SIDEAV;
END;
END
END;
WKPLNHT:=STWKPLNHT;
END;


PROCEDURE
WALLCALC(AMEASPOINT,BMEASPOINT:REAL;RMSURFACE
 INTEGER);
{CALCULATES THE DIRECT ILLUMINANCE RECEIVED
FROM EACH LUMINAIRE OVER
MANY POINTS OF THE VERTICAL ROOM SURFACES IE
WALLS.
IT CALLS THE WALL INTERP PROCEDURE TO ACTUALLY
CALCULATE THE ILLUMINANCE
AT THE POINT BY INTERPOLATION.}
{CALLED BY PROCEDURE WALLPTGRID. }

LABEL 2;
VAR K,II,JJ:INTEGER;
PINTX,PINTY,PINTZ,ILLUMATPT:REAL;
BEGIN
PTILUMTOT :=0;
FOR II:=1 TO LENNUMALONG DO BEGIN
FOR JJ:=1 TO WIDNUMALONG DO BEGIN
{IF (PTORLINLUM=1) THEN BEGIN
K :=LUMSPLIT;
XLUMCENT:=LUMPOS[II,JJ,1,K];
YLUMCENT:=LUMPOS[II,JJ,2,1];
WKPLNHT:=HEIGHT-BMEASPOINT;
IF (WKPLNHT < 0.01) THEN WKPLNHT:=0.01;
IF RMSURFACE=1 THEN XMEASPOINT:=AMEASPOINT;
IF RMSURFACE=2 THEN YMEASPOINT:=AMEASPOINT;
IF RMSURFACE=3 THEN XMEASPOINT:=AMEASPOINT;
IF RMSURFACE=4 THEN YMEASPOINT:=AMEASPOINT;
IF WRITNUM = 4 THEN BEGIN
LNPLNINTSECT(II,JJ,K);
IF NOOBEFFECT=1 THEN GOTO 1;
END;
IF (RMSURFACE=1) OR (RMSURFACE=3) THEN BEGIN
PINTX :=XLUMCENT-AMEASPOINT;
PINTY:=BMEASPOINT;
PINTZ:=ABS(YLUMCENT-YMEASPOINT);
END;
IF (RMSURFACE=2) OR (RMSURFACE=4) THEN BEGIN
PINTX:=YLUMCENT-AMEASPOINT;
PINTY:=BMEASPOINT;
PINTZ:=ABS(XLUMCENT-XMEASPOINT);
END;
WALLINTERP(RMSURFACE,PINTX,PINTY,PINTZ,ILLUMATP
T);
IF PINTZ < 0.05 THEN BEGIN
ILLUMATPT:=0;
GOTO 1;
END;
ILLUMATPT:=(1/SQR(PINTZ))*ILLUMATPT;
PTILUMTOT:=PTILUMTOT+ABS(ILLUMATPT);
1:END;
IF (PTORLINLUM=2) THEN BEGIN}
FOR K:=1 TO LUMSPLIT DO BEGIN
XLUMCENT:=LUMPOS[II,JJ,1,K];
YLUMCENT:=LUMPOS[II,JJ,2,1];
WKPLNHT:=HEIGHT-BMEASPOINT;
IF (WKPLNHT < 0.01) THEN WKPLNHT:=0.01;
IF RMSURFACE=1 THEN XMEASPOINT:=AMEASPOINT;
IF RMSURFACE=2 THEN YMEASPOINT:=AMEASPOINT;
IF RMSURFACE=3 THEN XMEASPOINT:=AMEASPOINT;
IF RMSURFACE=4 THEN YMEASPOINT:=AMEASPOINT;
IF WRITNUM = 4 THEN BEGIN
LNPLNINTSECT(II,JJ,K);
IF NOOBEFFECT=1 THEN GOTO 2;
END;
IF (RMSURFACE=1) OR (RMSURFACE=3) THEN BEGIN
PINTX:=XLUMCENT-AMEASPOINT;
PINTY:=BMEASPOINT;
PINTZ:=ABS(YLUMCENT-YMEASPOINT);
END;
IF (RMSURFACE=2) OR (RMSURFACE=4) THEN BEGIN
PINTX:=YLUMCENT-AMEASPOINT;
PINTY:=BMEASPOINT;
PINTZ:=ABS(XLUMCENT-XMEASPOINT);
END;
WALLINTERP(RMSURFACE,PINTX,PINTY,PINTZ,ILLUMATP
T);
IF PINTZ < 0.05 THEN BEGIN
ILLUMATPT:=0;
GOTO 2;
END;
ILLUMATPT:=(1/SQR(PINTZ))*ILLUMATPT;
PTILUMTOT:=PTILUMTOT+ABS(ILLUMATPT);
2:END;
{END;}
END;
END;
END;  {PROCEDURE WALLCALC}


PROCEDURE WALLPTGRID;
{CALCULATES THE DIRECT ILLUMINANCE RECEIVED
FROM EACH LUMINAIRE OVER
MANY POINTS OF THE VERTICAL ROOM SURFACES IE
WALLS.
IT CALLS THE WALLCALC PROCEDURE TO CALL THE
WALLINTERP PROCEDURE
 TO ACTUALLY CALCULATE THE ILLUMINANCE AT THE
POINT BY INTERPOLATION.}
{ILLUMINANCE OVER THE WALLS IS CALCULATED FROM
CORNER LOW COORD, LOW
COORD TO HIGH COORD, HIGH COORD. IE OPPOSITE THAT
USED IN THE
OBSTRUCTION ILLUMINANCE CALCULATION OF HIGH
HIGH TO LOW LOW   }

VAR
WHATN,WHATM,NHOWMANY,MHOWMANY,NARRAYNUM,M
ARRAYNUM,
II,JJ,I,J,N,M,RMSURFACE:INTEGER;
ELEADDILUM,ELEWIDTH,ELELENGTH,AMEASPOINT,BME
ASPOINT,LENORWID,STWKPLNHT,
XWALLDISCRE,YWALLDISCRE:REAL;
BEGIN
TOTELEMENTNUM:=0;
STWKPLNHT:=WKPLNHT;
FOR RMSURFACE:=1 TO 4 DO BEGIN
IF RMSURFACE=1 THEN BEGIN
LENORWID:=LENGTH;
YMEASPOINT:=0;
END;
IF RMSURFACE=2 THEN BEGIN
LENORWID:=WIDTH;
XMEASPOINT:=LENGTH;
END;
IF RMSURFACE=3 THEN BEGIN
LENORWID:=LENGTH;
YMEASPOINT:=WIDTH;
END;
IF RMSURFACE=4 THEN BEGIN
LENORWID:=WIDTH;
XMEASPOINT:=0;
END;
N:=ROUND(LENORWID/WALLDISCRE);
{THE MOD 3 AND 2 HERE ARE THE NUMBER OF
DISCRETIZATIONS IN EACH
HEIGHT AND LENGTH DIRECTION}
WHATN:=N DIV 3;
N:=3*WHATN;
M:=ROUND(HM/WALLDISCRE);
{NOTE THE USE OF HM IN THE ABOVE EQUATION}
WHATM:=M DIV 2;
M:=2*WHATM;
IF (N < 5.9) THEN N:=6; {THERE WILL ALWAYS BE A
MINIMUM OF 2 ELEMENTS
IN THE HORIZONTAL DIRECTION. IF THIS IS EVER
CHANGED THEN WATCH IF THE
ROOM IS SET TO BE TOO SMALL THEN THE
TOTELEMENTNUM IN PROCEDURE
ELEMENTARRAY STARTS TO PLAY UP, AND MIGHT FAIL.}
{WATCH HERE WITH THIS M & N < 1 CALCULATION POINT}
IF (M < 1.9) THEN M:=2;
XNMPT[RMSURFACE]:=N;
YNMPT[RMSURFACE]:=M;
XWALLDISCRE:=LENORWID/N;
YWALLDISCRE:=HM/M;
ACRMSURFDISCRE[RMSURFACE,1]:=XWALLDISCRE;
ACRMSURFDISCRE[RMSURFACE,2]:=YWALLDISCRE;
IF WRITNUM=3 THEN BEGIN
WRITE(G,'WALL ',RMSURFACE,' DISCRETIZATION: IN PLAN
```

```
= ',XWALLDISCRE:3:3);
WRITELN(G,' IN HEIGHT = ',YWALLDISCRE:3;3);
END; {WRITNUM=3}
FOR I:=0 TO N DO BEGIN   (*FOR EVERY POINT IN THE X
OR Y DIRECTION*)
FOR J:=0 TO M DO BEGIN   (*FOR EVERY POINT IN THE Z
DIRECTION*)
AMEASPOINT:=I*XWALLDISCRE;
BMEASPOINT:=J*YWALLDISCRE;
{GOTO TO CALCULATION OF ILLUMINANCE PROCEDURE}
WALLCALC(AMEASPOINT,BMEASPOINT,RMSURFACE);
WALLILLUM[WRITNUM,RMSURFACE,I,J]:=PTILUMTOT;
END {J COUNTER}
END; {I COUNTER}
NHOWMANY:=N DIV 3;
MHOWMANY:=M DIV 2;
RMSPLITINFO[RMSURFACE,1]:=NHOWMANY;
RMSPLITINFO[RMSURFACE,2]:=MHOWMANY;
ELELENGTH:=XWALLDISCRE*3;
ELEWIDTH:=YWALLDISCRE*2;
FOR I:=1 TO NHOWMANY DO BEGIN
FOR J:=1 TO MHOWMANY DO BEGIN
ELEADDILUM:=0;
FOR II:=0 TO 3 DO BEGIN
FOR JJ:=0 TO 2 DO BEGIN
NARRAYNUM:=((I*3)-3)+II;
MARRAYNUM:=((J*2)-2)+JJ;
ELEADDILUM:=WALLILLUM[WRITNUM,RMSURFACE,NARR
AYNUM,MARRAYNUM]+ELEADDILUM;
END {JJ COUNTER}
END; {II COUNTER}
TOTELEMENTNUM:=TOTELEMENTNUM+1;
ELEMITAV[TOTELEMENTNUM]:=ELEADDILUM/12;
GENINTELE[TOTELEMENTNUM,3,1]:=HEIGHT-
(ELEWIDTH*(J-1));
GENINTELE[TOTELEMENTNUM,3,2]:=HEIGHT-
(ELEWIDTH*J);
IF (RMSURFACE=1) THEN BEGIN
GENINTELE[TOTELEMENTNUM,1,1]:=ELELENGTH*(I-1);
GENINTELE[TOTELEMENTNUM,1,2]:=ELELENGTH*I;
GENINTELE[TOTELEMENTNUM,2,1]:=0;
GENINTELE[TOTELEMENTNUM,2,2]:=0;
END;
IF (RMSURFACE=2) THEN BEGIN
GENINTELE[TOTELEMENTNUM,2,1]:=ELELENGTH*(I-1);
GENINTELE[TOTELEMENTNUM,2,2]:=ELELENGTH*I;
GENINTELE[TOTELEMENTNUM,1,1]:=LENGTH;
GENINTELE[TOTELEMENTNUM,1,2]:=LENGTH;
END;

IF (RMSURFACE=3) THEN BEGIN
GENINTELE[TOTELEMENTNUM,1,1]:=ELELENGTH*(I-1);
GENINTELE[TOTELEMENTNUM,1,2]:=ELELENGTH*I;
GENINTELE[TOTELEMENTNUM,2,1]:=WIDTH;
GENINTELE[TOTELEMENTNUM,2,2]:=WIDTH;
END;
IF (RMSURFACE=4) THEN BEGIN
GENINTELE[TOTELEMENTNUM,2,1]:=ELELENGTH*(I-1);
GENINTELE[TOTELEMENTNUM,2,2]:=ELELENGTH*I;
GENINTELE[TOTELEMENTNUM,1,1]:=0;
GENINTELE[TOTELEMENTNUM,1,2]:=0;
END;

END {J COUNTER EACH ELEMENT IN HORIZONTAL
PLANE}
END; {I COUNTER EACH ELEMENT IN VERTICAL PLANE}
END; {ROOM SURFACES}
WKPLNHT:=STWKPLNHT;{RETURNS TO PREVIOUS VALUE
SINCE IT HAS BEEN CHANGED}
STTOTELEMENTNUM:=TOTELEMENTNUM;
END; {PROCEDURE WALLPTGRID}


PROCEDURE ILLUMINTERP(PINTX,PINTY:REAL;VAR
ILLUMATPT:REAL);
{INTERPOLATES THE DIRECT ILLUMINANCE FOR THE
GIVEN POINT ON THE WORKING
PLANE GIVEN THE LUMINAIRE AND CALCULATION POINT
COORDINATES IN THE
CEILING PROCEDURE ILUMCALC      }

LABEL 1;
VAR DELTAX,DELTAY:REAL;
KINDEX,MINDEX,IINDEX,JINDEX:INTEGER;
BEGIN
IF (ABS(PINTX)-ABS(XTOLOTOCOUNT) > 0.001) OR
(ABS(PINTY)-ABS(YTOLOTOCOUNT) > 0.001) THEN BEGIN
ILLUMATPT:=0;
GOTO 1;
END;
KINDEX:=TRUNC(4*PINTY+41);
ILINTSETUP(KINDEX,IINDEX);
MINDEX:=TRUNC(4*PINTX+41);
ILINTSETUP(MINDEX,JINDEX);
DELTAX:=(PINTX-C[JINDEX])/(C[JINDEX+1]-C[JINDEX]);
DELTAY:=(PINTY-R[IINDEX])/(R[IINDEX+1]-R[IINDEX]);
ILLUMATPT:=(BGILMPLN[1,IINDEX,JINDEX])*((1-
DELTAX)*(1-DELTAY))
+(BGILMPLN[1,IINDEX+1,JINDEX])*((1-DELTAX)*(DELTAY))
+(BGILMPLN[1,IINDEX,JINDEX+1])*((DELTAX)*(1-DELTAY))
+(BGILMPLN[1,IINDEX+1,JINDEX+1])*(DELTAX*DELTAY);
{WRITELN('ILLUMATPT= ',ILLUMATPT:3:2);}
1:END; {PROCEDURE ILLUMINTERP}


PROCEDURE ILUMCALC;
{CALCULATES THE DIRECT ILLUMINANCE FOR THE
VARIOUS POINTS ON THE WORKING
PLANE. CALCULATES THE INDIRECT ILLUMINANCE
COMPONENT FROM THE CEILING.
CALLED BY PROCEDURE ILUMPTGRID.        }

LABEL 1,2,3,4,6,8;
VAR I,J,LUMLENDISTRATIO,KK,K,II,JJ:INTEGER;
XLUMPOS,YLUMPOS,REDUCFACT,WKILLUMINANCE,WKPL
NILLUMINANCE,
DISTPTTOEMITAREA,ANGLE1,ANGLE2,ANGLE3,ANGLE4,H
MSQ,DIST,ILLUMATPT:REAL;
XEMITSQ,YEMITSQ,X1END,X2END,XDF1,XDF2,XDF3,AC,AB
:REAL;

BEGIN
STR6IDENUMBER:=10; { THIS IS A SAFETY NUMBER TO
ALLOW THE USE OF
        LNPLINTSECT BY THE CALCULATION OF
ILLUMINANCE OVER
        THE OBSTRUCTION SURFACES SINCE THEY
MUST AVOID
        CHECKING IF A SURFACE CAN BLOCK THE
ILLUMINANCE
        RECEIVED BY ITSELF}
PTILUMTOT:=0;
ILUMTOT:=0;
HMSQ:=SQR(HM);
FOR II:=1 TO LENNUMALONG DO BEGIN   { FOR EVERY
LUMINAIRE }
FOR JJ:=1 TO WIDNUMALONG DO BEGIN   { IN THE
ROOM       }
{USE THE SECTION OF LUMINAIRE SET AS THE CENTRE
TO REPRESENT IT}
{THROUGHOUT ALL INITIAL CHECK SITUATIONS IE II,JJ,1
OR 2, 0}
XLUMCENT:=LUMPOS[II,JJ,1,0];
YLUMCENT:=LUMPOS[II,JJ,2,0];
PINTX:=XLUMCENT-XMEASPOINT;
PINTY:=YLUMCENT-YMEASPOINT;
DIST:=SQRT(SQR(PINTX)+SQR(PINTY)+HMSQ);
IF ABS(PINTX) < 0.0001 THEN ANGLE1:=PI/2
ELSE ANGLE1:=ARCTAN(ABS(PINTY)/ABS(PINTX));
X1END:=XLUMCENT-LUMLEN/2;
X2END:=XLUMCENT+LUMLEN/2;
{EACH END OF THE LUMINAIRE}
IF (XMEASPOINT > (X1END - 0.001)) AND (XMEASPOINT <
(X2END + 0.01)) THEN BEGIN
{MEASURING POINT IS WITHIN THE LENGTH OF THE
LUMINAIRE}
ANGLE4:=PI/2;
GOTO 3;
END;
XDF1:=ABS(XMEASPOINT-X1END);
XDF2:=ABS(XMEASPOINT-X2END);
ANGLE2:=ARCTAN(ABS(PINTY)/XDF1);
ANGLE3:=ARCTAN(ABS(PINTY)/XDF2);
ANGLE4:=ABS(ANGLE3-ANGLE2);
3:LUMLENDISTRATIO:=ROUND(LUMLEN*5/DIST);
{DIVIDE LUMINAIRE INTO LUMLENDISTRATIO SECTIONS
}


IF (LUMLENDISTRATIO=1) OR (ANGLE4 < PI/10) THEN
BEGIN
{ALL OF LUMINAIRE MAY BE CONSIDERED AS ONE
SECTION}
IF WRITNUM = 2 THEN BEGIN
LNPLNINTSECT(II,JJ,0);
IF NOOBEFFECT=1 THEN GOTO 2;
END; { WRITNUM = 2 CHECK}
{LLUMINTERP(PINTX,PINTY,ILLUMATPT);}{PROD ILLUM
AT POINT PINTX, PINTY}
WALLINTERP(0,PINTX,PINTY,HM,ILLUMATPT);
ILLUMATPT:=(1/SQR(HM))*ILLUMATPT;
ILLUMATPT:=ILLUMATPT*(LUMSPLIT);
PTILUMTOT:=PTILUMTOT+ILLUMATPT; {DIRECT
```

```
COMPONENT}

{ALL OF CEILING EMMITANCE AREA WILL ALSO BE
CONSIDERED AS ONE}
REDUCFACT:=0.5;
IF ANGLE1 < PI/8 THEN REDUCFACT:=0.8;
{REDUCFACT TAKES ACCOUNT OF HOW MUCH OF TEH
CEILING ILLUMINANCE IS
BLOCKED BY THE LUMINAIRE SINCE ,
EMMITTANCE AREA ON OPPOSITE SIDE OF LUMINAIRE
FROM THE CALCULATION
POINT THEREFORE ILLUMINANCE BLOCKED BY
LUMINAIRE. }
WKILLUMINANCE:=(CEILONEQUADILUMTOT*RC*LAREMI
TAREA*HMSQ)/(SQR(SQR(DIST))*REDUCFACT);
WKILLUMINANCE:=WKILLUMINANCE/PI; {THIS HAS BEEN
ADDED TO TAKE INTO
ACCOUNT THE DIFFERENCE OF THE TWO SYSTEMS OF
CALCULATING LUMINANCE. IN
THE SYSTEM WE HAVE USED UP TILL NOW WE HAVE NOT
YET DIVIDED BY PI, IE
WE HAVE ONLY MULTIPLIED THE REFLECTANCE BY THE
ILLUMINANCE. }
PTILUMTOT:=PTILUMTOT+WKILLUMINANCE*(LUMSPLIT);
GOTO 2; {THE NEXT LUMINAIRE}
END. { (LUMLENDISTRATIO=1) OR (ANGLE4 < PI/10) }


IF (LUMLENDISTRATIO=2) OR (ANGLE4 < PI/5) THEN
BEGIN
YLUMCENT:=LUMPOS[II,JJ,2,1];
ILUMTOT:=0;
FOR KK:=1 TO 2 DO BEGIN
XLUMCENT:=LUMPOS[II,JJ,1,1]-
(LUMLEN/(2*LUMSPLIT))+(LUMLEN/2)*KK-(LUMLEN/4);
IF KK=1 THEN K:=ROUND(LUMSPLIT/4);
IF KK=2 THEN K:=ROUND(3*LUMSPLIT/4);
IF WRITNUM = 2 THEN BEGIN
LNPLNINTSECT(II,JJ,K);
IF NOOBEFFECT=1 THEN GOTO 6;
END; { WRITNUM = 2 CHECK}
PINTX =XLUMCENT-XMEASPOINT;
PINTY-=YLUMCENT-YMEASPOINT;
DIST:=SQRT(SQR(PINTX)+SQR(PINTY)+HMSQ);
{LLUMINTERP(PINTX,PINTY,ILLUMATPT);}{PROD ILLUM
AT POINT PINTX, PINTY}
WALLINTERP(0,PINTX,PINTY,HM,ILLUMATPT);
ILLUMATPT:=(1/SQR(HM))*ILLUMATPT;
ILLUMATPT:=ILLUMATPT*(LUMSPLIT/2);
PTILUMTOT:=PTILUMTOT+ILLUMATPT;
{ALL OF CEILING EMMITANCE AREA WILL BE
CONSIDERED AS ONE}
REDUCFACT:=0.6;
IF (ANGLE1 < PI/8) THEN REDUCFACT:=0.8; {ONLY THE
END OF THE LUMINAIRE
OBLITERATES THE CEILING COMPONENT}
{EMMITTANCE AREA ON OPPOSITE SIDE OF LUMINAIRE
FROM THE CALCULATION
POINT THEREFORE ILLUMINANCE BLOCKED BY
LUMINAIRE. }
WKILLUMINANCE:=(CEILONEQUADILUMTOT*RC*LAREMI
TAREA*HMSQ)/(SQR(SQR(DIST))*REDUCFACT);
{NOTE THAT THE DIST TERM USED ABOVE IS ACTUALLY
TO THE CENTRE OF THE
WHOLE LUMINAIRE SO IT IS SLIGHTLY INACCURATE BUT
THE TWO ERRORS, ONE
FROM EACH SECTION OF LUMINAIRE; SHOULD CANCELL
EACH OTHER OUT}
WKILLUMINANCE:=WKILLUMINANCE/PI; {THIS HAS BEEN
ADDED TO TAKE INTO
ACCOUNT THE DIFFERENCE OF THE TWO SYSTEMS OF
CALCULATING LUMINANCE. IN
THE SYSTEM WE HAVE USED UP TILL NOW WE HAVE NOT
YET DIVIDED BY PI, IE
WE HAVE ONLY MULTIPLIED THE REFLECTANCE BY THE
ILLUMINANCE. }
ILUMTOT:=ILUMTOT+WKILLUMINANCE;
6:END; {KK COUNTER }
PTILUMTOT:=PTILUMTOT+ILUMTOT*(LUMSPLIT/2);
GOTO 2; {NEXT LUMINAIRE}
END; { (LUMLENDISTRATIO=2) OR (ANGLE4 < PI/5) }

{IF (PTORLINLUM=1) THEN BEGIN
K:=LUMSPLIT;
XLUMCENT:=LUMPOS[II,JJ,1,K];
YLUMCENT:=LUMPOS[II,JJ,2,1];
XLUMPOS:=XLUMCENT;
YLUMPOS:=YLUMCENT;
IF WRITNUM = 2 THEN BEGIN
LNPLNINTSECT(II,JJ,K);
IF NOOBEFFECT=1 THEN GOTO 7;
END;
PINTX:=XLUMCENT-XMEASPOINT;
PINTY:=YLUMCENT-YMEASPOINT;
WALLINTERP(0,PINTX,PINTY,HM,ILLUMATPT);
ILLUMATPT:=(1/SQR(HM))*ILLUMATPT;
PTILUMTOT:=PTILUMTOT+ILLUMATPT;

ILUMTOT:=0;
FOR I:=0 TO 1 DO BEGIN
XEMITSQ:=(I*CEILDISCRE*NCEILPT)+((NCEILPT/2)*CEILDI
SCRE)-((NCEILPT)*CEILDISCRE);
FOR J:=0 TO 1 DO BEGIN
YEMITSQ:=(J*CEILDISCRE*MCEILPT)+((MCEILPT/2)*CEILD
ISCRE)-((MCEILPT)*CEILDISCRE);
XLUMCENT:=XLUMPOS+XEMITSQ;
YLUMCENT:=YLUMPOS+YEMITSQ;
REDUCFACT:=0.8;
IF (ANGLE1 < PI/8) THEN REDUCFACT:=0.9;
IF (XMEASPOINT > XLUMPOS) AND (XLUMPOS >
XLUMCENT) THEN REDUCFACT:=0.8;
IF (XMEASPOINT < XLUMPOS) AND (XLUMPOS <
XLUMCENT) THEN REDUCFACT:=0.8;
IF WRITNUM = 2 THEN BEGIN
LNPLNINTSECT(II,JJ,K);
IF NOOBEFFECT=1 THEN GOTO 5;
END;
PINTX:=ABS(XMEASPOINT-XLUMCENT);
PINTY:=ABS(YMEASPOINT-YLUMCENT);
DISTPTTOEMITAREA:=(SQR(PINTX)+SQR(PINTY)+HMSQ);
WKILLUMINANCE:=((CEILONEQUADILUMTOT*RC*SMEMI
TAREA*HMSQ)/
SQR(DISTPTTOEMITAREA))*REDUCFACT;
WKILLUMINANCE:=WKILLUMINANCE/PI;
PTILUMTOT:=PTILUMTOT+WKILLUMINANCE;
5:END;
END;
7:END;
IF (PTORLINLUM=2) THEN BEGIN}
FOR K:=1 TO LUMSPLIT DO BEGIN
XLUMCENT:=LUMPOS[II,JJ,1,K];
YLUMCENT:=LUMPOS[II,JJ,2,1];
XLUMPOS:=XLUMCENT;
YLUMPOS:=YLUMCENT;
IF WRITNUM = 2 THEN BEGIN
LNPLNINTSECT(II,JJ,K);
IF NOOBEFFECT=1 THEN GOTO 1;
END;
PINTX:=XLUMCENT-XMEASPOINT;
PINTY:=YLUMCENT-YMEASPOINT;
WALLINTERP(0,PINTX,PINTY,HM,ILLUMATPT);
ILLUMATPT:=(1/SQR(HM))*ILLUMATPT;
PTILUMTOT:=PTILUMTOT+ILLUMATPT;

ILUMTOT:=0;
FOR I:=0 TO 1 DO BEGIN
XEMITSQ:=(I*CEILDISCRE*NCEILPT)+((NCEILPT/2)*CEILDI
SCRE)-((NCEILPT)*CEILDISCRE);
FOR J:=0 TO 1 DO BEGIN
YEMITSQ:=(J*CEILDISCRE*MCEILPT)+((MCEILPT/2)*CEILD
ISCRE)-((MCEILPT)*CEILDISCRE);
XLUMCENT:=XLUMPOS+XEMITSQ;
YLUMCENT:=YLUMPOS+YEMITSQ;
REDUCFACT:=0.8;
IF (ANGLE1 < PI/8) THEN REDUCFACT:=0.9;
IF (XMEASPOINT > XLUMPOS) AND (XLUMPOS >
XLUMCENT) THEN REDUCFACT:=0.8;
IF (XMEASPOINT < XLUMPOS) AND (XLUMPOS <
XLUMCENT) THEN REDUCFACT:=0.8;
IF WRITNUM = 2 THEN BEGIN
LNPLNINTSECT(II,JJ,K);
IF NOOBEFFECT=1 THEN GOTO 8;
END;
PINTX:=ABS(XMEASPOINT-XLUMCENT);
PINTY:=ABS(YMEASPOINT-YLUMCENT);
DISTPTTOEMITAREA:=(SQR(PINTX)+SQR(PINTY)+HMSQ);
WKILLUMINANCE:=((CEILONEQUADILUMTOT*RC*SMEMI
TAREA*HMSQ)/SQR(DISTPTTOEMITAREA))*REDUCFACT;
WKILLUMINANCE:=WKILLUMINANCE/PI; {THIS HAS BEEN
ADDED TO TAKE INTO
ACCOUNT THE DIFFERENCE OF THE TWO SYSTEMS OF
CALCULATING LUMINANCE. IN
THE SYSTEM WE HAVE USED UP TILL NOW WE HAVE NOT
YET DIVIDED BY PI, IE
WE HAVE ONLY MULTIPLIED THE REFLECTANCE BY THE
ILLUMINANCE. }
PTILUMTOT:=PTILUMTOT+WKILLUMINANCE;
8:END;
END;
1:END;
{END;}
2:END;
4:END;
END; {PROCEDURE ILUMCALC}
```

