# A STUDY INTO THE ACCURACY OF RESULTS FROM COMPUTERISED LIGHTING DESIGN

# A STUDY INTO THE ACCURACY OF RESULTS FROM COMPUTERISED LIGHTING DESIGN

**TECHNICAL REPORT FOR CHARTERED ENGINEER REGISTRATION BY**

[redacted]

**JANUARY 2010**

**Contents**

**Introduction**

It is intended to show in this Technical Report that the accuracy of present day computerised lighting design programs is little different to the use of the Lumen Design Method 30 years ago. When I was at college studying illuminating engineering in 1979 my tutor made a statement; "If the measured results of a lighting design are within 20% of the calculated value then you have done well". This seemed like a very bold statement to make even 30 years ago when we were carrying out lighting design by manual calculations, but how can it be true when we have modern fast computers capable of vast ammounts of complex calculations in seconds?

There are many stages involved in the lighting design process, and the calculations themselves are but a small part. However, in the majority of cases the instructions received from an architect or client will consist primarily of CAD drawings, together with a brief specification of the proposed areas. Therefore, as a great deal of information is either not available, or indeed unknown, it necessarily follows that certain assumptions will have to be made so that the design process can move forward. These assumptions form part of the problem. Any professional engineer will make assumptions based upon 'good design practice', but with the best will in the world the results can be anything but similar.

It is with this intention of 'good design practice' that we can base the study on, and carry out calculations on, so that an evaluation and comparison can be made against various scenarios. This will eventually lead us to evaluate the accuracy of calculated results as compared with measured results.

**Aim of the Report**

The intention is to show that over the last 30 years, whilst the methods employed in lighting design may have changed significantly, the accuracy of results has not. Many people who rely on calculated results regard the values produced as being infinitely accurate. Whilst this is true in purely mathematical models, lighting design relies heavily on variables, which in most cases are assumed. This can and does mean that results can be widespread, with variances in excess of 20%. There are many instances where a consulting engineer or contractor takes a light meter around a building to check that illuminance values exceed the minimum values in the specification. When illuminance targets are not met, it is always assumed that the fault must lie either with the lighting designer or the luminaire used. No consideration is given to the variables within the design process, which are inevitably the cause of most inaccuracies. Within this report the word 'variance' is not a statistical unit, and means 'variation'. The report will show how these variances occur, and to what extent, whilst using fundamental lighting principles. In other words "Getting Back to Basics".

## Technical Content

The first consideration is for variables. These values or procedures can be described as being either Primary or Secondary to the design process. Primary Variables are those which directly affect the design results due to assumptions made by the designer, and Secondary Variables, which are outside the control of the designer, yet still can affect the resultant values.

1. **Primary Variables**
   
   a. **Reflectance Values**

   The incident light at any point within a room is made up of direct light from each luminaire, and reflected light from the room and other surfaces. The reflected light component consists usually of light that has been inter-reflected either once or many times. Reflectances are therefore critical for accurate calculation of illuminances, whether this is by using the Lumen Method[1] or by computer.

   If the amount of light flux incident on a surface is fixed, then the only variable to determine that surface's visibility or apparent brightness is it's reflectance. Illuminance cannot be seen, it is only the exitant illuminance or luminance of a surface that can.

$$\rho_s = \frac{\pi L_s}{E_s}$$

   Where $E_s$ is the illuminance on surface S
   
   $L_s$ is the luminance from surface S
   
   $\rho_s$ is the reflectance of surface S

   If the equation is rearranged slightly:

$$L_s = \frac{\rho_s \cdot E_s}{\pi}$$

   The luminance (or brightness) is equal to the product of illuminance and reflectance divided by a constant. Therefore, an increase in reflectance value of a surface will bring about a requirement for less incident light to produce the same brightness effect.

   When a rectangular room has luminaires suspended from the ceiling (Fig. 1.1) it is necessary to consider the cavity formed as having a lower reflectance than the ceiling alone. In practice, this must be taken into account only if the cavity height is greater than one sixth[2] of the height from working plane to the luminaire plane, $H_m$.