```
PROCEDURE ILUMPTGRID;
{THIS IS THE CONTROL PROCEDURE FOR CALCULATING
THE ILLUMINANCE OVER THE
WORKING PLANE. }
{DIRECTLY FROM THE LUMINAIRES AND BY THE FIRST
BOUNCE FROM THE CEILING}

VAR OBNUMBER,NUMWRIT,I,J,N,M:INTEGER;
BEGIN
BECAUSEDIRECTCASE:=1; {THIS HELPS IN PROCEDURE
LNPLNINTSECT}
WRITE(G,'FOR THE WORKING PLANE ',WKPLNDISCRE:3:2,'
M GRID THIS TIME');
WRITELN(G);
IF (XSTARTPT > 50) THEN XSTARTPT:=0;
IF (YSTARTPT > 50) THEN YSTARTPT:=0;
IF (XENDPT > 50) THEN XENDPT:=LENGTH;
IF (YENDPT > 50) THEN YENDPT:=WIDTH;
WRITE(G,'START OF CALCULATION GRID IN THE X
DIRECTION = ',XSTARTPT:3:2);
WRITELN(G,'IN THE Y DIRECTION = ',YSTARTPT:3:2);
WRITELN(G);
WRITE(G,'END OF CALCULATION GRID IN THE X
DIRECTION = ',XENDPT:3:2);
WRITELN(G,'IN THE Y DIRECTION = ',YENDPT:3:2);
WRITELN(G);
FOR NUMWRIT:=1 TO 2 DO BEGIN {NUMWRIT = 1 IS THE
EMPTY CASE, NUMWRIT=2
IS THE CASE OF THE OBSTRUCTIONS.}
WRITNUM:=NUMWRIT;
ACLENGTH:=(XENDPT-XSTARTPT);
ACWIDTH:=(YENDPT-YSTARTPT);
N:=ROUND(ACLENGTH/WKPLNDISCRE);
M =ROUND(ACWIDTH/WKPLNDISCRE);
IF WRITNUM=1 THEN BEGIN
WRITELN(G);
WRITELN(G,'FOR THE WORKING PLANE');
WRITELN(G,'NUMBER OF CALC POINTS LENGTHWISE=
',N 3,' WIDTHWISE= ',M 2);
WRITELN(G);
END; {IF WRITNUM=1 }
XNUMPT·=N;
YNUMPT.=M;
XWKPLNDISCRE:=ACLENGTH/N;
YWKPLNDISCRE·=ACWIDTH/M;
ACRMSURFDISCRE[5,1]:=XWKPLNDISCRE;
ACRMSURFDISCRE[5,2]:=YWKPLNDISCRE;
IF WRITNUM=1 THEN BEGIN
WRITE(G,'ACTUAL DISCRETIZATION : X DIRECTION=
',XWKPLNDISCRE·3·2);
WRITELN(G,' Y DIRECTION = ',YWKPLNDISCRE:3:2);
END; {IF WRITNUM=1 }
EMITAREA:=SQR(CEILDISCRE);
LAREMITAREA:=NCEILPT*MCEILPT*EMITAREA*4;
SMEMITAREA:=NCEILPT*MCEILPT*EMITAREA;
FOR I:=1 TO N DO BEGIN (*FOR EVERY POINT IN THE X
DIRECTION*)
FOR J:=1 TO M DO BEGIN (*FOR EVERY POINT IN THE Y
DIRECTION*)
XMEASPOINT:=I*XWKPLNDISCRE-
(XWKPLNDISCRE/2)+XSTARTPT;
YMEASPOINT:=J*YWKPLNDISCRE-
(YWKPLNDISCRE/2)+YSTARTPT;
IF WRITNUM=2 THEN BEGIN
FOR OBNUMBER:=1 TO OBNUM DO BEGIN
{THIS IS THE CHECK TO SEE IF THE CALCULATION POINT
IS ACTUALLY
UNDER AN OBSTRUCTION. }
IF (ABS(XMEASPOINT-OBLIMITS[OBNUMBER,1,1]) < 0.0001)
OR
(XMEASPOINT > OBLIMITS[OBNUMBER,1,1]) THEN BEGIN
IF (ABS(XMEASPOINT-OBLIMITS[OBNUMBER,1,2]) < 0.0001)
OR
(OBLIMITS[OBNUMBER,1,2] > XMEASPOINT) THEN BEGIN
IF (ABS(YMEASPOINT-OBLIMITS[OBNUMBER,2,2]) < 0.0001)
OR
(OBLIMITS[OBNUMBER,2,2] > YMEASPOINT) THEN BEGIN
IF (ABS(YMEASPOINT-OBLIMITS[OBNUMBER,2,1]) < 0.0001)
OR
(YMEASPOINT > OBLIMITS[OBNUMBER,2,1]) THEN BEGIN
PTILUMTOT:=0;
END
END
END
END
END; {OBNUMBER COUNTER }
END; {IF WRITNUM=2 }
{GOTO TO CALCULATION OF ILLUMINANCE PROCEDURE}
ILUMCALC;
GDILUM[WRITNUM,I,J]:=PTILUMTOT;
{1:WRITELN(WRITNUM,I,J,PTILUMTOT:3:0);}
END {M COUNTER OF MEASPOINT}
END;
END; {WRITNUMCOUNTER}
BECAUSEDIRECTCASE:=2; {THIS HELPS IN THE
LNPLNINTSECT PROCEDURE}
END; {PROCEDURE ILUMPTGRID}

BEGIN
ILUMPTGRID; {CALCULATES THE THE ILLUMINANCE AT A
POINT ON THE GRID}
WRITNUM:=3;
WALLPTGRID;
{WALLGRIDWRIT; }
WRITNUM:=4;
WALLPTGRID;
{WALLGRIDWRIT; }
OBILUMGRID; {CALCULATES ILLUMINANCE OVER
OBSTRUCTION SURFACES}

END; {PROCEDURE DIRECTCOMPONENT}


PROCEDURE THEUDIPS;
{ THIS MASTER PROCEDURE CALCULATES THE UDIPS IE
THE UNIT DISTANCE }
{ILLUMINANCE PLANES IN ALL DIRECTIONS INCLUDING
THE CEILING }
TYPE DY=ARRAY[0..10,0..10] OF REAL; {1/4 UDIPS OF EACH
OF 5 SURFACES}
DDY=ARRAY[1..4,1..21,0..10] OF REAL; {1/4 UDIPS OF EACH
OF 5 SURFACES}
VAR ILLUM:DY;
WILLUM:DDY; { 1/4 UDIPS OF EACH OF 5 SURFACES }


PROCEDURE INTENINTERP(ANG:REAL; VAR
INTENSITY:REAL);
VAR AA,BB,XX,YY,TT:REAL;
L:INTEGER;
{INTERPOLATES THE INTENSITY AT THE GIVEN ANGLE
OF ELEVATION FOR WHICH
THE CALCULATION POINT LIES FROM THE LUMINAIRE}

BEGIN
ANG:=ANG*180/PI;
L:=1;
WHILE (5*L)<(ANG) DO BEGIN
L:=L+1;
END;
AA:=5*L;
XX:=INTS[L,8];
L:=L-1;
YY:=INTS[L,8];
BB:=5*L;
TT:=(XX-YY)/(AA-BB);
INTENSITY:=TT*ANG+(YY-TT*BB);
ANG:=ANG*PI/180;
END; {PROCEDURE INTENINTERP}


PROCEDURE DISYMINTENINTERP(ANG1,ANG2:REAL; VAR
INTENSITY:REAL);
VAR XX,YY,TT:REAL;
AAA,BBB,XXX,YYY,TTT,ANG22:REAL;
ELEANG,AZIANG,AA,BB,UPLL,LOWLL,CC,LL,L:INTEGER;
{INTERPOLATES THE INTENSITY AT THE GIVEN ANGLE
OF ELEVATION FOR WHICH
THE CALCULATION POINT LIES FROM THE LUMINAIRE}

BEGIN
ANG1:=ANG1*180/PI;
ANG2:=ANG2*180/PI;
IF (PTORLINLUM =2) THEN BEGIN
IF (LAMPFIGGUIDE =1) AND (LUMINTTYPE =1) THEN
BEGIN
L:=0;
WHILE (5*L)<(ANG1) DO BEGIN
L:=L+1;
END;
LL:=0;
WHILE (30*LL) < (ANG2) DO BEGIN
LL:=LL+1;
END;
IF L=0 THEN L:=L+1;
CC:=L MOD 2;
```

```
IF CC=0 THEN L:=L-1;
IF LL=0 THEN LL:=LL+1;
AA:=30*LL;
XX:=TNTS[L,LL];
LL:=LL-1;
BB:=30*(LL);
YY:=TNTS[L,LL];
TT:=(XX-YY)/(AA-BB);
INTENSITY:=TT*ANG2+(YY-TT*BB);
END; {LAMPFIGGUIDE AND LUMINTTYPE =1}
IF (LAMPFIGGUIDE =2) AND (LUMINTTYPE =2) THEN
BEGIN
ANG22:=ANG2;
IF ANG22 > 270 THEN ANG22:=ANG22-180;
L:=0;
WHILE (5*L)<(ANG1) DO BEGIN
L:=L+1;
END;
LL:=0;
WHILE (90*LL) < (ANG22) DO BEGIN
LL:=LL+1;
END;
IF L=0 THEN L:=L+1;
CC:=L MOD 2;
IF CC=0 THEN L:=L-1;
IF LL=0 THEN LL:=LL+1;
AA:=90*LL;
XX:=TTTS[L,LL];
LL:=LL-1;
BB:=90*(LL);
YY:=TTTS[L,LL];
TT:=(XX-YY)/(AA-BB);
INTENSITY:=TT*ANG22+(YY-TT*BB);
END;{LAMPFIGGUIDE AND LUMINTTYPE =2}
END; {LINEAR LUMINAIRE}
IF (PTORLINLUM =1) THEN BEGIN
IF (LAMPFIGGUIDE =1) AND (LUMINTTYPE =1) THEN
BEGIN
L:=0;
WHILE (5*L)<(ANG1) DO BEGIN
L:=L+1;
END;
LL:=0;
WHILE (45*LL) < (ANG2) DO BEGIN
LL:=LL+1;
END;
IF L=0 THEN L:=L+1;
CC =L MOD 2;
IF CC=0 THEN L:=L-1;
IF LL=0 THEN LL:=LL+1;
AA =45*LL;
XX =INTS[L,LL];
LL:=LL-1;
BB:=45*(LL);
YY.=INTS[L,LL];
TT =(XX-YY)/(AA-BB);
INTENSITY:=TT*ANG2+(YY-TT*BB);
END,{LAMPFIGGUIDE AND LUMINTTYPE =1}
IF (LAMPFIGGUIDE =2) AND (LUMINTTYPE =2) THEN
BEGIN
L:=0;
WHILE (5*L)<(ANG1) DO BEGIN
L:=L+1;
END;
IF L=0 THEN L:=L+1;
CC:=L MOD 2;
IF CC=0 THEN L:=L-1;
AA:=5*L;
XX:=IIIS[L];
L:=L-1;
BB:=5*(L);
YY:=IIIS[L];
TT:=(XX-YY)/(AA-BB);
INTENSITY:=TT*ANG1+(YY-TT*BB);
END;{LAMPFIGGUIDE AND LUMINTTYPE =2}
IF (LAMPFIGGUIDE =3) AND (LUMINTTYPE =3) THEN
BEGIN
L:=0;
WHILE (5*L)<(ANG1) DO BEGIN
L:=L+1;
END;
LL:=0;
WHILE (30*LL) < (ANG2) DO BEGIN
LL:=LL+1;
END;
IF L=0 THEN L:=L+1;
CC:=L MOD 2;
IF CC=0 THEN L:=L-1;
IF LL=0 THEN LL:=LL+1;
AA:=30*LL;
XX:=TNTS[L,LL];
LL:=LL-1;
BB:=30*(LL);
YY:=TNTS[L,LL];
TT:=(XX-YY)/(AA-BB);
INTENSITY:=TT*ANG2+(YY-TT*BB);
END;{LAMPFIGGUIDE AND LUMINTTYPE =3}
END; {POINT SOURCE}
ANG1:=ANG1*PI/180;
ANG2:=ANG2*PI/180;
END; {PROCEDURE DISYMINTENINTERP }


PROCEDURE PTGEN(II:INTEGER;
VAR DIST:REAL);
{GENERATES THE POINTS OF CALCULATION FOR THE
UDIP CALCULATION PROCEDURE}

BEGIN
DIST:=II*0.25;
IF II=6 THEN DIST:=1.75;
IF II=7 THEN DIST:=2.5;
IF II=8 THEN DIST:=3.5;
IF II=9 THEN DIST:=5.0;
IF II=10 THEN DIST:=10.0;
{SYMMETRIC POINT SOURCE LUMINAIRE}
END; {PROCEDURE PTGEN}

PROCEDURE CEILUDIPILLUMCALC;
{CALCULATES THE UNIT DISTANCE ILLUMINANCE PLANE
UDIP FOR THE CEILING
PLANE.}

LABEL 1,2;
VAR ILLUMINANCE,XDIST,YDIST,PLANDIST,SQTOTDIST,
HMSQ,HM,LASTILUM,ANG,ANG1,ANG2,INTENSITY:REAL;
I,J:INTEGER;
BEGIN
FOR I:=1 TO 4 DO BEGIN
ILQUAD[I]:=0;
ENDIL[I]:=0;
END;
CEILONEQUADILUMTOT:=0;
CEILDISCRE:=CEILTOLUMHT/5;
HM:=CEILTOLUMHT;   {IE UNIT DISTANCE FROM
CEILING}
HMSQ:=SQR(HM);
FOR I:=1 TO NCEILPT DO BEGIN
XDIST:=(CEILDISCRE*I)-(CEILDISCRE/2);
{LUMWID IS THE WIDTH OF THE LUMINAIRE ITSELF}
FOR J:=1 TO MCEILPT DO BEGIN
YDIST:=(CEILDISCRE*J)-(CEILDISCRE/2);
PLANDIST:=SQRT(SQR(XDIST)+SQR(YDIST));
SQTOTDIST:=SQR(PLANDIST)+HMSQ;
{IF PTORLINLUM=2 THEN BEGIN}
ANG1:=PI-(ARCTAN(PLANDIST/HM));
IF XDIST=0 THEN BEGIN
IF YDIST=0 THEN ANG2:=0
ELSE ANG2:=PI/2;
GOTO 1;
END;
IF YDIST=0 THEN BEGIN
ANG2:=0;
GOTO 1;
END;
ANG2:=ARCTAN(YDIST/XDIST);
1:DISYMINTENINTERP(ANG1,ANG2,INTENSITY);{CALCULA
TES THE INTENSITY AT THESE ANGLES}
ANG1:=ARCTAN(PLANDIST/HM);
ILLUMINANCE:=INTENSITY*ABS(COS(ANG1))/(SQTOTDIST*
LUMSPLIT);
{END;
ELSE BEGIN
ANG:=ARCTAN(PLANDIST/HM);
ANG:=PI-ANG;
INTENINTERP(ANG,INTENSITY);
ANG:=PI-ANG;
ILLUMINANCE:=INTENSITY*ABS(COS(ANG))/SQTOTDIST;
END;}
ILLUM[I,J]:=ILLUMINANCE;
CEILONEQUADILUMTOT:=ILLUMINANCE+CEILONEQUADI
LUMTOT;
IF (I < 5.5) AND (J < 5.5) THEN BEGIN
ENDIL[1]:=ILLUMINANCE+ENDIL[1];
IF YDIST < LUMWID/2 THEN BEGIN
ILQUAD[1]:=ILLUMINANCE+ILQUAD[1];
GOTO 2;
END;
END;
IF (I > 5.5) AND (J < 5.5) THEN BEGIN
ENDIL[2]:=ILLUMINANCE+ENDIL[2];
IF YDIST < LUMWID/2 THEN BEGIN
ILQUAD[2]:=ILLUMINANCE+ILQUAD[2];
```

```
GOTO 2;
END;
END;
IF (I > 5.5) AND (J > 5.5) THEN
ENDIL[4]:=ILLUMINANCE+ENDIL[4];
IF (I < 5.5) AND (J > 5.5) THEN
ENDIL[3]:=ILLUMINANCE+ENDIL[3];
2:END; {J COUNTER}
END; {I COUNTER}
CEILONEQUADILUMTOT:=CEILONEQUADILUMTOT/(MCEI
LPT*NCEILPT);
ILQUAD[3]:=ENDIL[3];
ILQUAD[4]:=ENDIL[4];
ILQUAD[1]:=ENDIL[1]-ILQUAD[1];
ILQUAD[2]:=ENDIL[2]-ILQUAD[2];
FOR I:=1 TO 4 DO BEGIN
ILQUAD[I]:=ILQUAD[I]/((NCEILPT/2)*(MCEILPT/2));
ENDIL[I]:=ENDIL[I]/((NCEILPT/2)*(MCEILPT/2));
END;
END; {PROCEDURE CEILUDIPILLUMCALC}


PROCEDURE TWOQUADTOFOUR;
{TRANSFERS THE TWO QUADRANTS OF INFORMATION
WHICH HAVE BEEN FOUND
IN PROCEDURE WALLUDIPILUMCALC INTO THE FOUR
QUADRANT INFORMATION
REQUIRED FOR THE CALCULATION OF THE ILLUMINANCE
PATTERN OVER THE
ACTUAL WALLS OR VERTICAL SURFACES }

VAR N,M,I,J,RMSURFACE INTEGER;
AA·REAL;
BEGIN
FOR RMSURFACE =1 TO 4 DO BEGIN
FOR I =21 DOWNTO 1 DO BEGIN
FOR J.=0 TO 10 DO BEGIN
AA =WILLUM[RMSURFACE,I,J];
BGILMPLN[RMSURFACE+1,I,11-J]:=AA;
BGILMPLN[RMSURFACE+1,I,11+J]:=AA;
END;
END
END
END; {PROCEDURE TWOQUADTOFOUR}

PROCEDURE WALLUDIPILLUMCALC;
{CALCULATES THE UDIP (UNIT DISTANCE ILLUMINANCE
PLANES) FOR THE WALL
TYPE SURFACES FOR THIS LUMINAIRE INTENSITY
DISTRIBUTION}
{THIS PROCEDURE HAS BEEN COMPLICATED ALOT BY
THE DECISION TO MODEL}
{LINEAR LUMINAIRES MORE ACCURATELY}
LABEL 1,2,
VAR ILLUMINANCE,XDIST,YDIST,PLANDIST,SQTOTDIST,
HMSQ,ANG1,ANG2,STHM,LASTILUM,ANG,INTENSITY:REAL;
S,T,RMSURFACE,I,J.INTEGER;
BEGIN
STHM:=HM;
HM:=1 0; {FOR WALL UDIPS}
HMSQ:=SQR(HM);
FOR RMSURFACE:=1 TO 4 DO BEGIN
S =0;
FOR I:=10 DOWNTO 0 DO BEGIN
{THIS IS THE ABOVE THE LUMINAIRE UDIP CALC CASE}
S:=S+1;
PTGEN(I,XDIST);
{THE I COUNTER AND XDIST ARE VERTICAL}
FOR J:=0 TO 10 DO BEGIN
PTGEN(J,YDIST);
{THE J COUNTER AND YDIST ARE IN THE HORIZONTAL
PLANE}
PLANDIST:=SQRT(SQR(YDIST)+HMSQ);
SQTOTDIST:=SQR(PLANDIST)+SQR(XDIST);
{IF PTORLINLUM=2 THEN BEGIN}
ANG1:=(ARCTAN(XDIST/PLANDIST))+PI/2;
IF (RMSURFACE = 1) OR (RMSURFACE = 3) THEN BEGIN
IF YDIST=0 THEN BEGIN
ANG2:=0;
GOTO 1;
END;
ANG2:=ARCTAN(YDIST/HM);
END; {RMSURFACE = 1 OR RMSURFACE = 3}
IF (RMSURFACE = 2) OR (RMSURFACE = 4) THEN BEGIN
IF YDIST=0 THEN BEGIN
ANG2:=PI/2;
GOTO 1;
END;
ANG2:=ARCTAN(YDIST/HM)+PI/2;
END; {RMSURFACE = 2 OR RMSURFACE = 4}
1:DISYMINTENINTERP(ANG1,ANG2,INTENSITY);{CALCULA
TES THE INTENSITY AT THESE ANGLES}
ANG1:=ANG1-PI/2;
ILLUMINANCE:=INTENSITY*ABS(COS(ANG1))/(SQTOTDIST*
LUMSPLIT);
{END
ELSE BEGIN
ANG:=(ARCTAN(XDIST/PLANDIST))+PI/2;
INTENINTERP(ANG,INTENSITY);
ANG:=ANG-PI/2;
ILLUMINANCE:=INTENSITY*ABS(COS(ANG))/(SQTOTDIST);
END;}
WILLUM[RMSURFACE,S,J]:=ILLUMINANCE;
LASTILUM:=ILLUMINANCE;
END; {J COUNTER}
END; {I COUNTER}
FOR I:=1 TO 10 DO BEGIN
S:=S+1;
PTGEN(I,XDIST);
FOR J:=0 TO 10 DO BEGIN
PTGEN(J,YDIST);
PLANDIST:=SQRT(SQR(YDIST)+HMSQ);
SQTOTDIST:=SQR(PLANDIST)+SQR(XDIST);
ANG:=PI/2-(ARCTAN(XDIST/PLANDIST));
{IF PTORLINLUM=2 THEN BEGIN}
ANG1:=PI/2-(ARCTAN(XDIST/PLANDIST));
IF (RMSURFACE = 1) OR (RMSURFACE = 3) THEN BEGIN
IF YDIST=0 THEN BEGIN
ANG2:=0;
GOTO 2;
END;
ANG2:=ARCTAN(YDIST/HM);
END; {RMSURFACE = 1 OR RMSURFACE = 3}
IF (RMSURFACE = 2) OR (RMSURFACE = 4) THEN BEGIN
IF YDIST=0 THEN BEGIN
ANG2:=PI/2;
GOTO 2;
END;
ANG2:=ARCTAN(YDIST/HM)+PI/2;
END; {RMSURFACE = 2 OR RMSURFACE = 4}
2:DISYMINTENINTERP(ANG1,ANG2,INTENSITY);{CALCULA
TES THE INTENSITY AT THESE ANGLES}
ANG1:=ARCTAN(XDIST/PLANDIST);
ILLUMINANCE:=INTENSITY*ABS(COS(ANG1))/(SQTOTDIST*
LUMSPLIT);
{END
ELSE BEGIN
INTENINTERP(ANG,INTENSITY);
ANG:=ARCTAN(XDIST/PLANDIST);
ILLUMINANCE:=INTENSITY*ABS(COS(ANG))/SQTOTDIST;
END;}
WILLUM[RMSURFACE,S,J]:=ILLUMINANCE;
LASTILUM:=ILLUMINANCE;
END; {J COUNTER}
END; {I COUNTER}
END; {RMSURFACE}
HM:=STHM;
END; {PROCEDURE WALLUDIPILLUMCALC}


PROCEDURE ONEQUADTOFOUR;
{FROM ONE OF THE FOUR SYMMETRICAL QUADRANTS OF
THE UDIP FOR THE CEILING
AND WORKING PLANE IT PRODUCES A LARGE FOUR
QUADRANT ARRAY }
{NOTE THAT THE WORKING PLANE UDIP IS CALCULATED
WITH THE UNIT DISTANCE
SET AT 1.8 IE HM}

VAR N,M,I,J:INTEGER;
AA:REAL;
BEGIN
FOR I:=21 DOWNTO 1 DO BEGIN
FOR J:=21 DOWNTO 1 DO BEGIN
IF (I<=21) AND (I>=11) AND (J<=21) AND (J>=11) THEN
BEGIN
N:=I-11;
M:=J-11;
AA:=ILLUM[N,M];
BGILMPLN[RMSURFACE,I,J]:=AA;
END;
IF (I<11) AND (J<=21) AND (J>=11) THEN BEGIN
AA:=ILLUM[11-I,J-11];
BGILMPLN[RMSURFACE,I,J]:=AA;
END;
IF (I<11) AND (J<11) THEN BEGIN
AA:=ILLUM[11-I,11-J];
BGILMPLN[RMSURFACE,I,J]:=AA;
END;
IF (J<11) AND (I<=21) AND (I>=11) THEN BEGIN
AA:=ILLUM[I-11,11-J];
BGILMPLN[RMSURFACE,I,J]:=AA;
END;
END;
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END
END; {PROCEDURE ONEQUADTOFOUR}


PROCEDURE UDIPILLUMCALC;
{CALCULATE THE UNIT DISTANCE ILLUMINANCE PLANE
OVER THE WORKING PLANE
SURFACE. }
{NOTE THAT THE WORKING PLANE UDIP IS CALCULATED
WITH THE UNIT DISTANCE
SET AT 1.8 IE HM}
LABEL 1;
VAR ILLUMINANCE,XDIST,YDIST,PLANDIST,SQTOTDIST,
STHM,HMSQ,LASTILUM,ANG,ANG1,ANG2,INTENSITY:REAL;
I,J:INTEGER;
BEGIN
STHM:=HM;
HM:=1.0;
HMSQ:=SQR(HM);
RMSURFACE:=1;
TELLTALE:=0;
FOR I:=0 TO 10 DO BEGIN
PTGEN(I,XDIST);
LASTILUM:=10000;
FOR J:=0 TO 10 DO BEGIN
PTGEN(J,YDIST);
PLANDIST:=SQRT(SQR(XDIST)+SQR(YDIST));
SQTOTDIST:=SQR(PLANDIST)+HMSQ;
{IF PTORLINLUM=2 THEN BEGIN}
ANG1:=ARCTAN(PLANDIST/HM); {ANGLE OF ELEVATION}
IF XDIST=0 THEN BEGIN
IF YDIST=0 THEN ANG2:=0
ELSE ANG2:=PI/2;
GOTO 1;
END;
IF YDIST=0 THEN BEGIN
ANG2 =0;
GOTO 1;
END;
ANG2 =ARCTAN(YDIST/XDIST);
1 DISYMINTENINTERP(ANG1,ANG2,INTENSITY);{CALCULA
TES THE INTENSITY AT THESE ANGLES}
ILLUMINANCE:=INTENSITY*ABS(COS(ANG1))/(SQTOTDIST*
LUMSPLIT);
{END
ELSE BEGIN
ANG:=ARCTAN(PLANDIST/HM);
INTENINTERP(ANG,INTENSITY);
ILLUMINANCE:=INTENSITY*ABS(COS(ANG))/SQTOTDIST;
IF LASTILUM<ILLUMINANCE THEN TELLTALE:=1;
END;}
ILLUM[I,J]:=ILLUMINANCE;
LASTILUM:=ILLUMINANCE;
END; {J COUNTER}
END; {I COUNTER}
XTOLOTOCOUNT:=10*HM;
YTOLOTOCOUNT:=10*HM;
HM =STHM;
END; {PROCEDURE UDIPILLUMCALC}


PROCEDURE REDUCALC;

{SAVES CALCULATING THE ILLUMINANCE IF IT FALLS
BELOW A CERTAIN
THRESHOLD SET CURRENTLY AT 2.5 }

VAR I,J,XTELL,YTELL:INTEGER;
XDIST,YDIST:REAL;
BEGIN
TELLTALE:=0;
XTELL:=0;
YTELL:=0;
FOR I:=0 TO 10 DO BEGIN
IF (ILLUM[I,0] < 2.5) AND (XTELL=0) THEN BEGIN
PTGEN(I,XDIST);
XTOLOTOCOUNT:=XDIST;
XTELL:=1;
WRITELN(G,'UDIP X DIST FOR WHICH ILLUM TOO LOW=
',XTOLOTOCOUNT:3:2);
WRITELN(G);
END;
END;
FOR J:=0 TO 10 DO BEGIN
IF (ILLUM[0,J] < 2.5) AND (YTELL=0) THEN BEGIN
PTGEN(J,YDIST);
YTOLOTOCOUNT:=YDIST;
YTELL:=1;
WRITELN(G,'UDIP Y DIST FOR WHICH ILLUM TOO LOW=
',YTOLOTOCOUNT:3:2);
WRITELN(G);
END;
END
END; {PROCEDURE REDUCALC}


PROCEDURE CEILCALC;
{CALCULATES THE DIRECT ILLUMINANCE FOR THE
VARIOUS POINTS ON THE CEILING
PLANE. CALLED BY PROCEDURE GENCEILGRID.        }
{THIS IS NOT THE PROCEDURE WHICH CALCULATES THE
HIGH EMMITTANCE AREA
AROUND THE LUMINAIRES ONLY THE PROCEDURE WHICH
CALCULATES THE GENERAL
BACKGROUND CEILING AVERAGE EMMITTANCES.         }
{NO CHECK FOR OBSTRUCTIONS BLOCKING THIS DIRECT
ILLUMINANCE OVER THE
CEILING SINCE IT IS UNLIKELY TO MAKE MUCH
DIFFERENCE IN MOST CASES.}

LABEL 2;
VAR K,II,JJ:INTEGER;
VAR ILLUMINANCE,XDIST,YDIST,PLANDIST,SQTOTDIST,
ANG,ANG1,ANG2,INTENSITY:REAL;
ILLUMATPT:REAL;
BEGIN
STRSIDENUMBER:=10; { THIS IS A SAFETY NUMBER TO
ALLOW THE USE OF
        LNPLINTSECT BY THE CALCULATION OF
ILLUMINANCE OVER
        THE OBSTRUCTION SURFACES SINCE THEY
MUST AVOID
        CHECKING IF A SURFACE CAN BLOCK THE
ILLUMINANCE
        RECEIVED BY ITSELF}
PTILUMTOT:=0;
FOR II:=1 TO LENNUMALONG DO BEGIN
FOR JJ:=1 TO WIDNUMALONG DO BEGIN
{IF (PTORLINLUM=1) THEN BEGIN
K:=LUMSPLIT;
XLUMCENT:=LUMPOS[II,JJ,1,K];
YLUMCENT:=LUMPOS[II,JJ,2,1];
XDIST:=ABS(XLUMCENT-XMEASPOINT);
YDIST:=ABS(YLUMCENT-YMEASPOINT);
IF XDIST < 0.5 THEN XDIST:=0.5;
IF YDIST < 0.5 THEN YDIST:=0.5;
PLANDIST:=SQRT(SQR(XDIST)+SQR(YDIST));
SQTOTDIST:=SQR(PLANDIST)+SQR(CEILTOLUMHT);
ANG:=ARCTAN(PLANDIST/CEILTOLUMHT);
ANG:=PI-ANG;
INTENINTERP(ANG,INTENSITY);
ANG:=PI-ANG;
ILLUMINANCE:=INTENSITY*ABS(COS(ANG))/SQTOTDIST,
PTILUMTOT:=PTILUMTOT+ILLUMINANCE;
END;
IF (PTORLINLUM=2) THEN BEGIN}
FOR K:=1 TO LUMSPLIT DO BEGIN
XLUMCENT:=LUMPOS[II,JJ,1,K];
YLUMCENT:=LUMPOS[II,JJ,2,1];
XDIST:=ABS(XLUMCENT-XMEASPOINT);
YDIST:=ABS(YLUMCENT-YMEASPOINT);
IF XDIST < 0.5 THEN XDIST:=0.5;
IF YDIST < 0.5 THEN YDIST:=0.5;
PLANDIST:=SQRT(SQR(XDIST)+SQR(YDIST));
SQTOTDIST:=SQR(PLANDIST)+SQR(CEILTOLUMHT);
ANG1:=PI-(ARCTAN(PLANDIST/CEILTOLUMHT));
IF XDIST=0 THEN BEGIN
IF YDIST=0 THEN ANG2:=0
ELSE ANG2:=PI/2;
GOTO 2;
END;
IF YDIST=0 THEN BEGIN
ANG2:=0;
GOTO 2;
END;
ANG2:=ARCTAN(YDIST/XDIST);
2:DISYMINTENINTERP(ANG1,ANG2,INTENSITY);
ANG1:=ARCTAN(PLANDIST/CEILTOLUMHT);
ILLUMINANCE:=INTENSITY*ABS(COS(ANG1))/(SQTOTDIST*
LUMSPLIT);
PTILUMTOT:=PTILUMTOT+ILLUMINANCE;
END;  {K COUNTER FOR LUMSPLIT FOR LINEAR
LUMIAIRES}
{END;}
END;  {LUMINAIRES IN X ROW}
END;  {ALL LUMINAIRE COLUMNS}
END;  {PROCEDURE CEILCALC}



PROCEDURE GENCEILGRID;
{THIS IS THE CONTROL PROCEDURE FOR CALCULATING
THE GENERAL BACKGROUND NON
HIGH EMMITTANCE AREA ILLUMINANCE OVER THE
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CEILING PLANE. }

VAR I,J,N,M:INTEGER;
XCEILGRIDISCTIZATION,YCEILGRIDISCTIZATION:REAL;
BEGIN
CEILAV:=0;
WRITE(G,'WE WILL HAVE A ',CEILGRIDISCTIZATION:3:2,'
M GRID THIS TIME');
WRITELN(G);
N:=ROUND(LENGTH/CEILGRIDISCTIZATION);
M:=ROUND(WIDTH/CEILGRIDISCTIZATION);
{WRITELN(G);
WRITELN(G,'NUMBER OF CALC POINTS LENGTHWISE=
',N:3,' WIDTHWISE= ',M:2);
WRITELN(G); }
CEILXNUMPT:=N;
CEILYNUMPT:=M;
XCEILGRIDISCTIZATION:=LENGTH/N;
YCEILGRIDISCTIZATION:=WIDTH/M;
ACRMSURFDISCRE[6,1]:=XCEILGRIDISCTIZATION;
ACRMSURFDISCRE[6,2]:=YCEILGRIDISCTIZATION;
WRITE(G,'FOR THE CEILING ACTUAL DISCRETIZATION : ');
WRITE(G,'X DIRECTION= ',XCEILGRIDISCTIZATION:3:2);
WRITELN(G,' Y DIRECTION =
',YCEILGRIDISCTIZATION:3:2);
WRITELN(G);
FOR I:=1 TO N DO BEGIN (*FOR EVERY POINT IN THE X
DIRECTION*)
FOR J:=1 TO M DO BEGIN (*FOR EVERY POINT IN THE Y
DIRECTION*)
XMEASPOINT:=I*XCEILGRIDISCTIZATION-
(XCEILGRIDISCTIZATION/2);
YMEASPOINT:=J*YCEILGRIDISCTIZATION-
(YCEILGRIDISCTIZATION/2);
{GOTO TO CALCULATION OF ILLUMINANCE PROCEDURE}
CEILCALC;
BIGCEILGRID[I,J]:=PTILUMTOT;
CEILAV:=PTILUMTOT+CEILAV;
END.
END.
CEILAV =CEILAV/((N+1)*(M+1));
END. {PROCEDURE GENCEILGRID}



BEGIN
UDIPILLUMCALC; {CALCULATES THE UDIP FOR THE
LOWER HORIZONTAL
        PLANE ( WORKING PLANE OR FLOOR) }
ONEQUADTOFOUR; {TURNS SYM DATA FOR 1 QUAD TO
4}
WALLUDIPILLUMCALC; {CALCULATES THE UDIP FOR THE
VERTICAL PLANE.
        NOTE DUE TO SYMMETRY ALL ARE THE SAME
(WALLS)}
TWOQUADTOFOUR; {TURNS SYM DATA FOR 2 QUAD TO
4}
CEILUDIPILLUMCALC; {CALCULATES THE CEILING
EMMITTANCE CLOSE TO THE
        LUMINAIRES. }
GENCEILGRID; {CALCULATES THE GENERAL
ILLUMINANCE OVER THE CEILING}
{CEILGDWRITOUT;} {WRITESOUT THE CEILING
ILLUMINANCE }
{IF PTORLINLUM = 1 THEN REDUCALC; AVOIDS
CALCULATION OR INTERPOLATION}
{IF THE ILLUMINANCE FALLS BELOW A CERTAIN
THRESHOLD, CURRENTLY 2.5 LUX}
END; {PROCEDURE THEUDIPS}


PROCEDURE PTAVINT;
{AVERAGES INTENSITY DISTRIBUTION OF THE PT SOURCE
LUMINAIRE FOR EACH ANGLE OF ELEVATION}
VAR SUM,AAA:REAL;
  J,II,I:INTEGER;
BEGIN
IF (LAMPFIGGUIDE =1) AND (LUMINTTYPE =1) THEN
BEGIN
READ(LUMDATA,DLOR);
WRITELN(G,'DLOR =',DLOR:3:2);
FOR I:=0 TO 36 DO BEGIN
SUM:=0;
FOR J:=0 TO 7 DO BEGIN
SUM:=SUM+INTS[I,J];
END;
INTS[I,8]:=SUM/8;
END;
END;
IF (LAMPFIGGUIDE =2) AND (LUMINTTYPE =2) THEN
BEGIN
  FOR I:=0 TO 36 DO BEGIN
  READ(LUMDATA,AAA);
  IIIS[I]:=AAA*MULTFACT;
  INTS[I,8]:=IIIS[I];
IF EOLN THEN READLN;
END;
READ(LUMDATA,DLOR);
WRITELN(G,'DLOR:= ',DLOR:4:3);
END;
IF (LAMPFIGGUIDE =3) AND (LUMINTTYPE =3) THEN
BEGIN
READ(LUMDATA,DLOR);
WRITELN(G,'DLOR =',DLOR:3:2);
FOR I:=0 TO 36 DO BEGIN
SUM:=0;
FOR J:=0 TO 11 DO BEGIN
SUM:=SUM+TNTS[I,J];
END;
TNTS[I,12]:=SUM/12;
END;
END;
END; {PROCEDURE PTAVINT}


PROCEDURE REEDINTDIST;
LABEL 4;
{READS THE TYPE OF LUMINAIRE AND ITS PHOTOMETRIC
INTENSITIES}

VAR I,J,M,N,NN,MM:INTEGER;
  AAA:REAL;
BEGIN
READLN(LUMDATA,LAMPFIGGUIDE,LUMINTTYPE);
IF (PTORLINLUM = 1) THEN BEGIN
{??????????????????????}
WRITELN(G,'THIS IS A POINT SOURCE LUMINAIRE');
IF LUMTYPE=1 THEN WRITELN(G,'THORN SYMMETRIC
POINT VOL 1 P7.4 ');
IF LUMTYPE=2 THEN WRITELN(G,'THIS LUMINAIRE IS THE
SYMPT DATA FILE');
IF LUMTYPE=4 THEN WRITELN(G,'THORN SYMMETRIC
POINT VOL 1 P8.8 ');
IF (LUMTYPE < 1) OR (LUMTYPE > 4) THEN
WRITELN(G,'WHAT KIND OF DISTRIBUTION IS THIS
THEN?');
IF (LAMPFIGGUIDE =2) AND (LUMINTTYPE =2) THEN
BEGIN
MULTFACT:=LAMPOUTPUT/1000;
GOTO 4;
END;
IF (LAMPFIGGUIDE =1) AND (LUMINTTYPE =1) THEN
BEGIN
MULTFACT:=LAMPOUTPUT/1000;
FOR J:=0 TO 7 DO BEGIN
FOR I:=0 TO 36 DO BEGIN
READ(LUMDATA,AAA);
INTS[I,J]:=AAA*MULTFACT;
IF EOLN THEN READLN;
END;
END
END;
IF (LAMPFIGGUIDE =3) AND (LUMINTTYPE =3) THEN
BEGIN
MULTFACT:=LAMPOUTPUT/1000;
FOR J:=0 TO 11 DO BEGIN
FOR I:=0 TO 36 DO BEGIN
READ(LUMDATA,AAA);
TNTS[I,J]:=AAA*MULTFACT;
IF EOLN THEN READLN;
END;
END
END;
4:PTAVINT;
END; {POINT SOURCE LUMINAIRE
??????????????????????????}
IF (PTORLINLUM = 2) THEN BEGIN
WRITELN(G,'THIS IS A LINEAR LUMINAIRE');
IF LUMTYPE=1 THEN WRITELN(G,'THORN SYMMETRIC
POINT VOL 1 P7.4 ');
IF LUMTYPE=2 THEN WRITELN(G,'THIS LUMINAIRE IS THE
TM5LIN DATA FILE');
IF LUMTYPE=4 THEN
WRITELN(G,'BEDFORD HOUSE : OSRAM SPEEDPACK TWIN
OPAL PRISMATIC DIFFUSER OSSP260P ');
IF LUMTYPE=5 THEN WRITELN(G,'THORN FTRA 2675/FTRE
36');
IF LUMTYPE=6 THEN WRITELN(G,'MOORLIGHT 173B
13RT/W/N/1670');
IF LUMTYPE=7 THEN WRITELN(G,'THORN FTP236
LUMINAIRE');
IF LUMTYPE=8 THEN WRITELN(G,'FO217/P CEILING
MOUNTED PRISMATIC');
IF (LUMTYPE < 1) OR (LUMTYPE > 8) THEN
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WRITELN(G,'WHAT KIND OF DISTRIBUTION IS THIS
THEN?');
IF LAMPFIGGUIDE = 1 THEN BEGIN
IF LUMINTTYPE = 1 THEN BEGIN
MULTFACT:=LAMPOUTPUT/1000;
WRITELN(G,'INTENSITY DISTRIBUTION GIVEN IN FILE IS
MULTIPLIED BY ',MULTFACT:3:3);
WRITELN(G,'IN STEPS OF 5 DEGREES IN ELEVATION AND
30 IN AZIMUTH SO CHECK ITS ALL THERE');
FOR J:=0 TO 11 DO BEGIN
FOR I:=0 TO 36 DO BEGIN
READ(LUMDATA,AAA);
TNTS[I,J]:=AAA*MULTFACT;
IF EOLN THEN READLN;
END; {I COUNTER}
END; {J COUNTER}
END; { LUMINTTYPE = 1 }
END; { LAMPFIGGUIDE = 1 }
IF LAMPFIGGUIDE =2 THEN BEGIN
IF LUMINTTYPE =2 THEN BEGIN
MULTFACT:=LAMPOUTPUT/1000;
FOR J:=0 TO 3 DO BEGIN
FOR I:=0 TO 36 DO BEGIN
READ(LUMDATA,AAA);
TTTS[I,J]:=AAA*MULTFACT;
IF EOLN THEN READLN;
END; {I COUNTER}
WRITELN(G);
END {J COUNTER}
END {LUMINTTYPE=1}
END; { LAMPFIGGUIDE = 2 }
READ(LUMDATA,DLOR);
WRITELN(G,'DLOR =',DLOR:3:2);
WRITELN(G);
END; {LINEAR LUMINAIRE}
END;


PROCEDURE RANDCAR;
{SETS UP THE ARRAYS R AND C FOR THE UDIP SECTION}

VAR I,J,IJ:INTEGER;
BEGIN
FOR I =1 TO 11 DO BEGIN
R[I] =-(11-I)*0 25;
IF I=1 THEN R[I] =-10;
IF I=2 THEN R[I] =-5;
IF I=3 THEN R[I]:=-3 5;
IF I=4 THEN R[I]:=-2.5;
IF I=5 THEN R[I]:=-1.75;
END;
J =0;
FOR I:=12 TO 21 DO BEGIN
J =J+2;
IJ =I-J;
R[I]:=-R[IJ];
END;
FOR I:= 1 TO 21 DO BEGIN
C[I]:=R[I];
END
END;


PROCEDURE WHICHSURFACE;  {FORMS THE ARRAY
LUMOBDETAILS TO STORE THE
        THREE SIDES OF ANY OB THAT EACH
LUMINAIRE CAN "SEE"}
VAR K,II,JJ,ACOBNUM,OBNUMBER:INTEGER;
BEGIN
FOR II:=1 TO LENNUMALONG DO BEGIN
FOR JJ:=1 TO WIDNUMALONG DO BEGIN
YLUMCENT:=LUMPOS[II,JJ,2,1];
{IF (PTORLINLUM=1) THEN BEGIN
K:=LUMSPLIT;
XLUMCENT:=LUMPOS[II,JJ,1,K];
FOR OBNUMBER:=1 TO OBNUM DO BEGIN
IF (XLUMCENT < OBLIMITS[OBNUMBER,1,1]) THEN BEGIN
IF (YLUMCENT < OBLIMITS[OBNUMBER,2,1]) THEN BEGIN
LUMOBDETAILS[II,JJ,K,OBNUMBER,1]:=3;
LUMOBDETAILS[II,JJ,K,OBNUMBER,2]:=2;
LUMOBDETAILS[II,JJ,K,OBNUMBER,3]:=5;
END;
IF (YLUMCENT>=OBLIMITS[OBNUMBER,2,1]) AND
(YLUMCENT<=OBLIMITS[OBNUMBER,2,2])
THEN BEGIN
LUMOBDETAILS[II,JJ,K,OBNUMBER,1]:=2;
LUMOBDETAILS[II,JJ,K,OBNUMBER,2]:=5;
LUMOBDETAILS[II,JJ,K,OBNUMBER,3]:=0;
END;
IF (YLUMCENT > OBLIMITS[OBNUMBER,2,2]) THEN BEGIN
LUMOBDETAILS[II,JJ,K,OBNUMBER,1]:=1;
LUMOBDETAILS[II,JJ,K,OBNUMBER,2]:=2;
LUMOBDETAILS[II,JJ,K,OBNUMBER,3]:=5;
END
END;
IF (XLUMCENT>=OBLIMITS[OBNUMBER,1,1]) AND
(XLUMCENT<=OBLIMITS[OBNUMBER,1,2])
THEN BEGIN
IF (YLUMCENT < OBLIMITS[OBNUMBER,2,1]) THEN BEGIN
LUMOBDETAILS[II,JJ,K,OBNUMBER,1]:=3;
LUMOBDETAILS[II,JJ,K,OBNUMBER,2]:=5;
LUMOBDETAILS[II,JJ,K,OBNUMBER,3]:=0;
END;
IF (YLUMCENT>=OBLIMITS[OBNUMBER,2,1]) AND
(YLUMCENT<=OBLIMITS[OBNUMBER,2,2]) THEN BEGIN
LUMOBDETAILS[II,JJ,K,OBNUMBER,1]:=5;
LUMOBDETAILS[II,JJ,K,OBNUMBER,2]:=0;
LUMOBDETAILS[II,JJ,K,OBNUMBER,3]:=0;
END;
IF (YLUMCENT > OBLIMITS[OBNUMBER,2,2]) THEN BEGIN
LUMOBDETAILS[II,JJ,K,OBNUMBER,1]:=1;
LUMOBDETAILS[II,JJ,K,OBNUMBER,2]:=5;
LUMOBDETAILS[II,JJ,K,OBNUMBER,3]:=0;
END
END;
IF (XLUMCENT > OBLIMITS[OBNUMBER,1,2]) THEN BEGIN
IF (YLUMCENT < OBLIMITS[OBNUMBER,2,1]) THEN BEGIN
LUMOBDETAILS[II,JJ,K,OBNUMBER,1]:=3;
LUMOBDETAILS[II,JJ,K,OBNUMBER,2]:=4;
LUMOBDETAILS[II,JJ,K,OBNUMBER,3]:=5;
END;
IF (YLUMCENT>=OBLIMITS[OBNUMBER,2,1]) AND
(YLUMCENT<=OBLIMITS[OBNUMBER,2,2]) THEN BEGIN
LUMOBDETAILS[II,JJ,K,OBNUMBER,1]:=4;
LUMOBDETAILS[II,JJ,K,OBNUMBER,2]:=5;
LUMOBDETAILS[II,JJ,K,OBNUMBER,3]:=0;
END;
IF (YLUMCENT > OBLIMITS[OBNUMBER,2,2]) THEN BEGIN
LUMOBDETAILS[II,JJ,K,OBNUMBER,1]:=4;
LUMOBDETAILS[II,JJ,K,OBNUMBER,2]:=1;
LUMOBDETAILS[II,JJ,K,OBNUMBER,3]:=5;
END
END
END
END;
IF (PTORLINLUM=2) THEN BEGIN}
FOR K:=0 TO LUMSPLIT DO BEGIN
XLUMCENT:=LUMPOS[II,JJ,1,K];
FOR OBNUMBER:=1 TO OBNUM DO BEGIN
IF (XLUMCENT < OBLIMITS[OBNUMBER,1,1]) THEN BEGIN
IF (YLUMCENT < OBLIMITS[OBNUMBER,2,1]) THEN BEGIN
LUMOBDETAILS[II,JJ,K,OBNUMBER,1]:=3;
LUMOBDETAILS[II,JJ,K,OBNUMBER,2]:=2;
LUMOBDETAILS[II,JJ,K,OBNUMBER,3]:=5;
END;
IF (YLUMCENT>=OBLIMITS[OBNUMBER,2,1]) AND
(YLUMCENT<=OBLIMITS[OBNUMBER,2,2])
THEN BEGIN
LUMOBDETAILS[II,JJ,K,OBNUMBER,1]:=2;
LUMOBDETAILS[II,JJ,K,OBNUMBER,2]:=5;
LUMOBDETAILS[II,JJ,K,OBNUMBER,3]:=0;
END;
IF (YLUMCENT > OBLIMITS[OBNUMBER,2,2]) THEN BEGIN
LUMOBDETAILS[II,JJ,K,OBNUMBER,1]:=1;
LUMOBDETAILS[II,JJ,K,OBNUMBER,2]:=2;
LUMOBDETAILS[II,JJ,K,OBNUMBER,3]:=5;
END
END;
IF (XLUMCENT>=OBLIMITS[OBNUMBER,1,1]) AND
(XLUMCENT<=OBLIMITS[OBNUMBER,1,2])
THEN BEGIN
IF (YLUMCENT < OBLIMITS[OBNUMBER,2,1]) THEN BEGIN
LUMOBDETAILS[II,JJ,K,OBNUMBER,1]:=3;
LUMOBDETAILS[II,JJ,K,OBNUMBER,2]:=5;
LUMOBDETAILS[II,JJ,K,OBNUMBER,3]:=0;
END;
IF (YLUMCENT>=OBLIMITS[OBNUMBER,2,1]) AND
(YLUMCENT<=OBLIMITS[OBNUMBER,2,2]) THEN BEGIN
LUMOBDETAILS[II,JJ,K,OBNUMBER,1]:=5;
LUMOBDETAILS[II,JJ,K,OBNUMBER,2]:=0;
LUMOBDETAILS[II,JJ,K,OBNUMBER,3]:=0;
END;
IF (YLUMCENT > OBLIMITS[OBNUMBER,2,2]) THEN BEGIN
LUMOBDETAILS[II,JJ,K,OBNUMBER,1]:=1;
LUMOBDETAILS[II,JJ,K,OBNUMBER,2]:=5;
LUMOBDETAILS[II,JJ,K,OBNUMBER,3]:=0;
END
END;
IF (XLUMCENT > OBLIMITS[OBNUMBER,1,2]) THEN BEGIN
IF (YLUMCENT < OBLIMITS[OBNUMBER,2,1]) THEN BEGIN
LUMOBDETAILS[II,JJ,K,OBNUMBER,1]:=3;
LUMOBDETAILS[II,JJ,K,OBNUMBER,2]:=4;
LUMOBDETAILS[II,JJ,K,OBNUMBER,3]:=5;
END;
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IF (YLUMCENT>=OBLIMITS[OBNUMBER,2,1]) AND
(YLUMCENT<=OBLIMITS[OBNUMBER,2,2]) THEN BEGIN
LUMOBDETAILS[II,JJ,K,OBNUMBER,1]:=4;
LUMOBDETAILS[II,JJ,K,OBNUMBER,2]:=5;
LUMOBDETAILS[II,JJ,K,OBNUMBER,3]:=0;
END;
IF (YLUMCENT > OBLIMITS[OBNUMBER,2,2]) THEN BEGIN
LUMOBDETAILS[II,JJ,K,OBNUMBER,1]:=4;
LUMOBDETAILS[II,JJ,K,OBNUMBER,2]:=1;
LUMOBDETAILS[II,JJ,K,OBNUMBER,3]:=5;
END
END
END {OBNUMBER}
END {LUMSPLIT COUNTER}
{END}
END {JJ COUNTER}
END {II COUNTER}
END; {PROCEDURE WHICHSURFACE}


PROCEDURE SETOBLIMITS(OBNUM:INTEGER;
XDIR,YDIR,OBLEN,OBWID,OBHIT:REAL);
BEGIN
OBLIMITS[OBNUM,1,1]:=XDIR;          {ORDER FOR ARRAY}
OBLIMITS[OBNUM,1,2]:=XDIR+OBLEN;   {IS:
OBSTRUCTION}
OBLIMITS[OBNUM,2,1]:=YDIR;          {NUMBER;X,Y,Z; }
OBLIMITS[OBNUM,2,2]:=YDIR+OBWID;   {END CLOSEST
TO }
OBLIMITS[OBNUM,3,1]:=0;             {THE ORIGIN=1, }
OBLIMITS[OBNUM,3,2]:=OBHIT;         {FURTHEST FROM=2}
END; {PROCEDURE SETOBLIMITS}


PROCEDURE SETOBCORNERS(OBNUM:INTEGER;
XDIR,YDIR,OBLEN,OBWID,OBHIT:REAL);
BEGIN
{THE ARRAY A IS IN THE ORDER OF; OBSTRUCTION
NUMBER(MAX UNLIMITED),}
{SIDE OF OBSTRUCTION NUMBER,(ONLY 5 CONSIDERED),
POINT NUMBER( ONLY}
{3 REQUIRED,X Y OR Z VALUE}
A[OBNUM,3,1,1]:=XDIR+OBLEN;    {
}
A[OBNUM,3,1,2]:=YDIR;          { OBSTRUCTION
DIRECTIONAL COSINES }
A[OBNUM,3,1,3]:=OBHIT;         {                  }
A[OBNUM,3,2,1]:=XDIR;          { FIRST NUMBER:
OBSTRUCTION NUMBER }
A[OBNUM,3,2,2]:=YDIR;          {                  }
A[OBNUM,3,2,3]:=OBHIT;         { SECOND NUMBER: SIDE
NUMBER        }
A[OBNUM,3,3,1]:=XDIR;          {                  }
A[OBNUM,3,3,2]:=YDIR;          { THIRD NUMBER: POINT
NUMBER 1,2 OR 3 }
A[OBNUM,3,3,3]:=0;             {      ON SURFACE      }
A[OBNUM,4,1,1]:=XDIR+OBLEN;    {
}
A[OBNUM,4,1,2]:=YDIR+OBWID;    {
}
A[OBNUM,4,1,3]:=OBHIT;         { FOURTH NUMBER: X,Y OR
Z DIRECTION }
A[OBNUM,4,2,1]:=XDIR+OBLEN;    {
}
A[OBNUM,4,2,2]:=YDIR;          {                  }
A[OBNUM,4,2,3]:=OBHIT;         {                  }
A[OBNUM,4,3,1]:=XDIR+OBLEN;    {
}
A[OBNUM,4,3,2]:=YDIR;          {                  }
A[OBNUM,4,3,3]:=0;             {                  }
A[OBNUM,1,1,1]:=XDIR;          {                  }
A[OBNUM,1,1,2]:=YDIR+OBWID;    {
}
A[OBNUM,1,1,3]:=OBHIT;         {                  }
A[OBNUM,1,2,1]:=XDIR+OBLEN;    {
}
A[OBNUM,1,2,2]:=YDIR+OBWID;    {
}
A[OBNUM,1,2,3]:=OBHIT;         {                  }
A[OBNUM,1,3,1]:=XDIR+OBLEN;    {
}
A[OBNUM,1,3,2]:=YDIR+OBWID;    {
}
A[OBNUM,1,3,3]:=0;             {                  }
A[OBNUM,2,1,1]:=XDIR;          {                  }
A[OBNUM,2,1,2]:=YDIR;          {                  }
A[OBNUM,2,1,3]:=OBHIT;         {                  }
A[OBNUM,2,2,1]:=XDIR;          {                  }
A[OBNUM,2,2,2]:=YDIR+OBWID;    {
}
A[OBNUM,2,2,3]:=OBHIT;         {                  }
A[OBNUM,2,3,1]:=XDIR;          {                  }
A[OBNUM,2,3,2]:=YDIR+OBWID;    {
}
A[OBNUM,2,3,3]:=0;             {               ,  }
A[OBNUM,5,1,1]:=XDIR;          {                  }
A[OBNUM,5,1,2]:=YDIR;          {                  }
A[OBNUM,5,1,3]:=OBHIT;         {                  }
A[OBNUM,5,2,1]:=XDIR+OBLEN;    {
}
A[OBNUM,5,2,2]:=YDIR;          {                  }
A[OBNUM,5,2,3]:=OBHIT;         {                  }
A[OBNUM,5,3,1]:=XDIR+OBLEN;    {
}
A[OBNUM,5,3,2]:=YDIR+OBWID;    {
}
A[OBNUM,5,3,3]:=OBHIT;         {                  }
END; {PROCEDURE SETOBCORNERS}