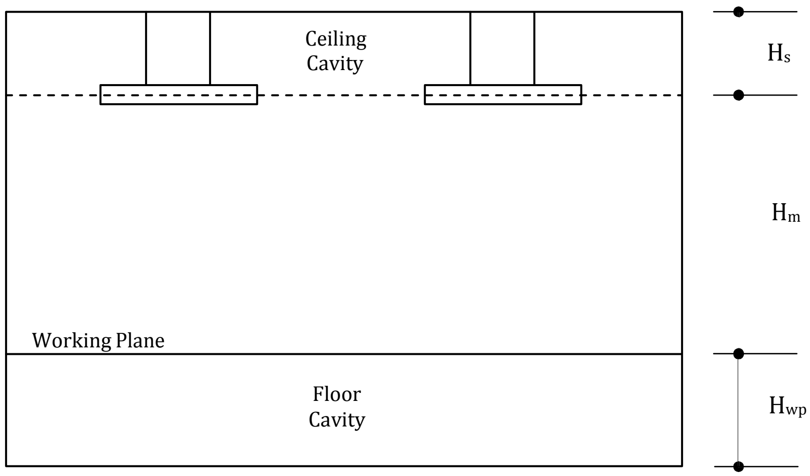



**Fig. 1.1:**

The effective reflectance of the ceiling cavity is given by Ken Lumsden in *Lamps and Lighting*[3] as being:

$$\rho_e = \frac{A_p \rho_a}{A_p \rho_a + A_s(1 - \rho_a)}$$

Where $A_p$ = plan area of the ceiling
$A_s$ = total area of all surfaces within the ceiling cavity
$\rho_a$ = average reflectance of all surfaces within the ceiling cavity

The derivation of the equation is explained by AR Bean and RH Simons in their book, *Lighting Engineering: Applied Calculations*[4]. The average reflectance of the ceiling cavity $\rho_a$ can be obtained from the following formula:

$$\rho_a = \frac{K_c \rho_c + 2\rho_w}{K_c + 2}$$

Where $K_c$ = the ceiling cavity index
$\rho_c$ = ceiling reflectance
$\rho_w$ = reflectance of upper wall surfaces

And the ceiling cavity index [illegible] is derived in a similar manner to the room index, namely:

$$[illegible]$$

Where [illegible]$_0$ = the luminaire suspension depth
[illegible] = length of the room (m)
[illegible] = width of the room (m)

This virtual or effective ceiling reflectance and height can then be used in the Lumen Method calculation to establish illuminance levels, and also in carrying out flux transfer evaluation. However, when using computerised design programs such as Dialux and Relux, these calculations are carried out by the program as part of their radiosity evaluation.

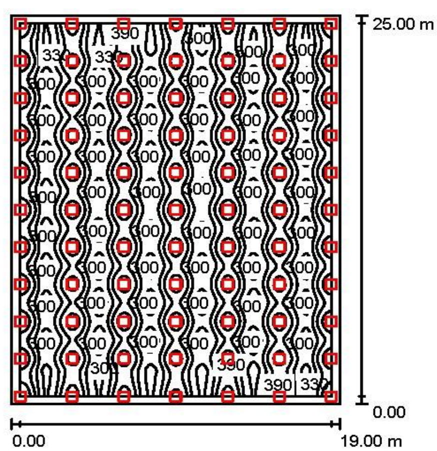
Recommended reflectance values of room surfaces are to be found in the CIBSE Code of Practice[5] and EN12464-1[6]. The recommended values are given as 0.7-0.9 for ceilings, 0.5-0.8 for walls, and 0.2-0.4 for the floor. In practice though the values of 70% for ceilings, 50% for walls, and 20% for floors have been used as the standard, working on the worst case scenario. These values were suitable in the 1970s as being representative of standard expected surface finishes, but use of accurate modern values will show a marked difference in the calculation. These values are also found in the Dialux User Manual V4.6 as being standard practice[7] in the UK. [see page A9]