PROCEDURE SETOBDIRCOS(OBNUM:INTEGER);
LABEL 1;
VAR
STORE,D1,D2,D3,NN1,NN2,N1,N2,N3,P,THETA,PHI,M,X:REAL;
I,J:INTEGER;
BEGIN
FOR I:=1 TO 5 DO BEGIN    {FOR EACH SURFACE}
NN1:=(A[OBNUM,I,2,2]-A[OBNUM,I,1,2])*(A[OBNUM,I,3,3]-
A[OBNUM,I,1,3]);
NN2:=(A[OBNUM,I,3,2]-A[OBNUM,I,1,2])*(A[OBNUM,I,2,3]-
A[OBNUM,I,1,3]);
N1:=NN1-NN2;
NN1:=(A[OBNUM,I,3,1]-A[OBNUM,I,1,1])*(A[OBNUM,I,2,3]-
A[OBNUM,I,1,3]);
NN2:=(A[OBNUM,I,2,1]-A[OBNUM,I,1,1])*(A[OBNUM,I,3,3]-
A[OBNUM,I,1,3]);
N2:=NN1-NN2;
NN1:=(A[OBNUM,I,2,1]-A[OBNUM,I,1,1])*(A[OBNUM,I,3,2]-
A[OBNUM,I,1,2]);
NN2:=(A[OBNUM,I,3,1]-A[OBNUM,I,1,1])*(A[OBNUM,I,2,2]-
A[OBNUM,I,1,2]);
N3:=NN1-NN2;
M:=SQRT(SQR(N1)+SQR(N2)+SQR(N3));
D3:=N3/M;
IF (D3=-1) OR (D3=1) THEN GOTO 1
ELSE THETA:=PI/2-ARCTAN(D3/SQRT(1-SQR(D3)));
1:IF (D3=-1) THEN THETA:=PI;
IF (D3=1) THEN THETA:=0;
D2:=N2/M;
IF SIN(THETA)=0 THEN X:=0
ELSE X:=D2/SIN(THETA);
IF (SQR(X)>=1) THEN STORE:=0
ELSE STORE:=SQRT(1-(SQR(X)));
IF (X=1) OR (STORE=0) THEN PHI:=PI/2
ELSE PHI:=ARCTAN(X/SQRT(1-(SQR(X))));
IF (X<0) THEN PHI:=-PHI;
D1:=N1/M;
P:=A[OBNUM,I,1,1]*D1+A[OBNUM,I,1,2]*D2+A[OBNUM,I,1,3]*
D3;
DIRCOS[OBNUM,I,1]:=THETA;      {                  }
DIRCOS[OBNUM,I,2]:=PHI;        { OBSTRUCTION
NUMBER,    }
DIRCOS[OBNUM,I,3]:=D1;         { SURFACE NUMBER,
}
DIRCOS[OBNUM,I,4]:=D2;         { DIRECTIONAL COSINE,
}
DIRCOS[OBNUM,I,5]:=D3;         {                  }
DIRCOS[OBNUM,I,6]:=P;          {                  }
END; {I COUNTER}
END; {PROCEDURE SETOBDIRCOS}


PROCEDURE OBDIRCOSIN;

{READS IN ALL THE OBSTRUCTION DETAILS.
CALCULATES THE DIRECTION COSINES
OF ALL SIDES OF OBSTRUCTIONS. IT IS CALLED BY
PROCEDURE OBCONTROL }

LABEL 2;
VAR
REFLECTOB,STORE,OBLEN,OBWID,OBHIT,XDIR,YDIR:REAL
;
  OBIDENT:INTEGER;

BEGIN
OBNUM:=OBNUM+1;
WRITELN(G);
READ(OBINFO,OBLEN,OBWID,OBHIT);
READLN(OBINFO,OBIDENT,XDIR,YDIR,REFLECTOB);
OBREFLECT[OBNUM]:=REFLECTOB;
IF (OBHIT-WKPLNHT < 0.050) THEN BEGIN
WRITELN(G,'THIS OBSTRUCTION IS TOO LOW TO HAVE
ANY EFFECT');
```

```
WRITELN(G);
OBNUM:=OBNUM-1;
GOTO 2;
END;
IF OBIDENT=1 THEN BEGIN
XDIR:=XDIR-OBLEN/2;
YDIR:=YDIR-OBWID/2;
END;
IF (OBHIT-HEIGHT > 0) THEN OBHIT:=HEIGHT;
IF ((XDIR+OBLEN) > LENGTH) THEN OBLEN:=LENGTH-
XDIR;
IF ((YDIR+OBWID) > WIDTH) THEN OBWID:=WIDTH-YDIR;
WRITELN(G,'THE OBSTRUCTION NUMBER',OBNUM,'
DIMENSIONS ARE:-');
WRITE(G,'LENGTH= ',OBLEN:3:3,' WIDTH= ',OBWID:3:3);
WRITELN(G,' HEIGHT= ',OBHIT:3:2,' REFLECTION FACTOR=
',REFLECTOB:3:2);
WRITELN(G);
SETOBLIMITS(OBNUM,XDIR,YDIR,OBLEN,OBWID,OBHIT);
IF (ABS(OBLIMITS[OBNUM,1,2]-OBLIMITS[OBNUM,1,1]) <
0.0001) THEN BEGIN
OBNUM:=OBNUM-1;
WRITELN(G,'OBSTRUCTION IS RIDICULOUSLY THIN TO BE
REALISTIC. IE LESS');
WRITELN(G,'THAN A TENTH OF A MILLIMETRE THICK. ');
GOTO 2;
END;
IF (ABS(OBLIMITS[OBNUM,2,2]-OBLIMITS[OBNUM,2,1]) <
0.0001) THEN BEGIN
OBNUM:=OBNUM-1;
WRITELN(G,'OBSTRUCTION IS RIDICULOUSLY THIN TO BE
REALISTIC. IE LESS');
WRITELN(G,'THAN A TENTH OF A MILLIMETRE THICK. ');
GOTO 2;
END;
WRITELN(G,'OBSTRUCTION NUMBER',OBNUM,' CORNER
NEAREST THE ORIGIN IS:-');
WRITELN(G,' IN X DIRECTION= ',XDIR:3:2,' IN Y
DIRECTION= ',YDIR:3:2);
WRITELN(G);
SETOBCORNERS(OBNUM,XDIR,YDIR,OBLEN,OBWID,OBHIT)
;
SETOBDIRCOS(OBNUM);
2:END; {PROCEDURE OBDIRCOSIN}


PROCEDURE OBACKORIG; {RETURNS THE OBSTRUCTION
TO ITS ORIGINAL POSITION}
VAR
XDIR,YDIR,OBWID,OBHIT,OBLEN,STORE1,STORE2:REAL;
OBNUMBER:INTEGER;
BEGIN
FOR OBNUMBER:= 1 TO OBNUM DO BEGIN
STORE1:=OBLIMITS[OBNUMBER,1,1];
STORE2:=OBLIMITS[OBNUMBER,1,2];
OBLIMITS[OBNUMBER,1,1]:=OBLIMITS[OBNUMBER,2,1];
OBLIMITS[OBNUMBER,1,2]:=OBLIMITS[OBNUMBER,2,2];
OBLIMITS[OBNUMBER,2,1]:=LENGTH-STORE2;
OBLIMITS[OBNUMBER,2,2]:=LENGTH-STORE1;
XDIR:=OBLIMITS[OBNUMBER,1,1];        {ORDER FOR
ARRAY}
OBLEN:=OBLIMITS[OBNUMBER,1,2]-XDIR;    {IS:
OBSTRUCTION}
YDIR:=OBLIMITS[OBNUMBER,2,1];        {NUMBER;X,Y,Z; }
OBWID:=OBLIMITS[OBNUMBER,2,2]-YDIR;    {END
CLOSEST TO }
OBHIT:=OBLIMITS[OBNUMBER,3,2];       {FURTHEST
FROM=2}
{NOTE THAT THE WIDTH IN THE ABOVE TWO LINES
ASSUMES THAT THE ROOM HAS
NOT YET BEEN TURNED AROUND . IF IT HAS THEN IT
MUST BE LENGTH.}
END;
END;    {PROCEDURE OBACKORIG }


PROCEDURE OBPOSSWAP(VAR OBNUMBER:INTEGER);
VAR STORE1,STORE2:REAL;
BEGIN
STORE1:=OBLIMITS[OBNUMBER,1,1];
STORE2:=OBLIMITS[OBNUMBER,1,2];
OBLIMITS[OBNUMBER,1,1]:=WIDTH-
OBLIMITS[OBNUMBER,2,2];
OBLIMITS[OBNUMBER,1,2]:=WIDTH-
OBLIMITS[OBNUMBER,2,1];
OBLIMITS[OBNUMBER,2,1]:=STORE1;
OBLIMITS[OBNUMBER,2,2]:=STORE2;
{NOTE THAT THE WIDTH IN THE ABOVE TWO LINES
ASSUMES THAT THE ROOM HAS
NOT YET BEEN TURNED AROUND . IF IT HAS THEN IT
MUST BE LENGTH.}
END;   {PROCEDURE OBPOSSWAP }

PROCEDURE OBTURN;
VAR PASSOBNUMBER,OBNUMBER:INTEGER;
XDIR,YDIR,OBLEN,OBWID,OBHIT:REAL;
BEGIN
FOR OBNUMBER:= 1 TO OBNUM DO BEGIN
PASSOBNUMBER:=OBNUMBER;
OBPOSSWAP(PASSOBNUMBER);
XDIR:=OBLIMITS[OBNUMBER,1,1];        {ORDER FOR
ARRAY}
OBLEN:=OBLIMITS[OBNUMBER,1,2]-XDIR;    {IS:
OBSTRUCTION}
YDIR:=OBLIMITS[OBNUMBER,2,1];        {NUMBER;X,Y,Z; }
OBWID:=OBLIMITS[OBNUMBER,2,2]-YDIR;    {END
CLOSEST TO }
OBHIT:=OBLIMITS[OBNUMBER,3,2];       {FURTHEST
FROM=2}
SETOBCORNERS(OBNUMBER,XDIR,YDIR,OBLEN,OBWID,OB
HIT);
SETOBDIRCOS(OBNUMBER);
WRITELN(G,'XDIR = ',XDIR:3:2,' YDIR ',YDIR:3:2,' OBLEN =
',OBLEN:3:2);
WRITE(G,'OBWID= ',OBWID:3:2,' OBHIT = ',OBHIT:3:2);
WRITELN(G,' OBNUMBER= ',OBNUMBER:1);
END;
END; {PROCEDURE OBTURN }


PROCEDURE OBCONTROL;
{CONTROLS THE READING IN OF ALL OBSTRUCTION
INFORMATION }
    !
VAR I,N:INTEGER;
BEGIN
OBNUM:=0;
WRITELN(G);
WRITE(G,'TOTAL NUMBER OF PERIMETER AND REAL
OBSTRUCTIONS:-  ');
{PERIMETER OBSTRUCTIONS CANNOT BLOCK ANY
ILLUMINANCE TO THE WORKING PLANE. }
{THE OBSTRUCTIONS ARE DISCRETIZED INTO AREAS
WITH DIMENSIONS OF THE
 DENOMINATOR OF XBITS, YBITS AND ZBITS CURRENTLY
PROPOBDIS}
READLN(OBINFO,N,PROPOBDIS);
WRITELN(G,N,' OBSTRUCTION(S)');
WRITELN(G);
WRITELN(G,'OBSTRUCTION SURFACES DISCRETIZATION IS
= ',PROPOBDIS:3:2);
WRITELN(G);
FOR I:=1 TO N DO BEGIN
OBDIRCOSIN;
END;
{WRITELN(G,'UP TO AND INCLUDING WHICH NUMBER OF
OBSTRUCTIONS WERE PERIMEER');
WRITELN(G,'OBSTRUCTIONS . IF NONE THEN INPUT ZERO
(0).');}
READ(OBINFO,PERIMOBNUM);
WRITELN(G,'THE NUMBER OF PERIMETER OBSTRUCTIONS
'USED TO COMPENSATE FOR');
WRITELN(G,'VARIATIONS OF THE WALLS REFLECTION
FACTORS IS : ',PERIMOBNUM:2);
WRITELN(G);
END;  {PROCEDURE OBCONTROL}


procedure manually;


 {this procedure positions all luminaires
  manually according to
  user definitions of their positions }

label 1;
  var ii,jj,i,j,k:integer;
     xd,yd:real;


begin
  if (timethru =1) then
  readln(manlum1,lennumalong,widnumalong);
  if (timethru =2) then
  readln(manlum2,lennumalong,widnumalong);
```

```
  writeln(g,'the number of luminaires in the length =
',lennumalong:2);
  writeln(g,'the number of luminaires in the width  =
',widnumalong:2);

  for j:=1 to widnumalong do begin
    for i:=1 to lennumalong do begin
      if (umethru =1) then
      read(manlum1,xd,yd);
      if (umethru =2) then
      read(manlum2,xd,yd);
      if (xd < 0.01) or (xd > length) then xd:=999;
      if (yd < 0.01) or (yd > width) then yd:=999;
      lumpos[i,j,1,0]:=xd;
      lumpos[i,j,2,0]:=yd;
      lumpos[i,j,2,1]:=yd;
      for k:=1 to lumsplit do begin
        lumpos[i,j,1,k]:=xd-(0.5*lumlen)-
        ((1/2)*(lumlen/(lumsplit)))+k*(lumlen/lumsplit);
      end;
      dirlumlen:=1; {* linear luminaire parallel to x direction *}
    1:end          {jj counter}
  end              {ii counter}
end;               {procedure manually}


procedure luminpos;


  {this procedure positions all luminaires after
   calculating how many are required in both
   directions of the room }

label 1,2,3,4;
var shmmax,ratio,bratio,lenspacing,widspacing:real;
   splitlum,alenspacing,blenspacing,awidspacing,
   bwidspacing,index:real;
   anumlamp,bnumlamp,alennumalong,blennumalong,
   awidnumalong,bwidnumalong,
   minnumlamp,minlennum,minwidnum,k,i,j:integer;

begin
  writeln(g,'the luminaire length is ',lumlen:3:2,' metres');
  writeln(g);
  splitlum:=hm/5;
  if (abs((lumlen/splitlum)-trunc(lumlen/splitlum)) < 0.001)
  then lumsplit:=trunc(lumlen/splitlum)
  else lumsplit:=trunc(lumlen/splitlum)+1;
writeln(g,'the luminaire will be split into',lumsplit:3,' equal
sections');
  if (posall = 1) then
  begin
    manually;    {positions all luminaires manually}
    goto 3;
  end;
  shmmax:=shmmax*hm;
  minlennum:=round((length/shmmax)+0.45);
  minwidnum:=round((width/shmmax)+0.45);


{if the minimum number of luminaires in the length direction ratio
turns out to be an integer + 0.04 then that number of luminaires
are needed as a minimum. if however it is a number + more than
0.04
then the number is rounded up.}

  write(g,'the minimum number of luminaire',' ');
  writeln(g,'allowed in the x direction :',minlennum:1);
  write(g,'the minimum number of luminaires',' ');
  writeln(g,'allowed in the y direction :',minwidnum:1);
  minnumlamp:=minlennum*minwidnum;
writeln(g,'the total minimum number of luminaires possible is
',minnumlamp:2);
  if (numlamp < (minnumlamp-0.1)) then numlamp:=minnumlamp;
  anumlamp:=numlamp;
  bnumlamp:=numlamp;


{this is the start of the first part}
  ratio:=length/width;
  1:alennumalong:=trunc(sqrt(ratio*anumlamp));
  awidnumalong:=(anumlamp)div(alennumalong);
  if ((alennumalong*awidnumalong) < anumlamp) then
  begin
    {if not eno   ugh luinaires then increase the number. }
    anumlamp:=anumlamp+1;
    goto 1;
  end;
  alenspacing:=length/alennumalong;
  awidspacing:=width/awidnumalong;
  if (alenspacing > shmmax) or (awidspacing > shmmax) then
  begin
    anumlamp:=anumlamp+1;
    goto 1;
  end;

{this is the start of the second part}
  bratio:=width/length;
  2:bwidnumalong:=trunc(sqrt(bratio*bnumlamp));
  blennumalong:=(bnumlamp)div(bwidnumalong);
  if ((blennumalong*bwidnumalong) < bnumlamp) then
  begin
    {if not enough luminaires then increase the number. }
    bnumlamp:=bnumlamp+1;
    goto 1;
  end;
  blenspacing:=length/blennumalong;
  bwidspacing:=width/bwidnumalong;
  if (blenspacing > shmmax) or (bwidspacing > shmmax) then
  begin
    bnumlamp:=bnumlamp+1;
    goto 2;
  end;

  if anumlamp < bnumlamp then
  begin
    numlamp:=anumlamp;
    lennumalong:=alennumalong;
    widnumalong:=awidnumalong;
    lenspacing:=alenspacing;
    widspacing:=awidspacing;
  end
  else begin
    numlamp:=bnumlamp;
    lennumalong:=blennumalong;
    widnumalong:=bwidnumalong;
    lenspacing:=blenspacing;
    widspacing:=bwidspacing;
  end;
  4:index:=lenspacing;
  if (index < lumlen) then
  begin
    lennumalong:=lennumalong-1;
    numlamp:=(numlamp-widnumalong)+(lennumalong);
    widnumalong:=(numlamp)div(lennumalong);
    lenspacing:=length/lennumalong;
    goto 4;
  end;

writeln(g,'number of luminaires in xdir or length=
',lennumalong:3);
  writeln(g);
writeln(g,'number of luminaires in ydir or width=
',widnumalong:3);
  writeln(g);
  for i:=1 to lennumalong do begin
    for j:=1 to widnumalong do begin
      lumpos[i,j,1,0]:=i*lenspacing-lenspacing/2;
      lumpos[i,j,2,0]:=j*widspacing-widspacing/2;
      lumpos[i,j,2,1]:=j*widspacing-widspacing/2;
      for k:=1 to lumsplit do begin
        lumpos[i,j,1,k]:=i*lenspacing-lenspacing/2-(0.5*lumlen)-
        ((1/2)*(lumlen/(lumsplit)))+k*(lumlen/lumsplit);
      end; {k counter of lumsplit}
      dirlumlen:=1;  { linear luminaire parallel to x direction}
    end;           {j counter}
  end;             {i counter}
3:end;             {procedure luminpos}


{PROCEDURE UTILFACTOR(VAR UF:REAL; RI:REAL);
READS THE UTILISATION FACTORS FROM THE FILE IN
WHICH THEY HAVE BEEN
STORED  (PREFERABLY GENERATED STRAIGHT FROM THE
TM5 PROGRAM )
TYPE UCOEF=ARRAY[1..9,1..9] OF REAL; TABLE OF
UTILIZATION FACTORS
VAR I,J,INDEX,RCINDEX,RWINDEX:INTEGER;
UFACT:UCOEF;
BEGIN
FOR I:=1 TO 9 DO BEGIN
FOR J:=1 TO 9 DO BEGIN
READ(UTILFACT,UFACT[J,I]);
IF EOLN THEN READLN(UTILFACT);
END
END;
IF RI >= 0.75 THEN I:=1;
IF RI >= 1.00 THEN I:=2;
IF RI >= 1.25 THEN I:=3;
IF RI >= 1.50 THEN I:=4;
IF RI >= 2.00 THEN I:=5;
IF RI >= 2.50 THEN I:=6;
IF RI >= 3.00 THEN I:=7;
```

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IF RI >= 4.00 THEN I:=8;
IF RI >= 5.00 THEN I:=9;
IF RC>=0.3 THEN RCINDEX:=6;
IF RC>=0.5 THEN RCINDEX:=3;
IF RC>=0.7 THEN RCINDEX:=0;
IF RWW>=0.1 THEN RWINDEX:=3;
IF RWW>=0.3 THEN RWINDEX:=2;
IF RWW>=0.5 THEN RWINDEX:=1;
J:=RCINDEX+RWINDEX;
UF:=UFACT[I,J];
WRITELN(G,'INTERPOLATED VALUE OF UTILIZATION
FACTOR USED= ',UF:3:2);
WRITELN(G,' ');
IF UF < 0.05 THEN WRITELN(G,'THIS UTISATION FACTOR IS
RUBBISH!!!!!');
END;}

PROCEDURE NUMLUMREQ;
{CALCULATES THE TOTAL NUMBER OF LUMINAIRES
REQUIRED TO PROVIDE THE
REQUIRED DESIGN ILLUMINANCE }

VAR UF,MF,RI,REQFLUX:REAL;
BEGIN
READ(RMINFO,UF,SHRNOM1,SHRNOM2,SHRMAX1,SHRMAX2
);
READLN(RMINFO,ILLUMREQ,MF);
WRITE(G,'DESIGN ILLUMINANCE = ',ILLUMREQ:1);
WRITELN(G,'   MAINTENANCE FACTOR = ',MF:2:1);
WRITELN(G);
RI:=(LENGTH*WIDTH)/(HM*(LENGTH+WIDTH));
WRITELN(G,'THE ROOM INDEX = ',RI:3:2);
WRITELN(G);
{UTILFACTOR(UF,RI);}
REQFLUX:=(ILLUMREQ*WIDTH*LENGTH)/(UF*MF);
READLN(LUMDATA,LAMPOUTPUT);
  WRITELN(G,'THE UTILIZATIN FACTOR USED IS  ',UF:3:2);
WRITELN(G,'LAMPOUTPUT = ',LAMPOUTPUT:1);
WRITELN(G);
NUMLAMP:=ROUND(REQFLUX/LAMPOUTPUT);
WRITELN(G,'TOTAL NUMBER OF LAMPS REQUIRED
CALCULATED BY ROUND METHOD =  ',NUMLAMP:3);
{NUMLAMP:=TRUNC(REQFLUX/LAMPOUTPUT)+1;
WRITELN(G,'TOTAL NUMBER OF LAMPS REQUIRED
CALCULATED BY TRUNC+1 METHOD = ',NUMLAMP:3);}
WRITELN(G);
READLN(LUMDATA,PTORLINLUM,LUMTYPE);
READ(LUMDATA,LUMLEN,LUMWID);
END;  {NUMLUMREQ}


PROCEDURE BACKTOORIGINAL;
VAR ST1:REAL;
ST2:INTEGER;
BEGIN
ST2:=XNUMPT;
XNUMPT:=YNUMPT;
YNUMPT:=ST2;
ST1:=XSTARTPT;
XSTARTPT:=YSTARTPT;
YSTARTPT:=ST1;
ST1:=XENDPT;
XENDPT:=YENDPT;
YENDPT:=ST1;
ACLENGTH:=(XENDPT-XSTARTPT);
ACWIDTH:=(YENDPT-YSTARTPT);
END;  {BACKTOORIGINAL}


PROCEDURE ZEROGRIDS;
VAR K,I,J:INTEGER;

BEGIN
FOR K:=1 TO 10 DO BEGIN
FOR I:=1 TO XNUMPT DO BEGIN
FOR J:=1 TO YNUMPT DO BEGIN
GDILUM[K,I,J]:=0;
END  {J COUNTER}
END  {I COUNTER}
END  {K COUNTER}
END;  {PROCEDURE ZEROGRIDS}


PROCEDURE TURNROOM;
VAR STRWIDTH:REAL;
BEGIN
STRWIDTH:=WIDTH;
WIDTH:=LENGTH;
LENGTH:=STRWIDTH;
END;

PROCEDURE TURNWALREFLECT;
VAR STRW:REAL;
BEGIN
STRW:=RW[3];
RW[3]:=RW[2];
RW[2]:=RW[1];
RW[1]:=RW[4];
RW[4]:=STRW;
END;  {PROCEDURE TURNWAKKREFLECT}


PROCEDURE ORIGWALREFLECT;
VAR STRW:REAL;
BEGIN
STRW:=RW[4];
RW[4]:=RW[1];
RW[1]:=RW[2];
RW[2]:=RW[3];
RW[3]:=STRW;
END;  {PROCEDURE ORIGWAKKREFLECT}

PROCEDURE ROOMLIMITS;  {THE PROCEDURE WHICH
DEFINES THE ENDS OF EACH
            SURFACE IN EACH DIRECTION. }
BEGIN
RMLIMITS[1,1,1]:=0;          {                    }
RMLIMITS[1,1,2]:=LENGTH;       { THE ORDER OF THIS
}
RMLIMITS[1,2,1]:=0;          {                    }
RMLIMITS[1,2,2]:=0;          {  ARRAY IS           }
RMLIMITS[1,3,1]:=WKPLNHT;     {                    }
RMLIMITS[1,3,2]:=HEIGHT;       {FIRST NUMBER:ROOM
SURFACE NUMBER}
RMLIMITS[2,1,1]:=LENGTH;       {                    }
RMLIMITS[2,1,2]:=LENGTH;       {SECOND NUMBER:
XDIRECTION = 1  }
RMLIMITS[2,2,1]:=0;          {          YDIRECTION = 2  }
RMLIMITS[2,2,2]:=WIDTH;       {          ZDIRECTION =
3 }
RMLIMITS[2,3,1]:=WKPLNHT;      {THIRD NUMBER:
LOWER LIMIT = 1  }
RMLIMITS[2,3,2]:=HEIGHT;       {                    }
RMLIMITS[3,1,1]:=0;          {        UPPER LIMIT = 2  }
RMLIMITS[3,1,2]:=LENGTH;       {                    }
RMLIMITS[3,2,1]:=WIDTH;        {                    }
RMLIMITS[3,2,2]:=WIDTH;        {                    }
RMLIMITS[3,3,1]:=WKPLNHT;      {                 .  }
RMLIMITS[3,3,2]:=HEIGHT;       {THE LOWER LIMIT IN
THE        }
RMLIMITS[4,1,1]:=0;          { Z DIRECTION SHOULD BE
WKPLNHT }
RMLIMITS[4,1,2]:=0;          { NOT 0. SINCE THIS IS USED
TO  }
RMLIMITS[4,2,1]:=0;          { DETERMINE THE
INDIRECT       }
RMLIMITS[4,2,2]:=WIDTH;        {ILLUMINANCE ON THE
WORKING    }
RMLIMITS[4,3,1]:=WKPLNHT;      {PLANE FROM THE
WALLS AND NONE  }
RMLIMITS[4,3,2]:=HEIGHT;       {CAN POSSIBLY COME
FROM BELOW.  }
RMLIMITS[5,1,1]:=0;          {  SURFACE NUMBER 5 IS
THE     }
RMLIMITS[5,1,2]:=LENGTH;       {  TAKEN FOR THIS
ARRAY AS    }
RMLIMITS[5,2,1]:=0;          {  THE CEILING           }
RMLIMITS[5,2,2]:=WIDTH;        {                    }
RMLIMITS[5,3,1]:=HEIGHT;       {                    }
RMLIMITS[5,3,2]:=HEIGHT;       {                    }
END;


PROCEDURE RMSIZE;
{READS IN THE SIZE OF THE ROOM AND ITS REFLECTION
FACTORS }

VAR RW1,RW2,RW3,RW4,STRWIDTH:REAL;
BEGIN
READ(RMINFO,WKPLNHT);
WRITELN(G,'WORKING PLANE HEIGHT= ',WKPLNHT:3:2);
READ(RMINFO,LENGTH,WIDTH,HEIGHT);
WRITE(G,' ROOM LENGTH = ',LENGTH:3:2,' ROOM WIDTH =
',WIDTH:3:2);
WRITELN(G,' ROOM HEIGHT = ',HEIGHT:3:2);
WRITELN(G);
READ(RMINFO,RC,RW1,RW2,RW3,RW4,RF);
IF RC=0.3 THEN RCFACT:=6;
IF RC=0.5 THEN RCFACT:=3;
IF RC=0.7 THEN RCFACT:=0;
WRITE(G,'ROOM REFLECT FACTORS RC =',RC:3:2,'  RF
=',RF:3:2);
WRITELN(G,' RW1 =',RW1:3:2  );
```

```
WRITELN(G);
WRITE(G,'ROOM REFLECT FACTORS RW2 =',RW2:3:2,' RW3
=',RW3:3:2);
WRITELN(G,' RW4 =',RW4:3:2);
REFLECT[1]:=RW1;
RW[1]:=RW1;
RW[2]:=RW2;
RW[3]:=RW3;
RW[4]:=RW4;
RWW:=(((RW1+RW3)*LENGTH)+((RW2+RW4)*WIDTH))/(2*(L
ENGTH+WIDTH));
HM:=HEIGHT-WKPLNHT;
WRITELN(G,'THE AVERAGE REFLECTION FACTOR OF THE
WALLS = ',RWW:3:2);
WRITELN(G);
WRITELN(G,' LUMINAIRE MOUNTING HEIGHT ABOVE
WORKING PLANE = ',HM:3:2);
WRITELN(G);
END; {PROCEDURE RMSIZE. }


PROCEDURE RECTRMDIRCOS;
BEGIN
{THIS PROCEDURE HAS BEEN BROUGHT INTO LINE SINCE
1..4 IS THE ROOM
 SURFACES 1..4 WHICH FOR THE ILLUMINANCE OVER THE
SURFACES PURPOSES
 IS STORED UNDER 1..4 . NOTE THAT IN THE UDIP
STORAGE ARRAY THE
 VALUES ARE ACTUALLY STORED UNDER 2.5 SINCE 1 IS
TAKEN UP BY THE
 WORKING PLANE ILLUMINANCE}
RMDIRCOS[6,1]:=0;        {-------------}
RMDIRCOS[6,2]:=0;        {  FLOOR      }
RMDIRCOS[6,3]:=0;        {             }
RMDIRCOS[6,4]:=0;        {  SURFACE    }
RMDIRCOS[6,5]:=1;        {             }
RMDIRCOS[6,6]:=0;        {_____________}
RMDIRCOS[5,1]:=PI;       {             }
RMDIRCOS[5,2]:=0;        { CEILING     }
RMDIRCOS[5,3]:=0;        {             }
RMDIRCOS[5,4]:=0;        { SURFACE     }
RMDIRCOS[5,5]:=-1;       {             }
RMDIRCOS[5,6]:=-HEIGHT;  {_____________}
RMDIRCOS[1,1]:= PI/2;    {             }
RMDIRCOS[1,2]:=-PI/2;    {             }
RMDIRCOS[1,3]:=0;        { WALL 1      }
RMDIRCOS[1,4]:=1;        {             }
RMDIRCOS[1,5]:=0;        {             }
RMDIRCOS[1,6]:=0;        {_____________}
RMDIRCOS[3,1]:=PI/2;     {             }
RMDIRCOS[3,2]:=-PI/2,    {             }
RMDIRCOS[3,3]:=0;        {             }
RMDIRCOS[3,4]:=-1;       {  WALL 3     }
RMDIRCOS[3,5]:=0;        {             }
RMDIRCOS[3,6]:=-WIDTH;   {_____________}
RMDIRCOS[4,1]:=PI/2;     {             }
RMDIRCOS[4,2]:=0;        {             }
RMDIRCOS[4,3]:=1;        { WALL 4      }
RMDIRCOS[4,4]:=0;        {             }
RMDIRCOS[4,5]:=0;        {             }
RMDIRCOS[4,6]:=0;        {_____________}
RMDIRCOS[2,1]:=-PI/2;    {             }
RMDIRCOS[2,2]:=0;        {             }
RMDIRCOS[2,3]:=-1;       {  WALL 2     }
RMDIRCOS[2,4]:=0;        {             }
RMDIRCOS[2,5]:=0;        {             }
RMDIRCOS[2,6]:=-LENGTH;  {_____________}
END;


PROCEDURE TURNAROUND;
BEGIN
OBTURN; {NOTE THAT THESE ARE TURNED FIRST
DELIBERATELY}
{ALL PROCEDURES FOR A TURN AROUND}
TURNROOM;
ROOMLIMITS;
TURNWALREFLECT;
LUMINPOS; {POSITIONS THE LUMINAIRES EVENLY
THROUGHOUT THE ROOM.
        IF MORE REQUIRED THEN DOES SO }
RECTRMDIRCOS; {FIXES THE VECTOR COSINES FOR THE
ROOM SURFACES.
        ( AS IN THE TREGENZA TABLES) }


END; {PROCEDURE TURNAROUND}

PROCEDURE CALCTURNEDROUND;
VAR NUMWRIT:INTEGER;
BEGIN
{ALL OF THE CALCULATIONS AGAIN}

WHICHSURFACE; {TO DECIDE WHICH SURFACE(S) OF THE
OBSTRUCTION}
        {IN QUESTION MUST BE CHECKED FOR THEIR OB
EFFECTS}
THEUDIPS; { CALCULATES THE UDIPS IE THE UNIT
DISTANCE
ILLUMINANCE PLANES IN ALL DIRECTIONS INCLUDING
THE CEILING }
DIRECTCOMPONENT; { CALCULATES THE DIRECT
ILLUMINANCE OVER ALL OF
 THE SURFACES IN THE ROOM INCLUDING THE WALLS
AND THE OBSTRUCTIONS.}


THEINTERREFLECTION; {THE MASTER PROCEDURE FOR
ALL OF THE INTER-REFLECTION PROCEDURES}

STOBNUM:=OBNUM;
FOR NUMWRIT:=3 TO 4 DO BEGIN
WRITNUM:=NUMWRIT;
IF WRITNUM=3 THEN OBNUM:=0;
IF WRITNUM=4 THEN OBNUM:=STOBNUM;
INDIRILUMPTGRID; {CALCULATES THE INDIRECT
ILLUMINANCES OVER THE
          WORKING PLANE}
END; { NUMWRIT COUNTER }
BACKTOORIGINAL;{RETURNS ENDPTS,NUMPTS, AND
STARTPTS TO ORIGINAL VALUES }
WRITECONTROL; {WRITES OUT THE WORKING PLANE
ILLUMINANCE GRIDS}
{ALL PROCEDURES FOR A TURN AROUND}
OBACKORIG; {RETURNS THE OBSTRUCTION TO ITS
ORIGINAL POSITION}
TURNROOM;
ORIGWALREFLECT;

DRAWOUTGRIDS; {THE GINO GRAPHICS ROUTINES WHICH
DRAW OUT THE ILLUM GRIDS. }


END; {PROCEDURE CALCTURNEDAROUND}


BEGIN
REWRITE(G);
RESET(RMINFO);
RESET(OBINFO);
RESET(MANPOSLUM);
RESET(LUMDATA);
RESET(CEILINFO);
RESET(MANLUM1);
RESET(MANLUM2);
INITVS;
GINO;
SAVDRA;
DEVPAP(280.0,210.0,0);
RMSIZE;{READS IN THE ROOM SIZE AND REFLECTION
FACTORS}
NUMLUMREQ;
READ(RMINFO,CEILGRIDISCTIZATION);
READ(RMINFO,WKPLNDISCRE,XSTARTPT,YSTARTPT,XEND
PT,YENDPT);
READ(RMINFO,WALLDISCRE,NUCONT);
READ(CEILINFO,CEILTOLUMHT,NCEILPT,MCEILPT);
READLN(MANPOSLUM,POSALL);
TIMETHRU:=1;
ROOMLIMITS;
SHRNOM:=SHRNOM1;
SHRMAX:=SHRMAX1;
  WRITELN(G,'SHRNOM= ',SHRNOM:3:2);
  WRITELN(G);
  WRITELN(G,'SHRMAX= ',SHRMAX:3:2);
WRITELN(G);
LUMINPOS; {POSITIONS THE LUMINAIRES EVENLY
THROUGHOUT THE ROOM.
        IF MORE REQUIRED THEN DOES SO }
RECTRMDIRCOS; {FIXES THE VECTOR COSINES FOR THE
ROOM SURFACES.
        ( AS IN THE TREGENZA TABLES) }
OBCONTROL; {READS IN ALL OBSTRUCTION INFO AND
CALCULATES THE
        VECTOR COSINES FOR ALL SURFACES}
WHICHSURFACE; {TO DECIDE WHICH SURFACE(S) OF THE
OBSTRUCTION}
        {IN QUESTION MUST BE CHECKED FOR THEIR OB
EFFECTS}
REEDINTDIST; {READ IN INTENSITY DISTRIBUTION
```

```
DATA}
RANDCAR; {SETS UP THE ARRAYS OF R AND T INDEX
ARRAYS}
THEUDIPS; { CALCULATES THE UDIPS IE THE UNIT
DISTANCE
ILLUMINANCE PLANES IN ALL DIRECTIONS INCLUDING
THE CEILING }
DIRECTCOMPONENT; { CALCULATES THE DIRECT
ILLUMINANCE OVER ALL OF
 THE SURFACES IN THE ROOM INCLUDING THE WALLS
AND THE OBSTRUCTIONS.}


THEINTERREFLECTION; {THE MASTER PROCEDURE FOR
ALL OF THE INTER-REFLECTION PROCEDURES}

STOBNUM:=OBNUM;
FOR NUMWRIT:=3 TO 4 DO BEGIN
WRITNUM:=NUMWRIT;
IF WRITNUM=3 THEN OBNUM:=0;
IF WRITNUM=4 THEN OBNUM:=STOBNUM;
INDIRILUMPTGRID; {CALCULATES THE INDIRECT
ILLUMINANCES OVER THE
            WORKING PLANE}
END; { NUMWRIT COUNTER }

WRITECONTROL; {WRITES OUT THE WORKING PLANE
ILLUMINANCE GRIDS}

DRAWOUTGRIDS; {THE GINO GRAPHICS ROUTINES WHICH
DRAW OUT THE ILLUM GRIDS. }
TIMETHRU.=2;
ZEROGRIDS;
ST1:=XSTARTPT;
XSTARTPT:=YSTARTPT;
YSTARTPT:=ST1;
ST1:=XENDPT;
XENDPT:=YENDPT;
YENDPT:=ST1;
SHRNOM.=SHRNOM2;
SHRMAX:=SHRMAX2;
  WRITELN(G,'THIS TIME THE SHRNOM= ',SHRNOM:3:2);
  WRITELN(G);
  WRITELN(G,'THIS TIME THE SHRMAX= ',SHRMAX:3:2);
WRITELN(G);
TURNAROUND;
CALCTURNEDROUND.
DEVEND.
GINEND.
ENDVS;
END.
```

Appendix D: VFR and OHR calculations

In Chapter 7 two parameters which characterise a space were introduced. These were the ratio of vertical obstruction surface area to floor area 'VFR' and the ratio of average obstruction height, above working plane, to mounting height 'OHR'. In this appendix the calculation of each one of them is explained through an example.

D1: VFR calculations

As it was pointed out in Chapter 6 modular work stations were used for all simulated interiors. This has reduced the calculation of VFR since any work station considered and any office containing that particular type of work stations would have the same VFR. For each of the standard obstruction configurations VFR is calculated on the basis of the vertical surface areas of individual elements which are shown in the table below.

No.	Element	Size of base (m x m)	Height (m)	Vertical surface area (m^2)
1	Paper rack	0.35 x 0.25	0.20	0.24
2	Human head	0.16 x 0.20	0.48	0.3456
3	Human torso	0.48 x 0.40	0.30	0.528
4	V.D.U.	0.40 x 0.40	0.40	0.64
5	F. cabinet	0.60 x 0.60	0.50	1.20
6	Partition	1.50 x 0.03	0.50	1.53
7			0.75	2.295
8			1.00	3.06
9			1.25	3.825

Those individual values are used in different combinations to give the vertical surface ares for the different types of obstruction configuration as shown in the following table.

Standard configuration	Components	Vert. surf. area (m^2)	Floor area (m^2)	VFR
Light	1, 2, 3	1.1136	12	0.0928
Medium (V.D.U.)	1, 2, 3, 4	1.7536	12	0.1461
Medium (F.C.)	1, 2, 3, 5	2.3136	12	0.1928
Heavy (1.25 m)	2, 3, 5, 6	3.6036	12	0.3003
Heavy (1.50 m)	2, 3, 5, 7	4.3686	12	0.3641
Heavy (1.75 m)	2, 3, 5, 8	5.1336	12	0.4278
Heavy (2.00 m)	2, 3, 5, 9	5.8986	12	0.4916

D2: OHR calculations

Again, because of the use of modular work stations, the value of OHR for any work station in an interior with a given mounting height would be equal to that of any office size containing so many of the same work station type, as long as the mounting height is unchanged. This has reduced the calculations since the number of elements involved is reduced.

In calculating OHR, first each obstruction is represented by four vertical surfaces of the same height and each of them has a breadth which is equal to one of the obstruction sides. The surfaces are assumed to be adjoining each other in a linear combination for which the ratio of its length to the floor area is found. This ratio is then multiplied by the height of the obstruction so that the floor area weighted height can be calculated. When the total weighted height of all elements is divided by the mounting height, the OHR is obtained. An example of calculation is given in the table below.

Element	Size of base (m x m)	Perimeter of base P (m)	Floor area F (m^2)	P/F	Height H (m)	Weighted height H*P/F (m)
Paper rack	0.35 x 0.25	1.2	12	0.1	0.2	0.0200
Human head	0.16 x 0.20	0.72	12	0.06	0.48	0.0288
Human torso	0.48 x 0.40	1.76	12	0.1466	0.30	0.0440
Total average weighted height						0.0928
Mounting height						2.30
OHR						0.0403

This OHR value is for a lightly obstructed case. The same calculations were performed for other standard obstructed cases at different mounting heights. The table below summarises the results of the calculations.

Standard obstructed case	OHR			
	Hm 2.00 m	Hm 2.30 m	Hm 2.50 m	Hm 2.58 m
Light	0.0464	0.0403	0.0371	0.0360
Medium (V.D.U.)	0.0731	0.0635	0.0584	0.0566
Medium (F.C)	0.0964	0.0838	0.0771	0.0747
Heavy (1.25 m)	0.1502	0.130.6	0.1201	0.1164
Heavy (1.50 m)	0.1821	0.1583	0.1456	0.1411
Heavy (1.75 m)	0.2139	0.1860	0.1711	0.1658
Heavy (2.00 m)	0.2458	0.2137	0.1966	0.1905

Appendix E: Published papers

Title: Modified Spacing to Height Ratio for Obstructed Spaces.

Titel: Abgeanderte Waagerrecht-senkrechte Verhaltnisse in Versperrton Raumen.

Titre: Modification de la methode du Rapport de l'Espacement á la Hauteur pour des Interieurs Obstrués.

Authors: Hocine Bougdah and David Carter

Summary:
A computer based technique for calculating a modified spacing to height ratio to allow for obstruction loss is described. The nature of obstruction commonly encountered in office interiors is examined and a classification system for different obstruction sizes and densities is put forward.The program results are compared with existing guidance on spacing to height ratio given by luminaire manufacturers and professional bodies.

Zusammenfassung:
Der artikel beschreibt eincomputer verfahren, das abgeanderte waagerechte-senkrechte verhaltnisse in versperrten raumen rechnet. Er handelt sich mit eineir untersunchung der haunflicher in buroinnern begegnten versperrungen und schlagt ein einordnungsystem fur verschiedene versperrgs - gross und dichten ror. Die prograsergebnisse werden mit empfehlungen von herstellern und fachgruppen uber das waagrecht - senkrechte verhaltniss verglichen.

Sommaire:
Une technique informatisée et modifiée pour le calcul du Rapport Espacement/Hauteur (REH) tenant compte des pertes de lumière dûe aux obstructions est presentée. La nature des obstructions generalement rencontrées á l'interieur des bureaux a été examinée et un systeme de classification des differents obstructions et de leurs dimensions et concentration a été mis en place. Les resultats obtenus du programme on été comparés avec les normes existantes sur le (REH) données par les fabricants de lampadaires et les organismes professionnels.

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1 Introduction

Most working building interiors contain objects such as furniture, office equipment or human occupants in the space between the plane of the ceiling mounted general lighting luminaires and the working plane, and obstruction loss caused by these objects can affect working efficiency and safety. Despite this the majority of schemes are planned using lighting design methods that assume that the space is empty with no specific allowance for light loss and shadow being made. The lumen Method is the most popular design method for general lighting schemes and has its principal aim the provision of uniform illuminance over the working plane. In practice, although the uniformity of illuminance on the unobstructed working plane may be satisfactory, obstruction may cause serious shadow problems. There is presently little guidance available relating to the use of the lumen method of design in obstructed spaces and little published information on the achieved lighting quality in such interiors. The Chartered Institute of Building Services Engineers Technical Memoranda No. 5 [1] and the Illuminating Engineering Society of North America Handbook [2] for example, both acknowledge that obstructions may cause a problem but their sole suggestion to overcome it is that luminaires be installed at closer spacings than are appropriate for empty spaces. Neither document offers any quantitative guidance as to how much closer to move luminaires in a particular circumstance. Design guidance is desirable since over compensation for obstruction using unnecessarily close spacing of luminaires can lead to problems of lack of uniformity and a greater chance of discomfort glare. A number of other approaches have been put forward for the treatment of obstructions in lighting design and a full discussion of these is published elsewhere [3]. This paper describes work at the University of Liverpool to extend the existing guidance for lighting design for empty rooms by the development of a modified maximum spacing to height ratio that allows for "standard obstruction loss" and which may be used in addition to the normal maximum spacing to mounting height ratio in installation design.

2 The obstructed SHR concept

Previous work at the University of Liverpool introduced the concept of an "obstructed SHR" to make allowance for interior obstruction of known size and position [4]. This work took as a starting point the standard U.K method for calculation of SHR in empty rooms as described in the CIBSE Technical Memoranda No. 5 [1]. This defines the SHR as the ratio of the spacing in a stated direction between photometric centres of adjacent luminaires to the mounting height of the luminaires above the horizontal reference plane. Using a standard array of sixteen identical luminaires in a square grid the luminaires are positioned, at first, very close together and then moved apart in ordered steps so that the SHR is increased until the uniformity ratio defined by the minimum to maximum illuminance falls below the 0.7 threshold value. In order to calculate uniformity, the direct illuminance is calculated over a grid of points in the central area of the standard array of luminaires. In the case of point source luminaires, Point By Point calculation methods are used whereas the Aspect Factor Method is used for linear luminaires [5]. Two SHR's are defined in the calculation: SHRMAX is the value of SHR which gives the widest spacing at which a ratio of minimum to maximum illuminance greater or equal to 0.7 is achieved over the central area and SHRNOM is the greater value of SHR in the prefered series of steps to achieve the 0.7 min/max uniformity ratio. The modification to the TM5 method of calculation of SHR took account of light loss caused by defined obstructions positioned within the central area of the standard square array and was implemented by means of a computer program. The obstructions, based ostensibly on the results of a survey carried out in an open plan office, represented a desk with either a partition or a filing cabinet at one end with a person seated at the desk. For each SHR value of the preferred series the program calculated the direct illuminance at each point on a calculation grid within the central area of the luminaire array taking into account the presence of obstructions.

The early work had a number of conceptional and practical limitations associated with assumptions about notional task area and obstruction configurations. The size of the task area and the position and number of calculation points varied at different stages of the calculation procedure leading to the possibility of similar illuminance conditions at different SHR's producing different task uniformity ratios. The two obstruction configurations were in reality, similar and were of simplicity such that they were not capable of representing the range of sizes or densities of equipment found in office interiors. This paper presents a computer based method of calculation of SHR for luminaires intended for use in a wide range of commercial interiors.

3 Computer program for modified SHR

The standard obstructions used in the modified program (illustrated in figure 1) consist of a horizontal task area surrounded by a human form and furniture. The task area and furniture size and configurations were derived from a survey of equipment as installed by a number of major European office equipment manufacturers. Analysis of the survey data yielded the most common combinations of desk size and obstructions size and configuration and the standard obstructions in figure 1 are representatives of these. The task area is taken as being the horizontal area of the desk. The representation of the human form was found in the previous work to have a major influence on task illuminance conditions and in the modified version the CIE standard for "body shadow" used in Contrast Rendering Factor computation was adopted as this was capable of acknowledging the separate contributions of head and body to obstruction [6]. The flow chart for the modified computer program based on the obstructed SHR concept set out in the previous section is given in figure 2. The program uses intensity distribution of luminaires for 0° - 90° elevation in steps of 5° and at steps of 45° azimuth for point source, and 30° azimuth for linear sources. The program introduces the standard obstruction either parallel or perpendicular to the luminaire axis. For each SHR value of the preferred series the illuminance from each of the 16 luminaires at each point on a 10 cm square calculation grid over the task area is calculated taking into account the presence of obstructions. The uniformity ratio based on minimum/maximum illuminance over the task area, excluding a 10 cm, wide edge strip, is then calculated.The edge strip is excluded from the uniformity ratio calculation since this would not in practice be used for visual tasks.

The effect of obstructions is a major element in the illuminance calculation procedure and is assessed by separate consideration of how much of the luminaire, if any, may be "seen". For luminaires which are assumed to be point sources the check is either "see" or "no-see" and the illuminance may be calculated easily following this check, using a point-by-point calculation. For linear luminaires checks are initially required to determine if a luminaire is partly or wholly blocked by an obstruction by comparison of angles subtended at the point considered by the ends of the obstruction and that of the luminaire in plan and elevation. Illuminance from parts of luminaires that are visible at a calculation point are calculated using an Aspect Factor calculation.

4 Results

To study the effects of the various standard obstructions the uniformity ratios for the preferred series of SHR set out in CIBSE TM5 was calculated for a number of examples. The results are summarised as a table in figure 3 and as graphs in figure 4 and 5 for both linear and symetric point luminaires and include examples for standard obstructions positioned such that their axes are parallel or perpendicular to those of the linear luminaires. To provide a reference to the obstructed case the uniformity ratio for the empty case is also shown.

The reduction in SHR for the symetric luminaires is shown in figure 4. There are large differences in SHRMAX between empty and obstructed cases and smaller but significant differences between the obstructed cases. In terms of SHRNOM, which is a major concern to designers, the difference become even more marked. For luminaire 3, for example, the value for the heavy obstructed case falls two preferred increments from empty. The major contributing factor to the large reduction in uniformity ratio when considring point sources is when the point of minimum illuminance on the task area moves from "seeing" to "not seeing" the luminaires with major illuminance contributions and under these circumstanses shadow may be a problem.

Marked differences between empty and obstructed cases for linear luminaires are apparent from figure 5, in some cases this being up to two increments of SHRNOM. Cases with work stations perpendicular to luminaires give acceptable uniformity ratios for all obstruction configurations but with relatively little difference between the obstructed cases in terms of SHRMAX. For work stations parallel to luminaires only the light and some medium cases have acceptable results but at SHRNOM value three increments lower than empty. This appear to lead to the general conclusion that the effect of an individual obstruction component is greater when perpendicular than parallel to a linear luminaire.

5 Conclusion

It is clear that obstructions have a major effect on illuminance conditions within an interior and that designers ignore that at their peril. The difference between the empty and various obstructed cases indicates that not only the presence of obstructions is important but also their size and disposition. The modified SHR described in this work may be used by designers in two ways: Either to indicate the design SHR at which acceptable task uniformities will be obtained or to give a warning of the need for local lighting.

6 References

1 :The calculation and use of utilization factors, Technical Memoranda No. 5, CIBSE, London, 1980.

2 :IES Lighting Handbook Reference Volume,IES (NY), 3-36, 1981.

3 :Mc Ewan, I and Carter, D.J., Some approaches to the treatment of obstructions in interior lighting design, Lighting Research and Technology, 17 (3), 107, 1985.

4 :Carter D.J. and Mc Ewan I., The treatment of obstruction in interior lighting design- calculation of spacing to height ratio, Lighting Research and Technology, 18 (2), 79, 1986.

5 :The calculation of direct illuminance from linear sources, Technical Report N0. 11, IES, London, 1968.

6 :Guide on interior lighting, Publication 29-2, CIE,Vienna,1986

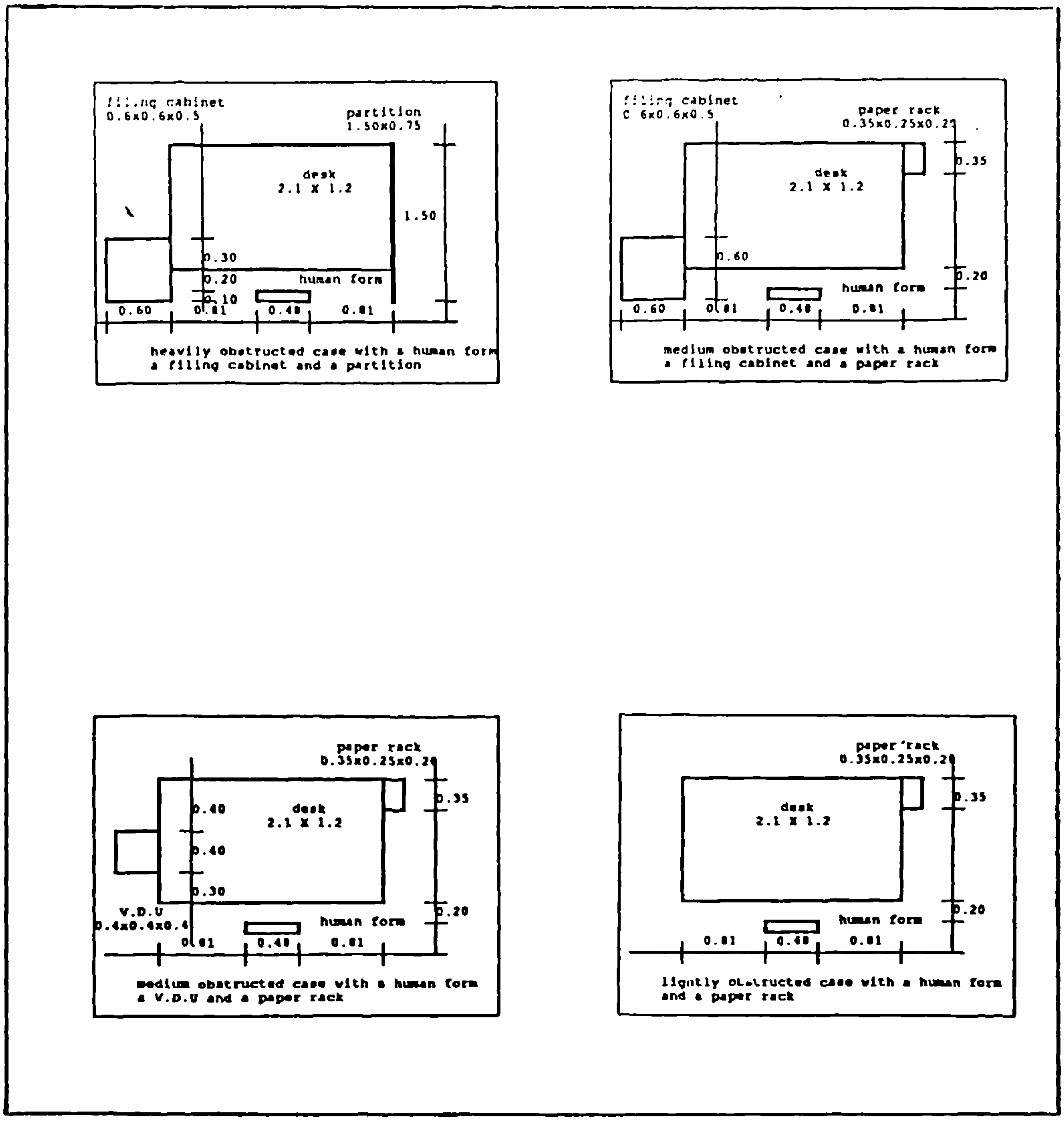


Figure 1: Standard obstruction configurations used in the modified SHR program.

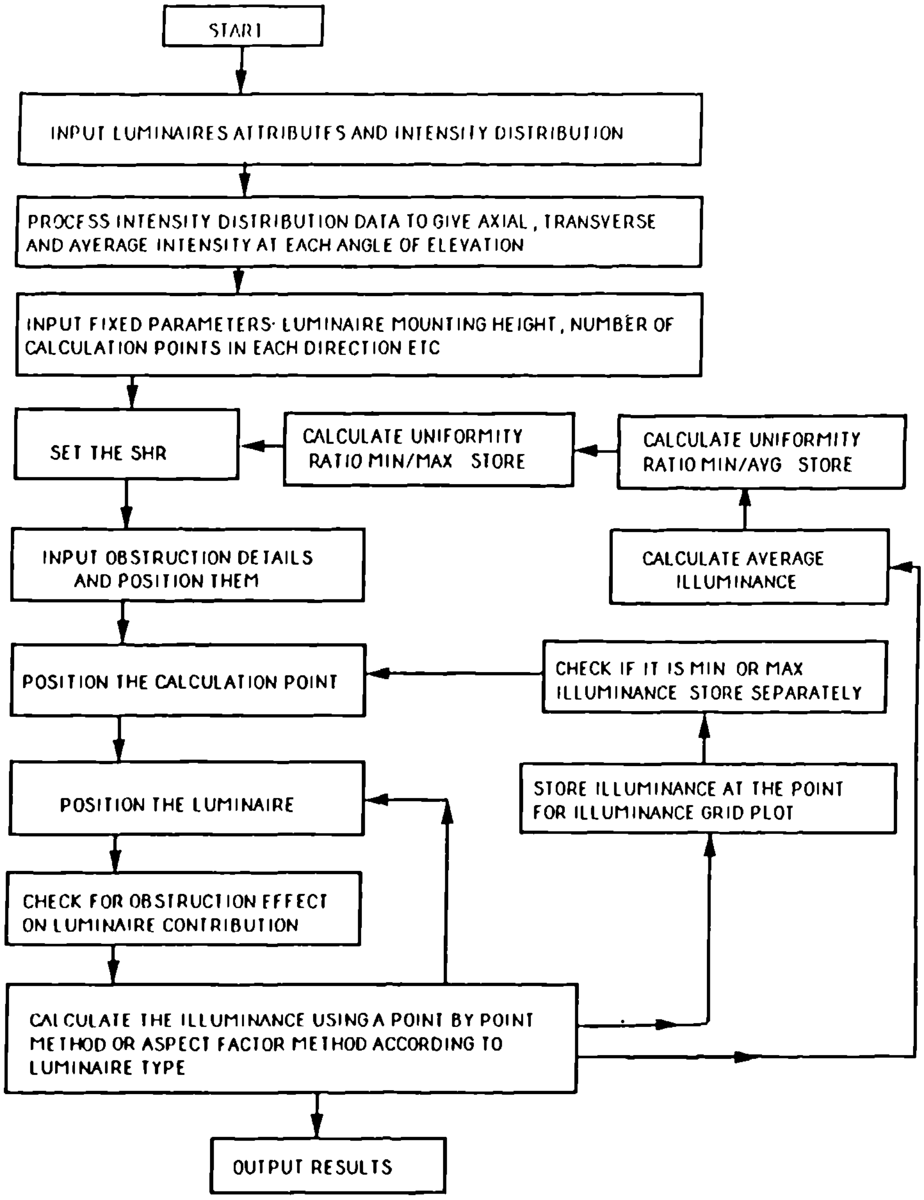
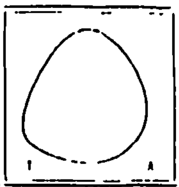
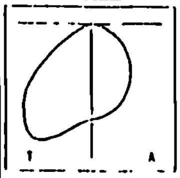
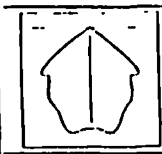


Figure 2: Flow chart diagram for calculating SHR for obstructed interiors.

Figure 3: Table of SHRMAX for different cases of obstructed intériors lit by different types of luminaires.

luminaire type	polar curve	position of work station	empty room	lightly obstructed case	medium obstructed case		heavily obstructed case
					V.D.U	filing cabinet	
600 mm twin lamp prismatic panel (linear)		perpendicular to luminair axis	1.70	1.40	1.40	1.33	1.27
		parallel to luminaire axis	1.70	1.00	—	0.85	—
twin batwing reflector (linear)		perpendicular to luminaire axis	1.89	1.52	1.50	1.25	1.25
		parallel to luminaire axis	1.90	1.00	—	—	—
square downlight (point source)		perpendicular or parallel to luminaire axis	1.33	1.15	1.14	1.13	1.13
compact source (point source)		perpendicular or parallel luminaire axis	1.74	1.42	1.35	1.35	1.17

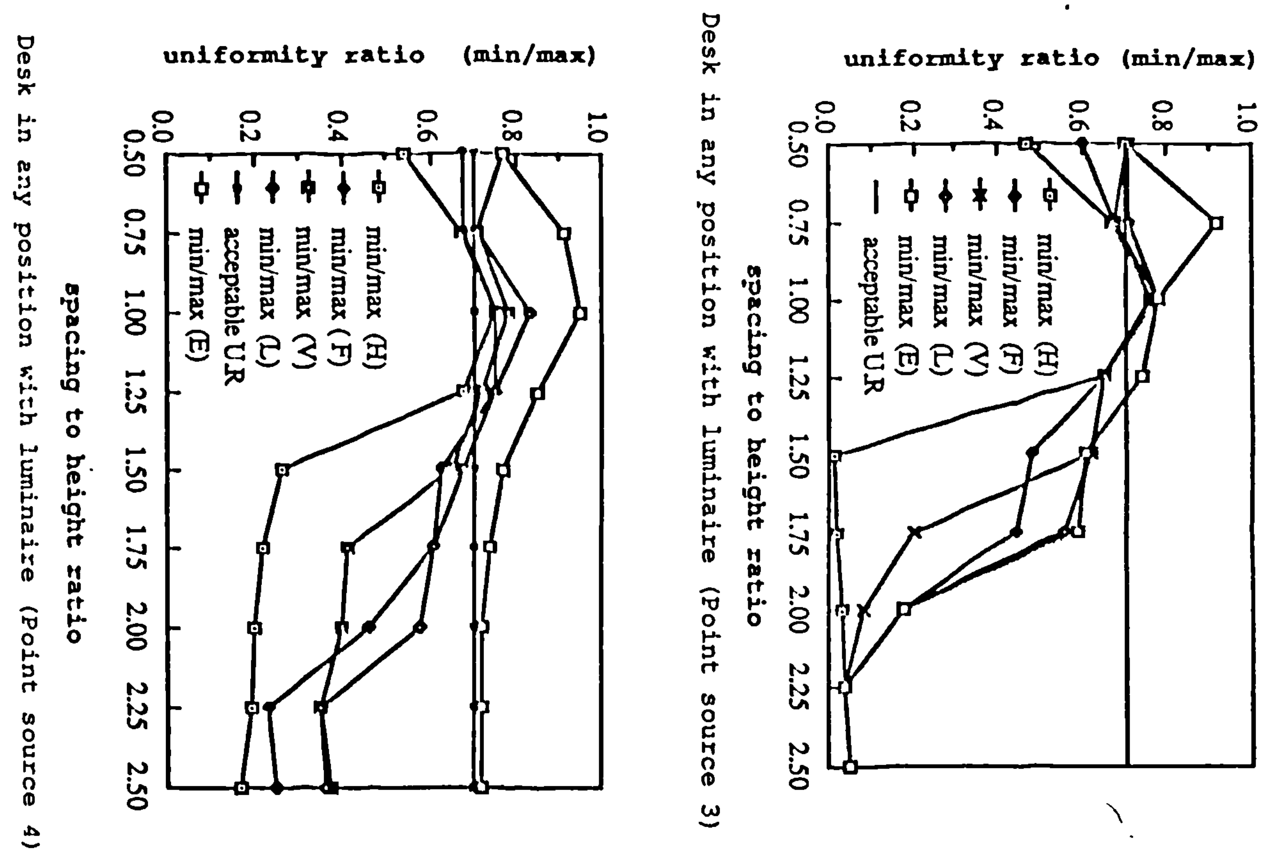


Figure 4: Variations in uniformity ratio as a function of SHR for empty and obstructed spaces lit by symetric point luminaires

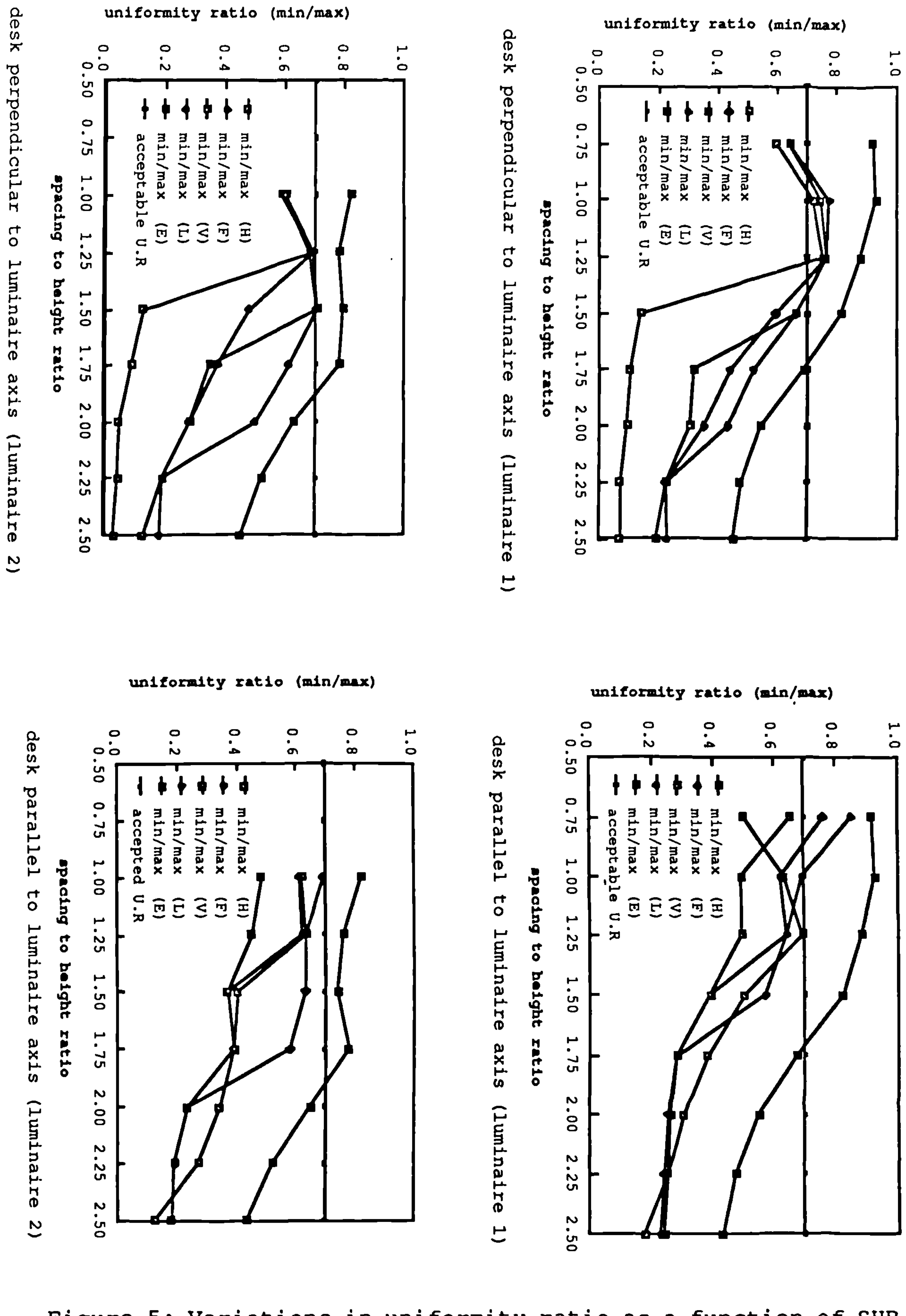


Figure 5: Variations in uniformity ratio as a function of SHR for empty and obstructed spaces lit by linear luminaires.

UNIFORMITY OF ILLUMINANCE - THE NEED FOR A DIVERSE APPROACH

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Illuminance from any lighting installation will never be completely uniform over a working plane. The desire to limit this variation is usually regarded as a major quality concern of the lighting designer and is incorporated into the Lumen Method of design. This paper reviews the various representations of uniformity that have been promulgated and describes how they may be incorporated into SHR calculations for both empty and obstructed spaces.

INTRODUCTION

The illuminance obtained in any lighting installation in practice will never be completely uniform over the entire plane. In naturally lit rooms illuminance levels are primarily determined by the distance from the windows but in artificially lit spaces the illuminance varies with the change in location with respect to the luminaire array with the superimposed variation due to the discrete nature of luminaires. Additionally room contents may obstruct the passage of light from the source to the task area and cause areas of local illuminance diversity. The desire to limit the magnitude of change in illuminance across a working plane is usually regarded as a major quality concern of the lighting designer. Design methods enshrine this notion in the concept of the provision of average standard service illuminance over the working plane within some prescribed limit of uniformity. Uniformity standards evolved in the early days of artificial lighting development and probably were due to the desire for uniform illuminance as a reaction to the diversity of daylight schemes (Harrison and Anderson(1)). At that time acceptable average working plane illuminance levels were as low as 50 lux and the calculation process was developed to maintain an acceptable level of minimum task illuminance and this, despite general illuminance levels having increased in the meantime, still forms the basis of the common representations of uniformity in use today. There is evidence that in addition to ensuring minimum working plane illuminance, uniformity is a factor in producing desirable performance levels of the visual task and in providing user satisfaction with installation appearance (Ewing (2) and Boyce (3)).

The lumen method is the most popular design technique for general lighting schemes and has as its principal aim the provision of uniform illuminance over a working plane (Pritchard(4). The core of the method is the spacing to height ratio (SHR) which determines the layout of the luminaires. The standard U.K. method for calculation of SHR in empty rooms is described in the CIBSE Technical Memoranda No.5 (5) and defines SHR as the ratio of the spacing in a stated direction between photometric centres of adjacent luminaires to the mounting height of the luminaires above the horizontal reference plane. Using a standard array of sixteen identical luminaires in a square grid the luminaires are positioned, at first, very close together and then moved apart in ordered steps so that the SHR is increased until the uniformity ratio defined by the minimum to maximum illuminance falls below the 0.7 threshold value. In order to calculate uniformity, the direct illuminance is calculated over a grid of points in the central area of the standard array of luminaires. Two SHR's are defined in the calculation: SHRMAX is the value of SHR which gives the widest spacing at which a ratio of minimum to maximum illuminance greater or equal to 0.7 is achieved over the central area and SHRNOM is the greatest value of SHR in the preferred series of steps to achieve the 0.7 minimum/maximum uniformity ratio.

A modification to the TM5 method of SHR calculation has been developed that allows for the effect of obstruction loss caused by the contents of non-empty rooms (McEwan and Carter(6), Bougdah and Carter(7 and 8)). The modified method takes account of light loss caused by defined obstructions positioned within the central area of the standard square array and is implemented by means of a computer program. In both the empty and obstructed SHR calculations the method of representation and threshold value of uniformity ratio are critical factors. When using the uniformity ratio defined by the ratio of minimum to maximum illuminance the result depends on two point illuminance values. The illuminance grids for typical SHR calculations of the type described in TM5 for empty rooms are characterised by smooth gradients of illuminance from point to point and the minimum and maximum values used to define the uniformity ratio will usually be representative of conditions over relatively large areas of the working plane. Adding obstructions to the calculations, on the other hand, causes sharp decreases in local illuminance due to the shadowing of the notional room contents. The resulting uniformity ratio could thus be adversely influenced by a large single isolated value of minimum or maximum illuminance that is unrepresentative of adjacent areas.

The purpose of the present work is to derive and test alternative representations of uniformity which overcome the drawbacks outlined above, for use in both empty and obstructed SHR calculations. This paper reviews the various representations of uniformity that have been promulgated, describes how some may be incorporated into SHR calculations and presents results for a range of luminaires.

MEASURES OF UNIFORMITY

Ratios of Minimum/Maximum/Average Illuminance

This system forms the basis of the specification of uniformity in most of the major national and international lighting codes. The CIBSE Code (9) uses a uniformity ratio defined as the minimum to average illuminance over the task area and recommends that its value should not fall below 0.8. To attempt to ensure that this is the case, luminaires are recommended to be installed at an SHR which limits to 0.7 the ratio of minimum to maximum direct illuminance values obtained beneath and between luminaires in a square array at the middle of an installation. This ratio is known as the mid-point ratio and provides a simplified worst case calculation as a basis for determining SHRMAX which normally gives a uniformity ratio of 0.8 over the central region of an installation(CIBSE (5). The SHRMAX calculation procedure attempts to ensure that the uniformity criterion would be acceptable at any spacing up to the maximum for the type of luminaire distribution. The limiting value of mid-point ratio of 0.7 appears to result from the work of McWhirter (10), and experimental work by Saunders (11) showed that people's assessment of uniformity worsened as minimum/maximum illuminance fell below 0.7 to a point at 0.5 where the majority was dissatisfied. As pointed out by Cuttle (12) the minimum/average and minimum/maximum limits have a mathematical relationship such that for an unbiased distribution a minimum/average ratio of 0.8 would be equivalent to a minimum/maximum ratio of 0.67, thus representing a slight relaxation of standards. By a similar argument the minimum/maximum limit of 0.7 is equivalent to that of 0.82 minimum/average . The CIE Code on Interior Lighting (13) and the DIN Standard 5035 (14) adopt a minimum/average criterion for specification of uniformity on the working plane with limiting values of 0.8 and 0.66 respectively although neither is explicitly linked to luminaire spacing.

Statistical Representations of Uniformity

Concern that minimum/maximum/average ratio methods of representing uniformity produced a result heavily influenced by a single point.value - usually the minimum- lead to the development of statistical techniques for determining the distribution about the average of all points of illuminance calculation or measurement. Mahler and LeVere (15) put forward "Uniformity of illuminance" (UI) as a measure related to both average and the distribution of planar illuminance.

$$UI = \left(1 - \frac{MD}{E_{ave}}\right) X\ 100 \qquad \text{.......(1)}$$

where MD is the mean deviation and is calculated from the following expression:

$$MD = \sum_{p=1}^{n} |E_{ave} - E_p| \ / \ n \qquad \text{.......(2)}$$

where:

E_{ave} = average planar illuminance
E_p = point illuminance
n = number of points of measurement

The major omission in the UI method were that no indication of the number and position of points of calculation for working planes of different sizes was given, and that there was no guidance as to what constitutes desirable, or otherwise, limiting values of UI.

The use of the standard deviation (S) technique was proposed by Jones and Levin (after Mahler and LeVere(15)) as means of giving some indication of the distribution of the points measurement and at the same time more heavily weights extreme values.

$$S = \sum_{p=1}^{n} \sqrt{(E_p - E_{ave})^2 / n} \qquad \text{.......(3)}$$

This approach has the advantage that the lighting designer would be able to tell for example, that about two-thirds of the measurement points would be found within plus or minus one standard deviation of the average, and by dividing standard deviation by average, an index (S/Avg) could be defined which express uniformity in terms of percentage of illuminance variation from average, related to the number of measurement points. Mathieu (16) incorporated the standard deviation approach into the measure of "Statistical Uniformity" (SU)

$$SU = (E_{ave} + S) / (E_{ave} - S) \qquad \text{.......(4)}$$

A test for convergence is required to establish the number of calculation points required to give acceptable results for E_{ave} and S. Mathieu (16) suggested that the appropriate number of points could be obtained by varying the size of the calculation grid subject to a minimum of 100. A generalised relationship between SU and uniformity ratio (in terms of minimum and average) exists, SU being effectively a measure of "maximum/minimum" ratio. This means that a uniformity expressed as an SU could be interpreted in a similar manner to the maximum/minimum planar illuminance ratio if, for example, a design specification was in terms of illuminance of adjacent areas.

Gradient Techniques

Fink (17) and Ewing (2) developed measures of uniformity based on gradient of illuminance between adjacent points on a plane and calculated as percentage change in illuminance over a finite distance, usually for most applications 0.1 X mounting height of luminaire. Fink also reported the results of some experiments which attempted to determine the size of gradients that observers found noticeable, and also to relate gradient measures to minimum/maximum/average ratios. Although the results should be treated with caution due to the small number of observers tested, the experiments indicated that a uniformity ratio of 0.8 minimum/average was equivalent to about 10% gradient, this being valid if no large gradients existed. It was also demonstrated that the gradient techniques could be used, in place of minimum/average uniformity ratio, in calculation of SHR in empty rooms.

APPLICATION OF UNIFORMITY MEASURES

For each value of the preferred series the SHR calculation was performed using different uniformity criteria and was then assessed against limits appropriate to each measure. Details of the SHR calculation procedure are given elsewhere in this conference (8).The method of representation of the criteria and derivation of the limits is described below.

Minimum/Maximum/Average Illuminance

The task area was divided into a grid of points at 0.1m centres at which direct illuminance was calculated. Maximum and minimum points were selected, average illuminance calculated for the whole grid area and the appropriate ratios calculated. An additional 16 point minimum/maximum ratio was derived this being the lowest and highest illuminance averaged over areas on the task of size of approximately an A4 piece of paper. This produced, it was hoped, a measure that was not unduly influenced by single points values, and was calculated by dividing the illuminance grid into sub-areas of 16 points over which an average was calculated. The limit of this measure was taken as 0.8 since it was expressed in terms of averages.

Statistical Measures

The standard deviation approach was used to develop two measures of uniformity together with appropriate limits. The first is the ratio standard deviation/average illuminance with an associated limiting value derived from the familiar ratio of minimum/maximum illuminance of 0.7. Assuming a normal distribution in which 95% of points (i.e. two standard deviations) satisfy the criterion then:

$$E_{min} = E_{ave} - 2S \quad \text{.......(5)}$$

$$E_{max} = E_{ave} + 2S \quad \text{.......(6)}$$

If the ratio Min./Max is expressed in terms of equations (5) and (6) we then get:

$$(E_{ave} - 2S) / (E_{ave} + 2S) = 0.7 \quad \text{.......(7)}$$

$$\text{hence} \quad S = 0.1\, E_{ave} \quad \text{.......(8)}$$

Illuminance values at all points on the grid, standard deviations, and the uniformity measure (S/E_{ave}) X 100 were calculated for comparison with the limiting value of 10%.

The second statistical measure considered is Statistical Uniformity (SU) which uses one standard deviation as the basis of its calculation process. Based on a minimum/maximum ratio of 0.7 and substituting for S by the expression in equation (8), SU can be written as:

$$SU = (E_{ave} + 0.1\,E_{ave}) / (E_{avg} - 0.1E_{avg}) \qquad (9)$$

Solving the equation will result in a limiting value for SU of 1.22.

Gradient Measures

Gradients were calculated between all individual points having a separation of 0.3m in both directions over the whole illuminance grid. The spacing of 0.3m was selected for the calculation since it represented the size of the "area" of task already used in the 16 point minimum/maximum measure and was similar to the size of the grid of points used for gradient calculations by Fink (17). For each point on the 0.3m grid the gradient was calculated in both directions as follows:

$$\text{Gradient}_{a\,b} = 2\,(E_a - E_b) / (E_a + E_b) \qquad (10)$$

where a and b are adjacent grid points. All gradient values are calculated and the maximum value is selected as the uniformity measure. Fink suggests an acceptable maximum gradient of 10% although this was determined for empty spaces lit by luminaires with smooth intensity distributions.

RESULTS

To study the effect of the various uniformity measures, SHR calculations were performed for both empty and obstructed spaces using a number of luminaire types and results for four luminaires (two linear and two point sources) are presented in Table 1 in terms of SHRMAX and in Table 2 in terms of SHRNOM. Inspection of Table 1 indicates that the relationship between the various measures and SHR follow similar general patterns for each luminaire. More detailed results for luminaires 1 and 3 in Table 1 are shown in Figures 1.1 to 1.12 and 2.1 to 2.21 respectively. These show in graphical form results using six uniformity measures applied to both empty and obstructed calculations and enable the relationships to be examined in terms of both SHRMAX and SHRNOM. Since a number of the measures rely on either the magnitude or location of the minimum point the SHR calculations were repeated with the minimum point value arbitrarily reduced by 20%. The results are also shown in Table 1. The purpose of the test was to give a pointer to the robustness of the the measures when dealing with illuminance grids that may contain isolated local areas of low illuminance, this being a particular problem in obstructed spaces.

Point Source (figures 1.1 to 1.12)

The results of using the various minimum/maximum/average measures are illustrated in figures 1.1 to 1.12. The results indicate that using all the various uniformity measures, the greater the degree of obstruction the smaller the maximum SHR permitted. The minimum/maximum measure using two illuminance points which has been used to date in all SHR calculations, gives very different SHRMAX values for the various obstructed cases, but the same SHRNOM, one increment lower than that of the empty case. SHRNOM calculations using the minimum/average measure with single point minimum were higher than the equivalent minimum/maximum calculation by two increments for the empty case and three increments for lightly obstructed case. Interestingly the SHRNOM values for the medium and heavy cases of obstruction were similar to those calculated using minimum/maximum. This is due to the obstructions causing a change in the statistical distribution of the illuminance grid from smoothly to rapidly varying which in turn causes average illuminance and maximum point illuminance to vary at different rates. The minimum/maximum values calculated using the 16 point sub- areas of the illuminance grid gave higher SHRMAX value than the single point minimum/maximum in all cases despite the higher limiting value of the 16 point measure. In terms of SHRNOM the empty case was the same as single point but the obstructed cases were all one SHR increment higher. This result is not unexpected since given the "averaging" effect, the use of the A4 sized sub-areas would tend to produce minimum/maximum ratio that approaches unity.

Both statistical measures give higher SHRMAX results than single point minimum/maximum but with a less steep fall in SHR from the light to the heavy obstructed cases. The effect on SHRNOM was to produce the same value for all obstructed cases, one increment higher than the equivalent minimum/maximum value. The major difference between the two measures was apparent only in the heavily obstructed cases where a substantial number of points on the illuminance grid, with low illuminance values, lay between one and two standard deviations and in this case the S/Ave measure was better able to take account of the widely dispersed points at or near the minimum.

Discussion of the gradient measures was difficult because of uncertainty about what constitutes a limiting value of maximum gradient. The application of Fink's suggested figure of 10% would mean that the empty case would have a maximum of 0.9 and light and medium obstructed cases 0.5 SHR. The results should be treated with caution since they are considerably at variance with the results produced by the other measures. Inspections of the curves in Figures 1.1 to 1.12 suggest that an alternative limit that gives resultsof a similar order to those of the other measures may be the point at which the graph of uniformity measure increases sharply. This would, for example, give a value of SHRNOM for the empty case of 1.75 compared with minimum/average of 1.75 and minimum/maximum of 1.25. It is likely that the point of sharp increase of maximum gradient is caused by large areas of low value illuminance on the grid at the particular SHR and that under these circumstances the maximum gradient may be through the point of minimum illuminance.

The effect of arbitrary reduction of the minimum point illuminance can be seen in column 4 in Table 1 (for luminaire 1). The effect on minimum/maximum and minimum/average is dramatic, as it may be expected, since the measures are highly dependent on the single value of minimum illuminance. In both cases neither uniformity measure attains the limiting value although all other points on the illuminance grid remain the same. The effect on 16 point minimum/maximum and on the statistical measures are negligible, all attaining the same SHRNOM as before. The effect on gradient measures is erratic. The difference between the results produced by original and modified measure suggest that this is due to the variations in geographic locations of the maximum gradient.

Linear Sources (figure 2.1 to 2.21)

The results of application of the calculation process to linear sources show the same general characteristics for the point source. SHR decreases with increase in degree of obstruction. This transition being smooth in the case of statistical and 16 point minimum/maximum measures but as a sudden drop between empty and obstructed in the other minimum/maximum/average cases. It is apparent that in nearly all calculation the SHR values for obstruction placed perpendicular to the work station are higher than when placed parallel. The gradient measures with the exception of the empty case produce results which are of little practical use in determining SHR.

CONCLUSION

It is apparent that the use of the various measures of uniformity as the basis of SHR calculations gives results of the same general pattern but exhibiting some important variations. The most important of these in terms of current practice is the difference between the results obtained using minimum/maximum, the basis of calculations in CIBSE TM5, and minimum/average which is used for specification of uniformity in CIBSE Code for Interior Lighting. Minimum/maximum/average calculations have the advantages of simplicity, which make them easy to understand and suitable for hand calculations, and of association with limiting values which appear to have some experimental validation and which have been in use for a long time,albeit with limits that do not equate to each other. The problems with these measures are caused under the circumstances where isolated point minimum or maximum values adversely affect the results. This lack of robustness is to some extent overcome by the use of the 16 point minimum/maximum measure. The two statistical measures, appear from the the experimental evidence, to produce robust result and have limiting values developed from the tried and tested minimum/maximum/average values. It is clear however that for most illuminance grids which have wide spreads of points that the S/Eave measure is superior to SU. Both were more complex than the other measures tested but since most SHR calculations are performed on computers this is not a major drawback in practice. The gradient measures produce results that deviate most from the general pattern. The use of maximum gradient as a measure makes both interpretation of results and definition of suitable limits very difficult. The measure suffers from the same disadvantage as minimum/maximum/average in that it critically depends on localised point values and there is a clear need for more subjective work to establish acceptable limiting maximum gradient of illuminance.

This work has tested a number of alternative uniformity measures for use in SHR calculations. Gradient measures have been shown to be unsuitable for this purpose whilst single point minimum/maximum/average measures exhibit inconsistency. Statistical and 16 point minimum/maximum measures on the other hand have been shown to have potential for the development as the basis of SHR calculations.

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TABLE 1- SHRMAX for typical luminaires calculated using different uniformity measures.

luminaire type	uniformity measure	empty case	lightly obstructed case		medium obstructed case		heavily obstructed case	
1 Point Source	Min/Max	1.33	1.15	---£	1.13		1.13	
	Min16/Max16	1.31	1.31	1.29£	1.31		1.27	
	Min/Avg	1.76	1.75	---£	1.15		1.18	
	S/Avg	1.41	1.41	1.38£	1.38		1.27	
	S.U.	1.42	1.39	1.35£	1.38		1.27	
	Max. grad	0.92	0.50	0.50£	0.50		---	
2 Point Source	Min/Max	1.74	1.42		1.35		1.17	
	Min16/Max16	2.00	1.75		1.75		1.28	
	Min/Avg	2.50	1.55		1.37		1.25	
	S/Avg	2.50	2.12		1.87		1.31	
	S.U.	2.40	2.10		1.87		1.30	
	Max. grad	2.00	0.53		0.53		---	
3 Linear Source	Min/Max	1.69	**1.40**	1.00	**1.33**	0.85	**1.27**	---
	Min16/Max16	1.88	**1.55**	1.50	**1.50**	1.25	**1.27**	1.16
	Min/Avg	1.92	**1.35**	0.91	**1.30**	0.75	**1.26**	---
	S/Avg	1.75	**1.62**	1.55	**1.56**	1.37	**1.27**	1.29
	S.U.	1.75	**1.62**	1.53	**1.55**	1.36	**1.27**	1.29
	Max. grad	1.75	---	0.80	---	0.75	---	---
3 Linear Source	Min/Max	1.89	**1.52**	1.00	**1.25**	---	**1.25**	---
	Min16/Max16	1.86	**1.62**	1.75	**1.62**	1.08	---	1.00
	Min/Avg	2.25	**1.50**	1.00	**1.25**	---	**1.25**	---
	S/Avg	1.95	**1.25**	1.25	**1.50**	1.12	---	1.00
	S.U.	1.92	**1.25**	1.78	**1.50**	1.08	---	1.00
	Max. grad	1.85	---	---	---	---	---	---

&& The bold figures indicate that the work station is perpendicular to the luminaire axis
---For all SHR values the uniformity criteria does not reach the limit
£ SHRMAX values obtained with a minimum illuminance reduced by 20 %

TABLE 2- SHRNOM for typical luminaires calculated using different uniformity measures.

luminaire type	uniformity measure	empty case	lightly obstructed case		medium obstructed case		heavily obstructed case	
1 Point Source	Min/Max	1.25	1.00	---£	1.00		1.00	
	Min16/Max16	1.25	1.25	1.25£	1.25		1.25	
	Min/Avg	1.75	1.75	---£	1.00		1.00	
	S/Avg	1.25	1.25	1.25£	1.25		1.25	
	S.U.	1.25	1.25	1.25£	1.25		1.25	
	Max. grad	0.75	0.50	0.50£	0.50		---	
2 Point Source	Min/Max	1.50	1.25		1.25		1.00	
	Min16/Max16	2.00	1.75		1.75		1.25	
	Min/Avg	2.50	1.50		1.25		1.25	
	S/Avg	2.50	2.00		1.75		1.25	
	S.U.	2.00	2.00		1.75		1.25	
	Max. grad	2.00	0.50		0.50		---	
3 Linear Source	Min/Max	1.50	**1.25**	1.00	**1.25**	0.75	**1.25**	---
	Min16/Max16	1.75	**1.50**	1.50	**1.50**	1.25	**1.25**	1.00
	Min/Avg	1.75	**1.25**	0.75	**1.25**	0.75	**1.25**	---
	S/Avg	1.75	**1.50**	1.50	**1.50**	1.25	**1.25**	1.25
	S.U.	1.75	**1.50**	1.50	**1.50**	1.25	**1.25**	1.25
	Max. grad	1.75	---	0.75	---	0.75	---	---
3 Linear Source	Min/Max	1.75	**1.50**	1.00	**1.25**	---	**1.25**	---
	Min16/Max16	1.75	**1.50**	1.75	**1.50**	1.00	---	1.00
	Min/Avg	2.25	**1.50**	1.00	**1.25**	---	**1.25**	---
	S/Avg	1.75	**1.25**	1.25	**1.50**	1.00	---	1.00
	S.U.	1.75	**1.25**	1.75	**1.50**	1.00	---	1.00
	Max. grad	1.75	---	---	---	---	---	---

&&: The bold figures indicate that the work station is perpendicular to the luminaire axis

---: For all SHR values the uniformity criteria does not reach the limit

£ : SHRNOMvalues obtained with a minimum illuminance reduced by 20 %

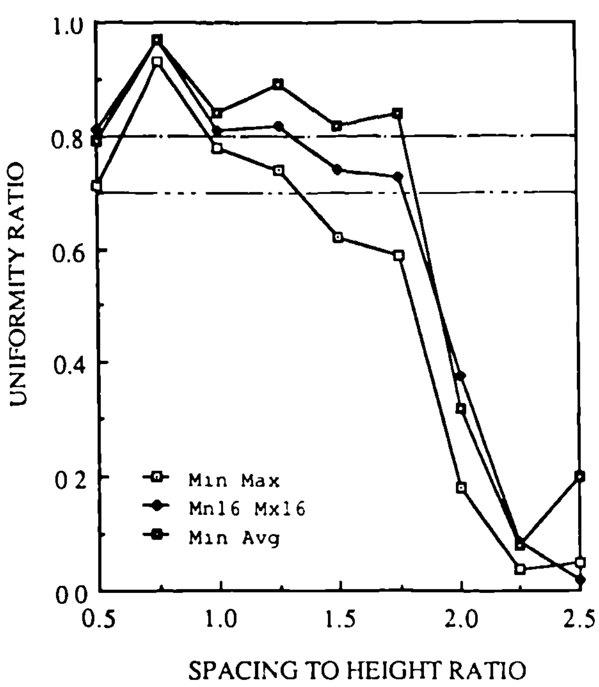


Figure 1 1 Min max and min avg measures for an empty space lit by point sources.

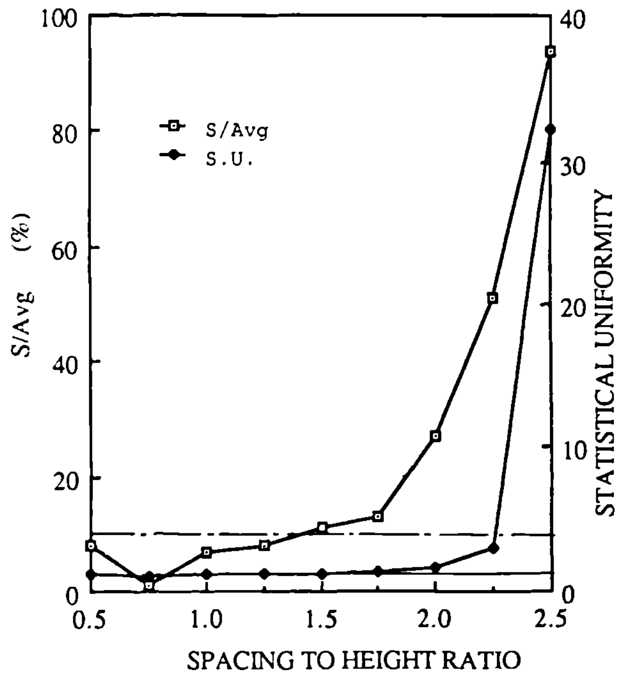


Figure 1.2 Statistical measures for an empty space lit by point sources.

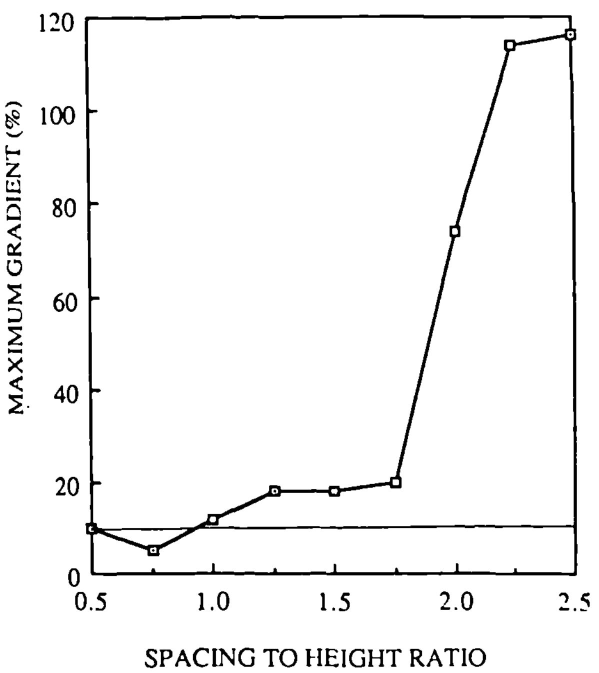


Figure 1.3 Maximum gradient for an empty space lit by point sources.

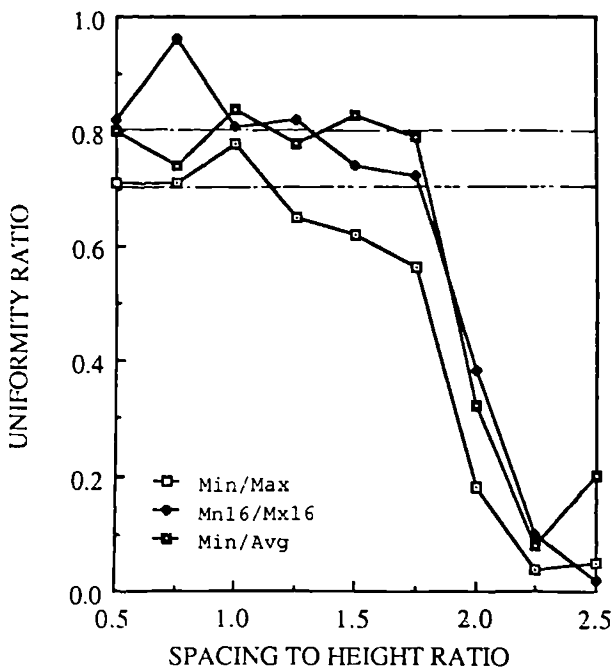


Figure 1.4 Min/max and min/avg measures for a lightly obstructed space lit by point sources.

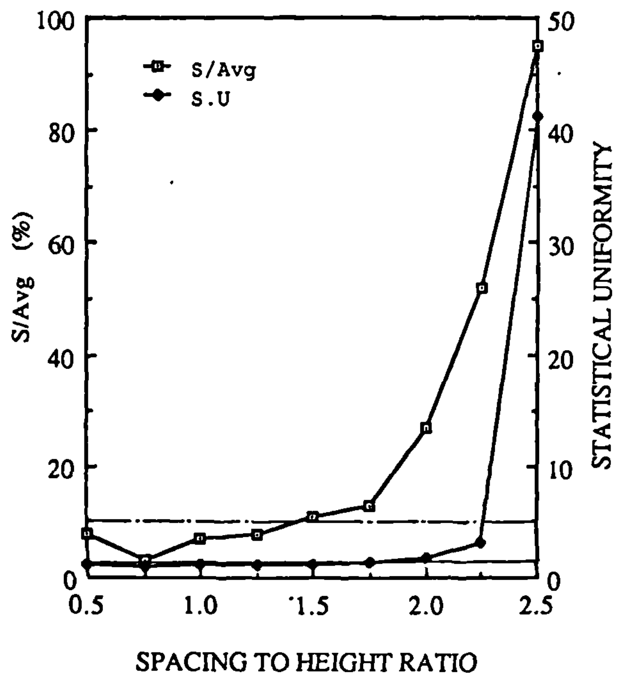


Figure 1.5 Statistical measures for a lightly obstruced space lit by point sources.

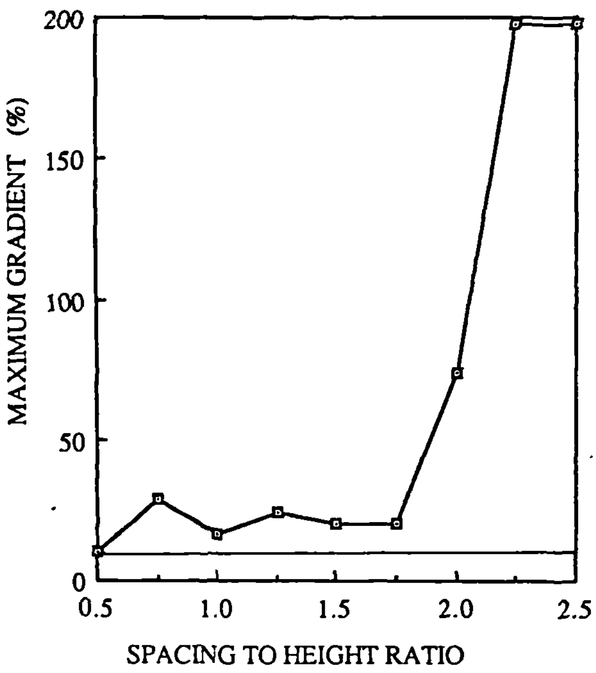


Figure 1.6 Maximum gradient for a lightly obstructed space lit by point sources.

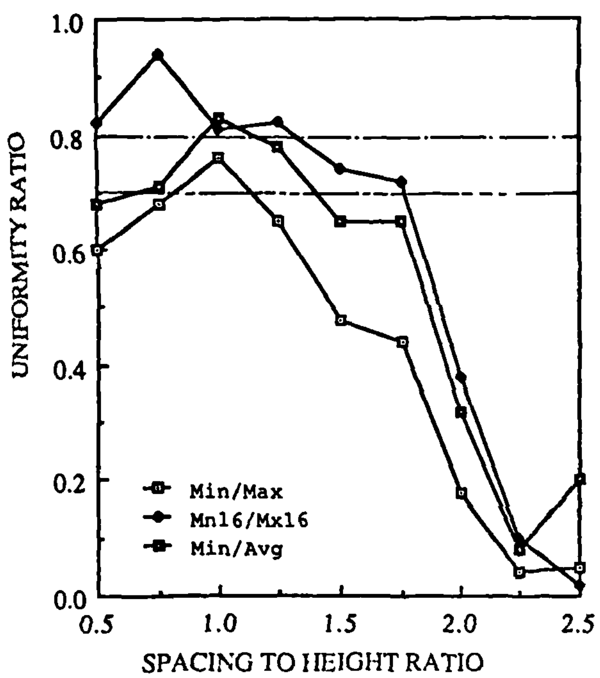


Figure 1.7 Min/max and min/avg measures for a medium obstructed space lit by point sources.

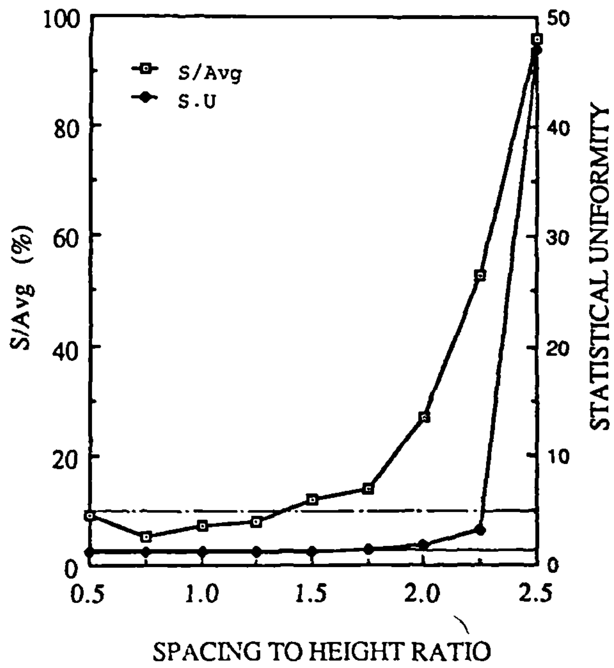


Figure 1.8 Statistical measures for a medium obstructed space lit by point sources.

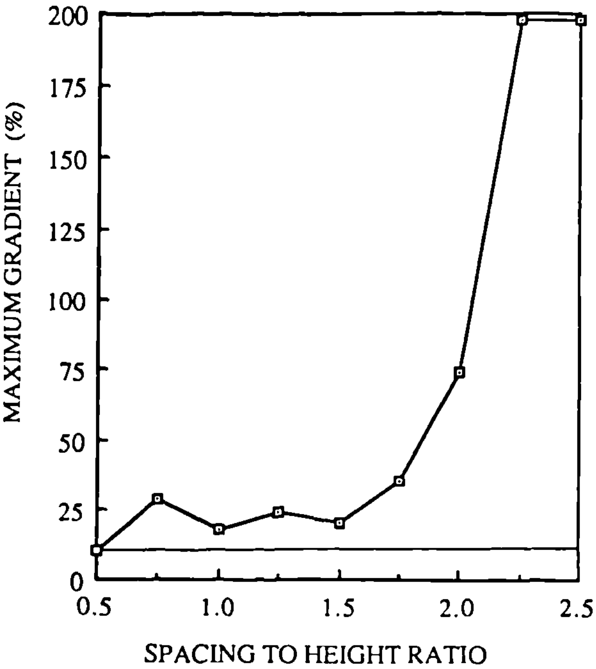


Figure 1.9 Maximum gradient for a medium obstructed space lit by point sources.

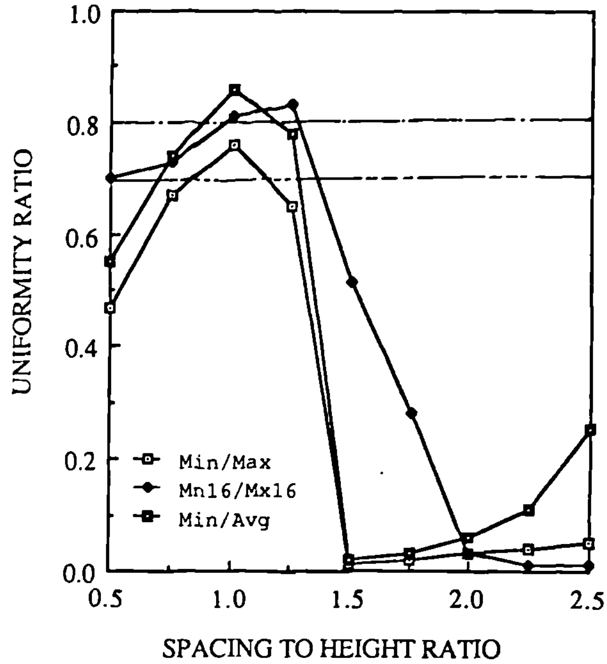


Figure 1.10 Min/max and min/avg measures for a heavily obstructed space lit by point sources.

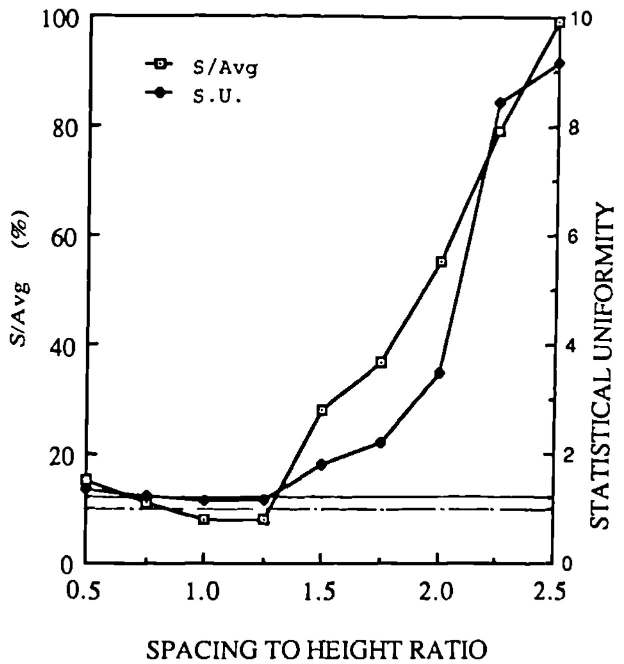


Figure 1.11 Statistical measures for a heavily obstructed space lit by point sources.

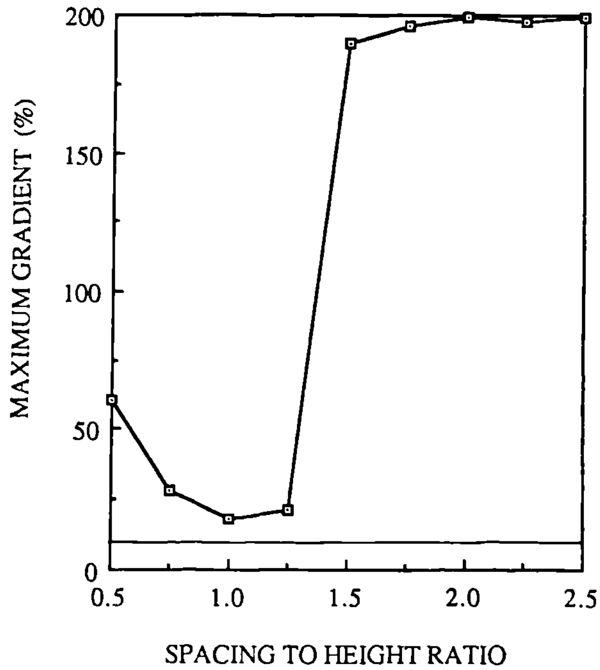


Figure 1.12 Maximum gradient for a heavily obstructed space lit by point sources.

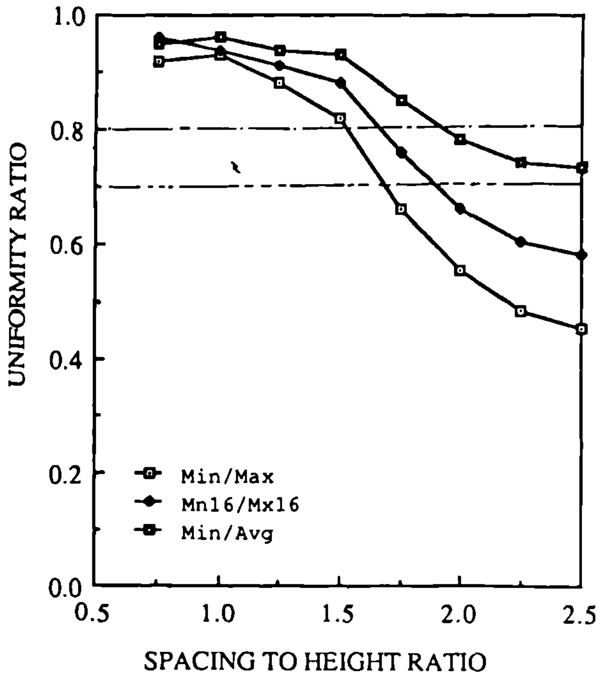


Figure 2.1 Min/max and min/avg measures for an empty space lit by linear sources.

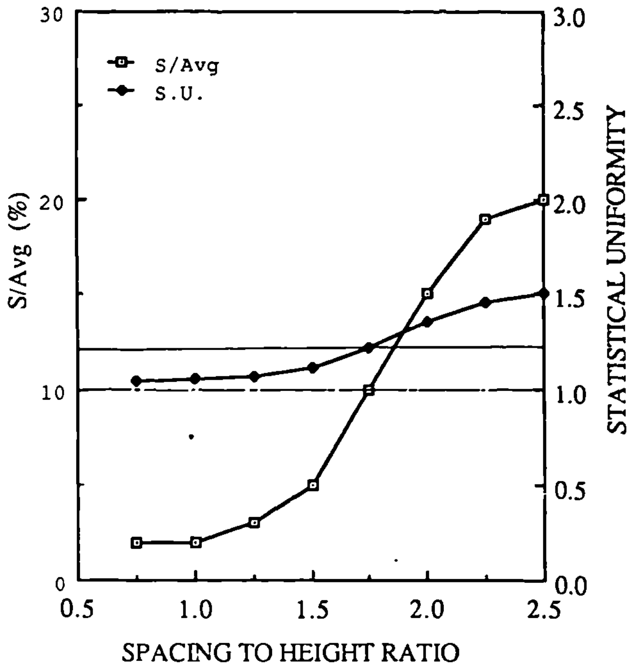


Figure 2.2 Statistical measures for an empty space lit by linear sources.

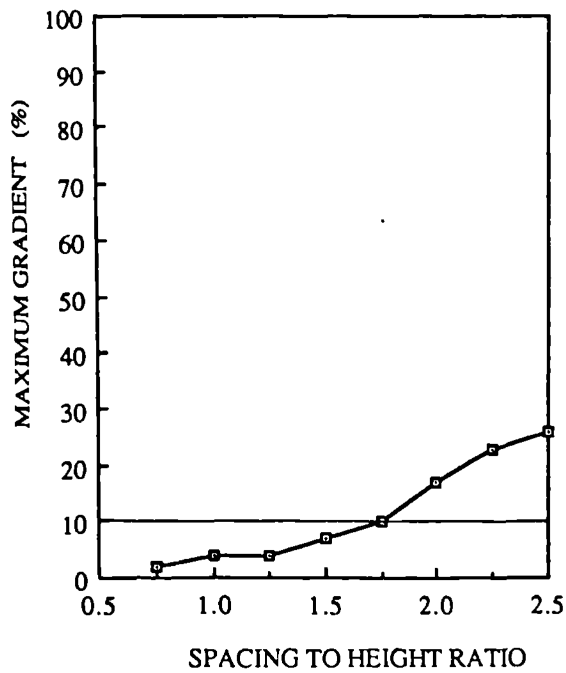


Figure 2.3 Maximum gradient for an empty space lit by linear sources.

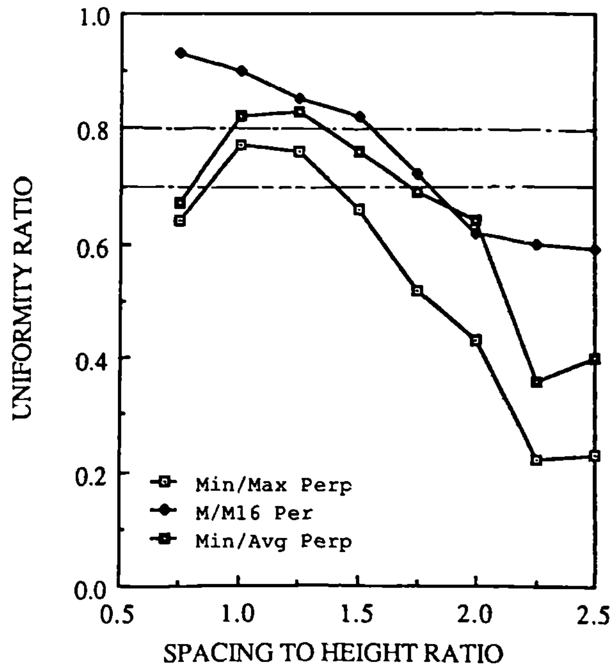


Figure 2.4 Min/max and min/avg measures for a lightly obstructed space (perp.) lit by linear sources.

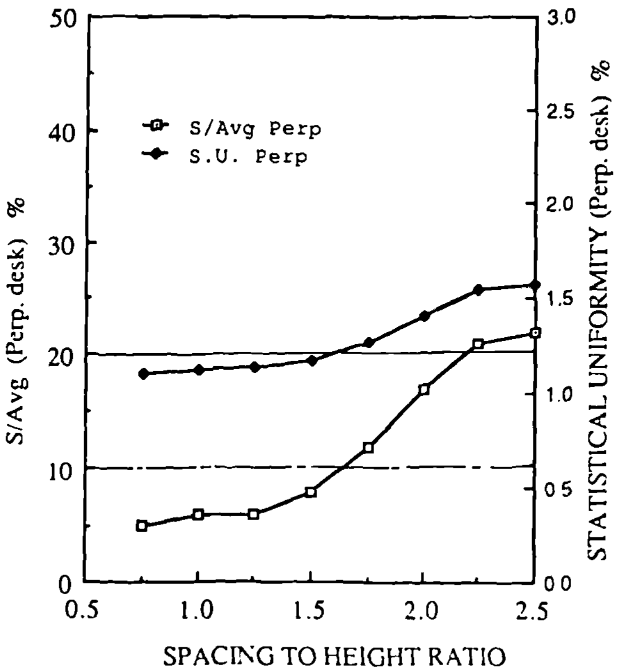


Figure 2 5 Statistical measures for alightly obstruced space (perp.) lit by linear sources.

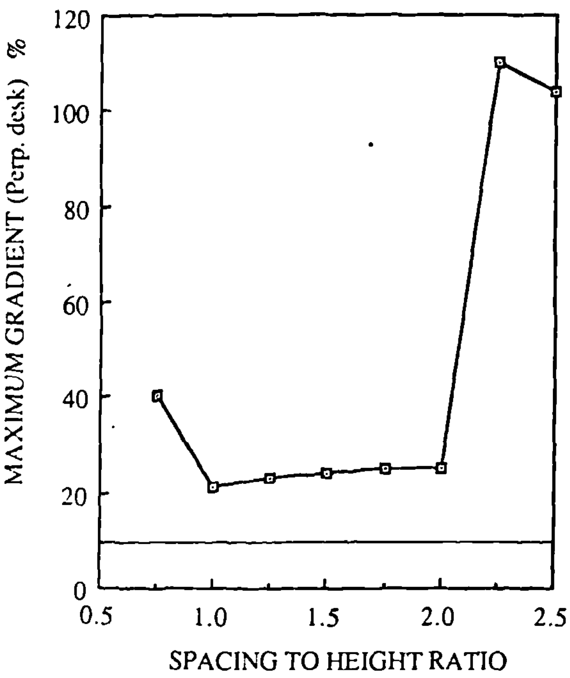
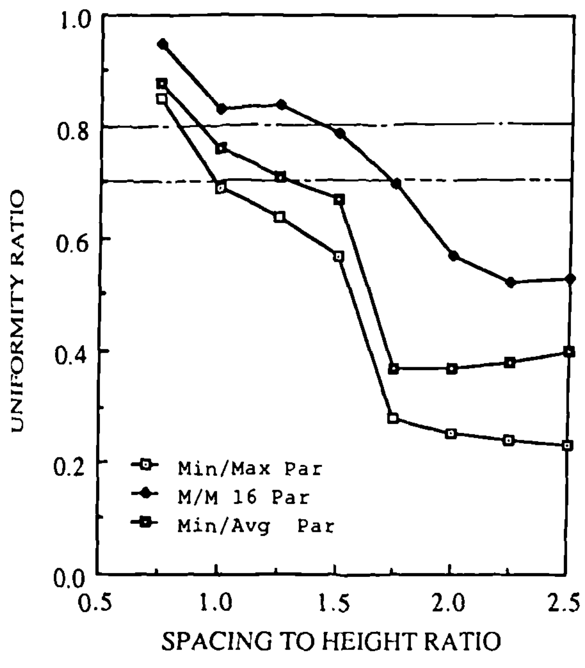


Figure 2.6 Maximum gradient for a lightly obstructed space (perp.) lit by linear sources.



igure 2.7 Min/max and min/avg measures for a ghtly obstructed space (para.) lit by linear sources.

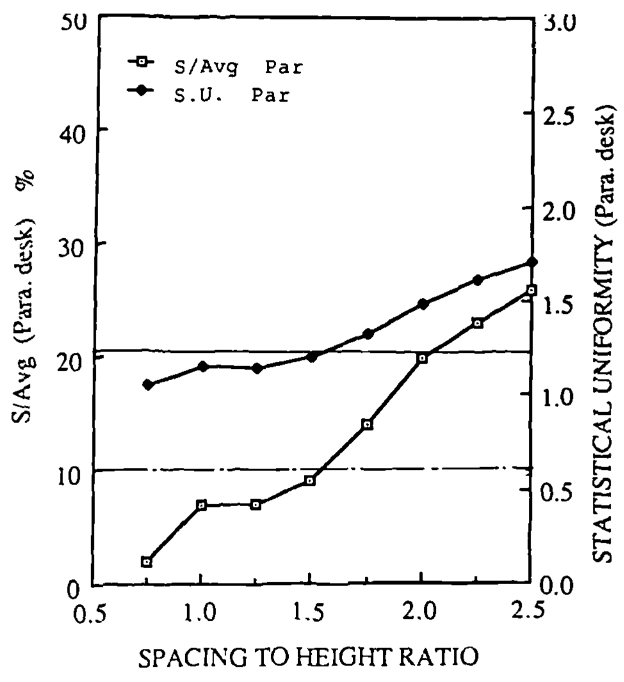


Figure 2.8 Statistical measures for alightly obstruced space (para.) lit by linear sources

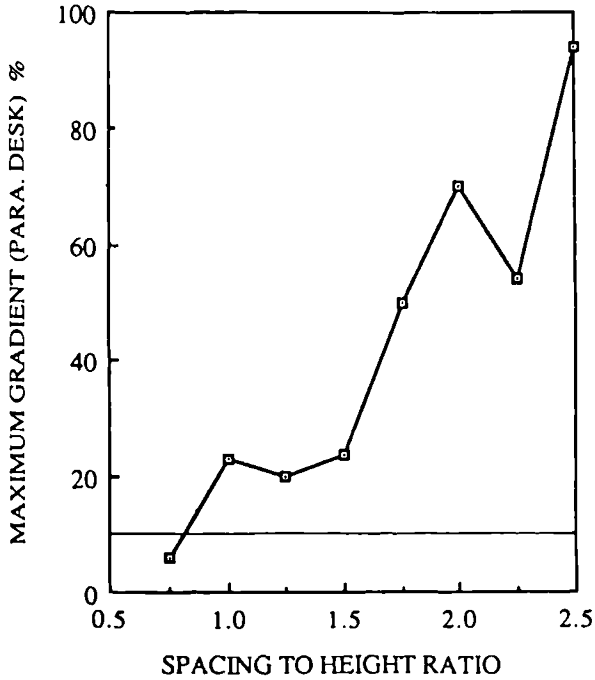


Figure 2.9 Maximum gradient for a lightly obstructed space (para.) lit by linear sources.

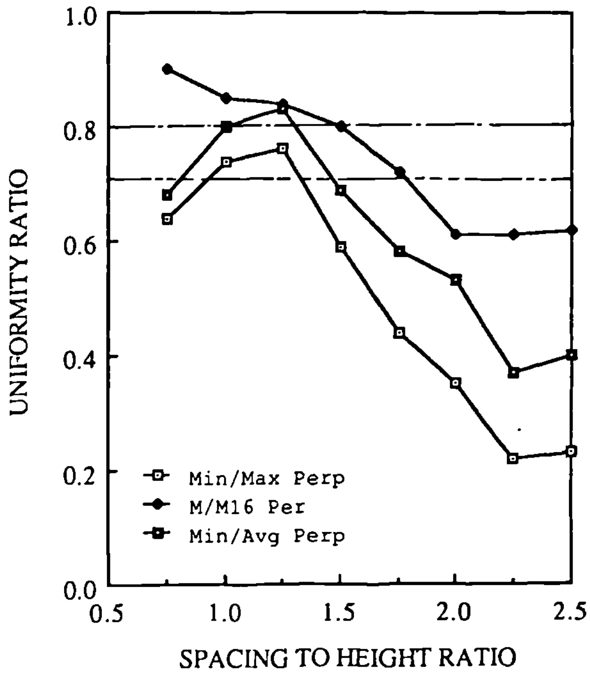
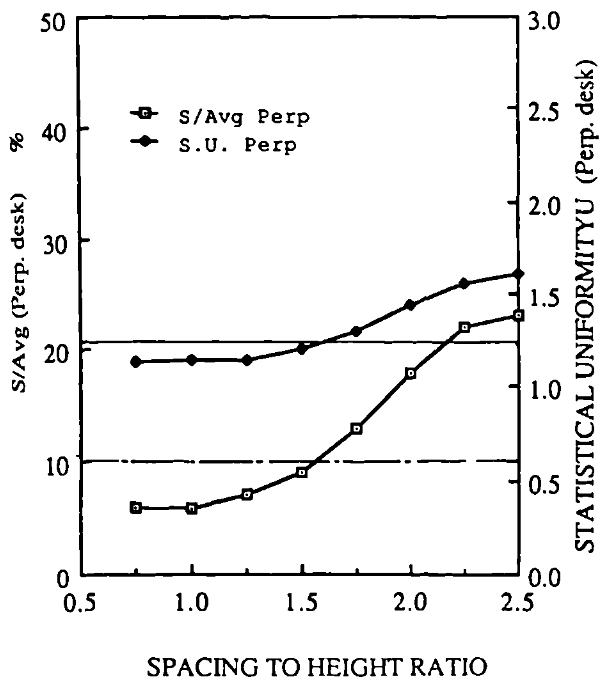


Figure 2.10 Min/max and min/avg measures for a medium obstruct. space (perp.) lit by linear sources.



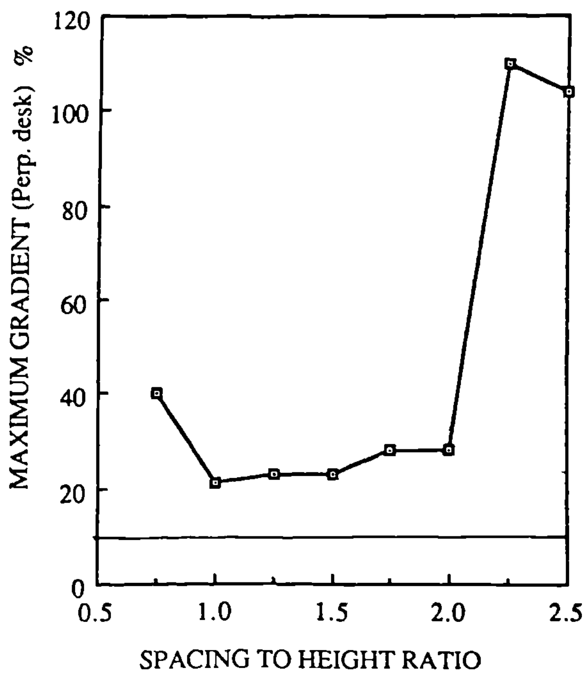


Figure 2.12 Maximum gradient for a medium obstructed space (perp.) lit by linear sources.

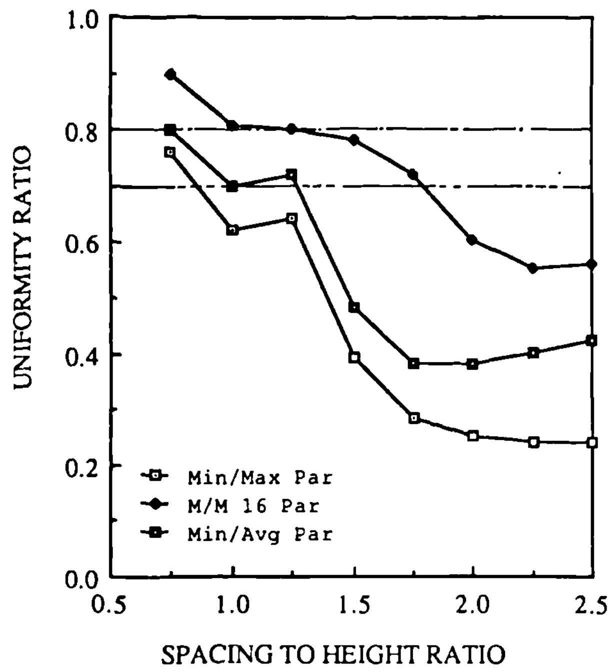


Figure 2.13 Min/max and min/avg measures for a medium obstruct. space (para.) lit by linear sources.

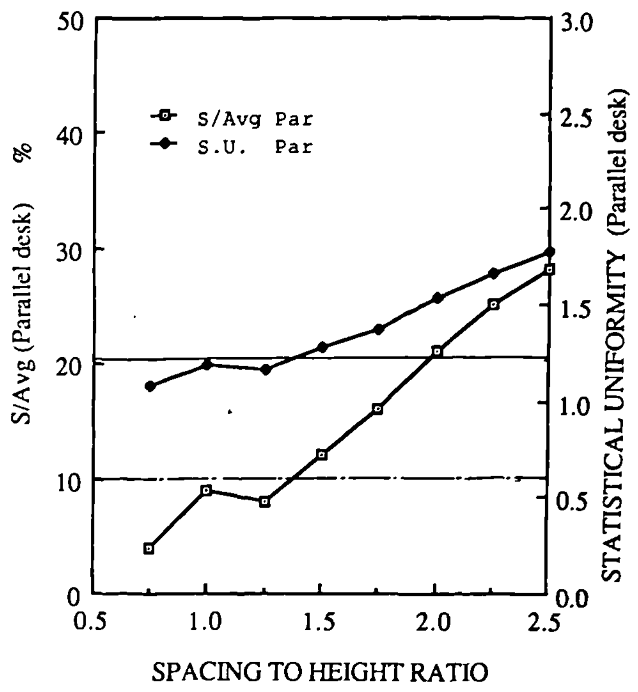


Figure 2.14 Statistical measures for a medium obstructed space (para.) lit by linear sources.

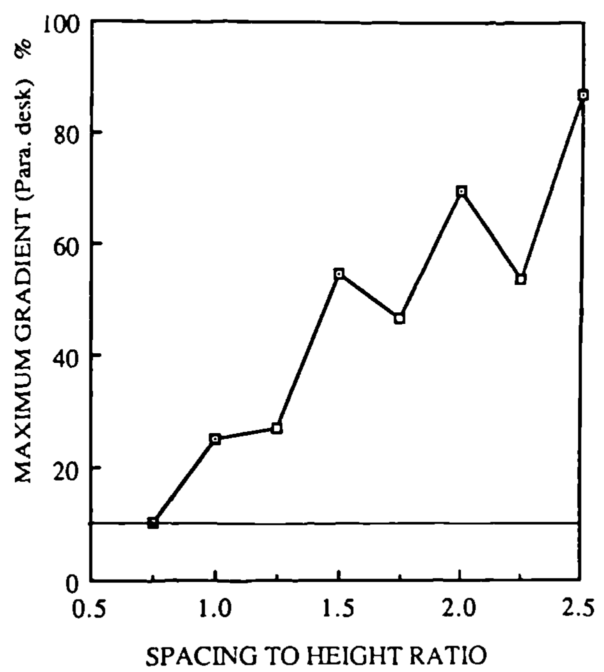


Figure 2.15 Maximum gradient for a medium obstructed space (para.) lit by linear sources.

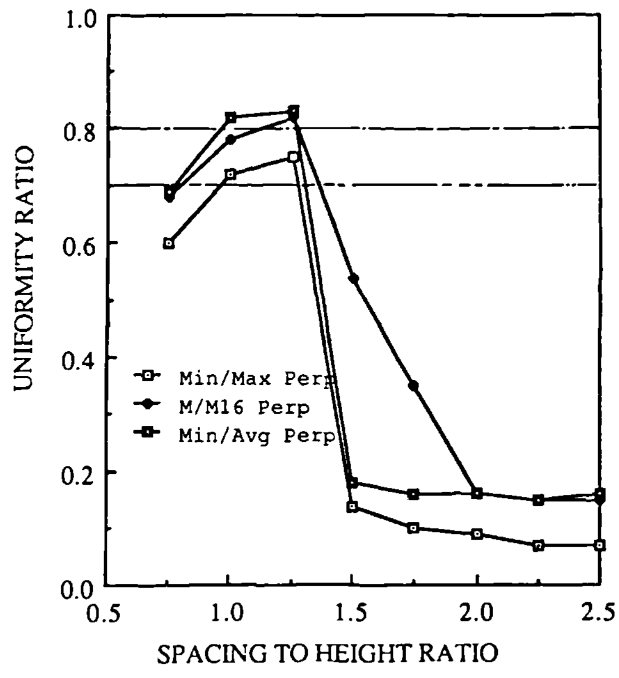


Figure 2.16 Min/max and min/avg measures for a heavily obstruct. space (perp.) lit by linear sources.

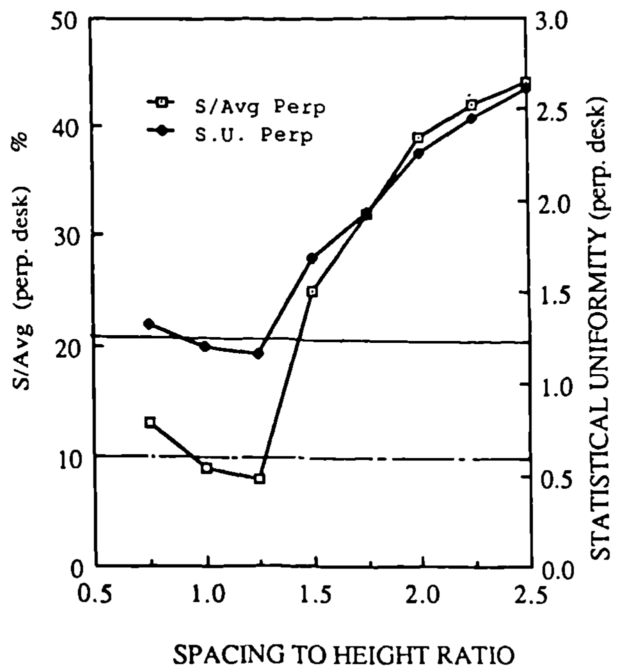


Figure 2.17 Statistical measures for a heavily obstructed space (perp.) lit by linear sources.

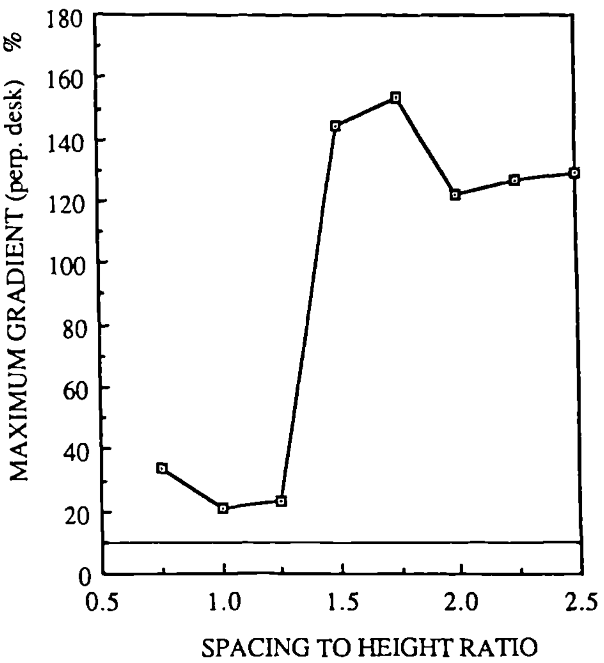


Figure 2.18 Maximum gradient for a heavily obstructed space (perp.) lit by linear sources.

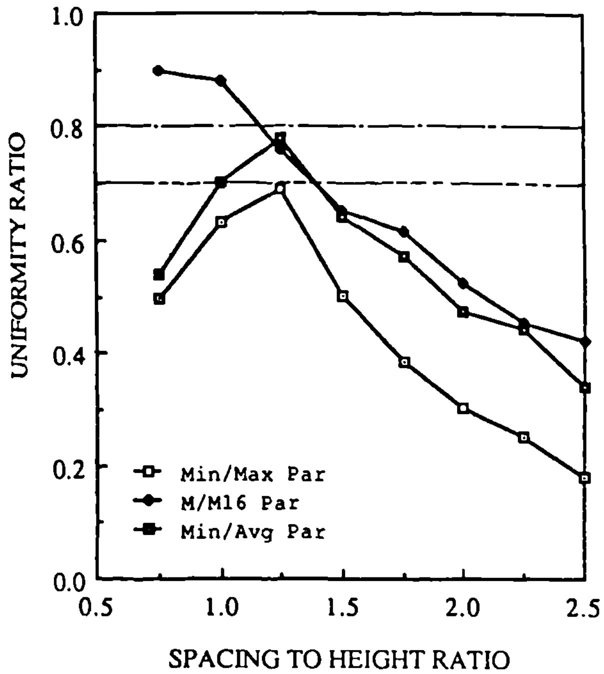


Figure 2.19 Min/max and min/avg measures for a heavily obstruct. space (para.) lit by linear sources.

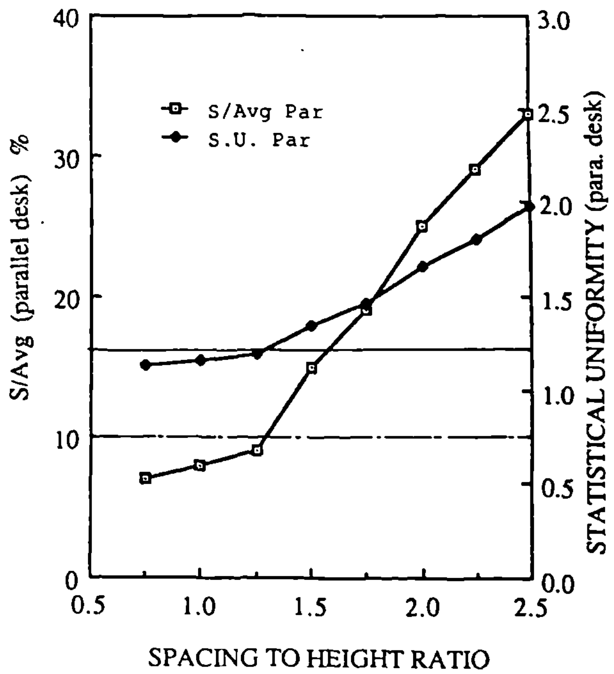


Figure 2.20 Statistical measures for a heavily obstructed space (para.) lit by linear sources.

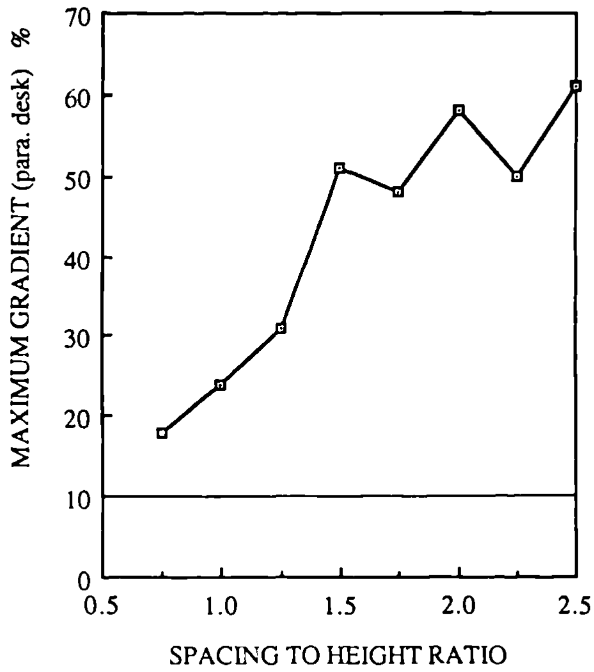


Figure 2.21 Maximum gradient for a heavily obstructed space (para.) lit by linear sources.

AN IMPROVED METHOD OF CALCULATING SPACING -TO-HEIGHT RATIO IN OBSTRUCTED COMMERCIAL INTERIORS.

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THE OBSTRUCTED SHR CONCEPT

Previous work at the University of Liverpool introduced the concept of an "obstructed SHR" to make allowance for interior obstruction of known size and position (McEwan and Carter (1)). This work took as a starting point the standard U.K method for calculation of SHR in empty rooms as described in the CIBSE Technical Memoranda No.5 (2) which was modified to take account of light loss caused by defined obstructions positioned within the central area of the standard square array and was implemented by means of a computer program. The obstructions, based ostensibly on the results of a survey carried out in an an open plan office, represented a desk with either a partition or a filing cabinet at one end with a person seated at the desk. For each SHR value of the preferred series the program calculated the direct illuminance at each point on a calculation grid within the central area of the luminaire array taking into account the presence of obstructions.

The early work had a number of conceptional and practical limitations associated with assumptions about notional task area and obstruction configurations. The size of the task area and the position and number of calculation points varied at different stages of the calculation procedure leading to the possibility of similar illuminance conditions at different SHR's producing different task uniformity ratios. The two obstruction configurations were in reality, similar and were of simplicity such that they were not capable of representing the range of sizes or densities of equipment found in office interiors.

This paper presents a computer based method of calculation of SHR for luminaires intended for use in a wide range of commercial interiors.

COMPUTER PROGRAM FOR MODIFIED SHR

The standard obstructions used in the modified program consist of a horizontal task area surrounded by three combinations of human form and furniture. These represent conditions within interiors containing obstructions of differing sizes and densities and which are classified as having either light, medium or heavy obstruction. The task area and furniture size and configurations were derived from a survey of equipment as installed by a number of major European and American office equipment manufacturers. The task area is taken as being the horizontal area of the desk. The representation of the human form was found in the previous work to have a major influence on task illuminance conditions and in the modified version of the program the CIE standard for "body shadow" used in Contrast Rendering Factor computation was adopted as this was capable of acknowledging the separate contributions of head and body to obstruction (CIE(3)).

The program introduces the standard obstruction either parallel or perpendicular to the luminaire axis. For each SHR value of the preferred series, at each point on a 0.10 m square grid over the task, the illuminance from each of the 16 luminaires is calculated taking into account the presence of obstructions. The uniformity ratio based on minimum/maximum illuminance over the task area, excluding a 0.10 m wide edge strip, is then calculated. The edge strip is excluded from the uniformity ratio calculation since this would not in practice be used for visual tasks.

The effect of obstructions is a major element in the illuminance calculation procedure and is assessed by separate consideration of how much of the luminaire, if any, may be "seen". For luminaires which are assumed to be point sources the check is either "seen" or "not seen" and the illuminance may calculated easily following this check, using a point -by-point calculation. For linear luminaires checks are initially required to determine if a luminaire is partly or totally blocked by an obstruction, by comparison of angles subtended at the point considered by the ends of the obstruction and that of the luminaire both in plan and elevation. Illuminance from parts of luminaires that are visible at a calculation point are calculated using an Aspect Factor Calculation (IES(4)).

RESULTS

To study the effects of the various standard obstructions the uniformity ratios for the preferred series of SHR set out in CIBSE TM5 (2) was calculated for a number of examples. The results are summarised in Table 1. To provide a reference for the obstructed case the uniformity ratio for the empty case is also shown.

There are large differences, in SHRMAX for symmetric luminaires, between empty and obstructed cases and smaller but significant differences between the various obstructed cases. In terms of SHRNOM, which is a major concern to designers, the difference become even more marked. For luminaire 3, for example, the value for the heavy obstructed case falls two preferred increments from empty. The major contributing factor to the large reduction in uniformity ratio when considering point sources is when the point of minimum illuminance on the task area moves from "seeing" to "not seeing" the luminaires with major illuminance contributions and under these circumstances shadow may be a problem.

Marked differences between empty and obstructed cases for linear luminaires are apparent, in some cases this being up to two increments of SHRNOM. Cases with work stations perpendicular to luminaires give acceptable uniformity ratios for all obstruction configurations but with relatively little difference between the various obstructed cases in terms of of SHRMAX. For work stations parallel to luminaires only the "light" and some "medium" cases have acceptable results but at SHRNOM values three increments lower than empty. This appear to lead to the general conclusion that the effect of an an individual obstruction component is greater when perpendicular than parallel to a linear luminaire.

CONCLUSION

It is clear that obstructions have a major effect on illuminance conditions within an interior and that designers ignore that at their peril. The difference between the empty and various obstructed cases indicates that not only the presence of obstructions is important but also their size and disposition. The modified SHR described in this work may be used by designers in two ways: Either to indicate the design SHR at which acceptable task uniformities will be obtained or to give a warning of the need for local lighting.

REFERENCES

1. McEwan, I. and Carter, D.J., Some approaches to the treatment of obstructions in interior lighting design, Lgt. Res. and Tech., 17 (3), 107, 1985.

2. C.I.B.S.E., The calculation and use of utilization factors, Technical Memoranda No.5, CIBSE, London, 1980.

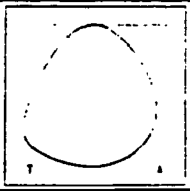
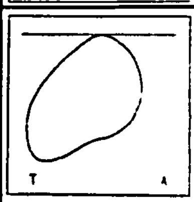
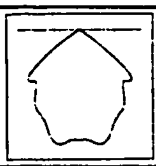
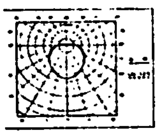
3. C.I.E., Guide on interior Lighting, Publication 29-2, CIE, Vienna,1986.

4. I.E.S, The calculation of direct illuminance from linear sources, Technical Report N0.11, IES, London , 1968.

ACKNOWLEDGMENT

This work is supported by Moorlite Electrical Ltd. and Thorn Lighting Ltd.

TABLE 1 - SHRMAX values for different cases of obstructed interiors lit by different luminaires.

luminaire type	polar curve	position of work station	empty room	lightly obstructed case	medium obstructed case		heavily obstructed case
					V.D.U	filing cabinet	
600 mm twin lamp prismatic panel (linear)		perpendicular to luminair axis	1.70	1.40	1.40	1.33	1.27
		parallel to luminaire axis	1.70	1.00	—	0.85	—
twin batwing reflector (linear)		perpendicular to luminaire axis	1.89	1.52	1.50	1.25	1.25
		parallel to luminaire axis	1.90	1.00	—	—	—
square downlight (point source)		perpendicular or parallel to luminaire axis	1.33	1.15	1.14	1.13	1.13
compact source (point source)		perpendicular or parallel luminaire axis	1.74	1.42	1.35	1.35	1.17