I carried out research in 2007 to look at the effect on LG7 compliance by using more realistic reflectance values for the room surfaces. A Powerpoint presentation was prepared and is to be found in the Appendix. In the past, Floor reflectance was taken at 20% due to the wide use of wood, linoleum and dark carpeting in the 1950s and 1960s. As designs were carried out using the Lumen Method, the luminaire UF needed to be readily available, and although UF values could be re-calculated for different floor reflectances, this was rarely done. This was due to the drawn-out work involved using conversion tables in CIBSE Technical Memorandum 5. During the research I contacted Europe's largest supplier of carpet tiles, Interface PLC, to find out what plain coloured tiles are the most popular, and was told that it is their Palette 2000 range. Unfortunately, there are 80 different colours within the range but I was given each of their respective reflectance values. The selection of 4 tiles as shown on page A3 illustrates the wide variety of choice, coupled with reflectance values. A value of 30-40% is more realistic than the norm of 20%. The use of more accurate values is easily available now with the internet, as long as the information is given by the client.

The same situation occurs with ceiling reflectances. [redacted] provide reflectance values for their ceiling tiles, standard white fibre having a value of 83%. This is a far cry from the 70% normally used. However, whatever the ceiling is, the exact reflectance value is necessary to establish accuracy.

Likewise, it is normal design practice to use 50% reflectance value for the walls. Further investigation revealed that Dulux Trade Paints produce a Magnolia Matt paint which is their most popular wall coating for the trade. This has a reflectance of 78%.

If the average horizontal illuminance in a sample room is calculated, firstly with 'standard' surface reflectances of 70%/50%/20%, and then with the 83%/78%/30% values referred to above, we can compare the results. From the calculation summary sheets used in Dialux the following illuminance values are seen:




Height of Room: 2.700 m, Mounting Height: 2.700 m, Maintenance factor: 0.80

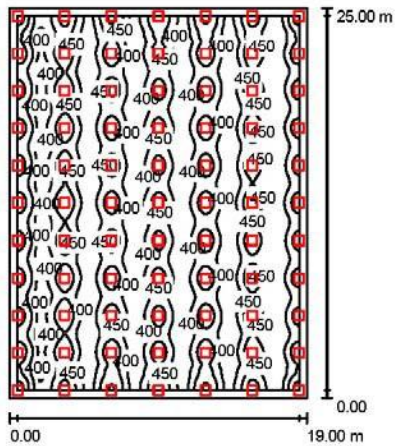
Values in Lux, Scale 1:321

| Surface | ρ [%] | $E_{av}$ [lx] | $E_{min}$ [lx] | $E_{max}$ [lx] | u0 |
|---|---|---|---|---|---|
| Workplane | / | 342 | 279 | 417 | 0.815 |
| Floor | 20 | 331 | 283 | 358 | 0.856 |
| Ceiling | 70 | 105 | 70 | 696 | 0.669 |
| Walls (4) | 50 | 242 | 106 | 932 | / |

**Workplane:**
Height: 0.760 m
Grid: 128 x 128 Points
Boundary Zone: 0.500 m
Illuminance Quotient (according to LG7): Walls / Working Plane: 0.804, Ceiling / Working Plane: 0.307.

**Fig. 1.2:**

Room calculation in Dialux using 70%/50%/20% reflectance values.




Height of Room: 2.700 m, Mounting Height: 2.700 m, Maintenance factor: 0.80

Values in Lux, Scale 1:321

| Surface | ρ [%] | $E_{av}$ [lx] | $E_{min}$ [lx] | $E_{max}$ [lx] | u0 |
|---|---|---|---|---|---|
| Workplane | / | 423 | 352 | 566 | 0.832 |
| Floor | 30 | 414 | 387 | 486 | 0.934 |
| Ceiling | 83 | 179 | 129 | 850 | 0.721 |
| Walls (4) | 78 | 326 | 165 | 1084 | / |

**Workplane:**
Height: 0.760 m
Grid: 128 x 128 Points
Boundary Zone: 0.500 m
Illuminance Quotient (according to LG7): Walls / Working Plane: 0.855, Ceiling / Working Plane: 0.423.

**Fig. 1.3:**

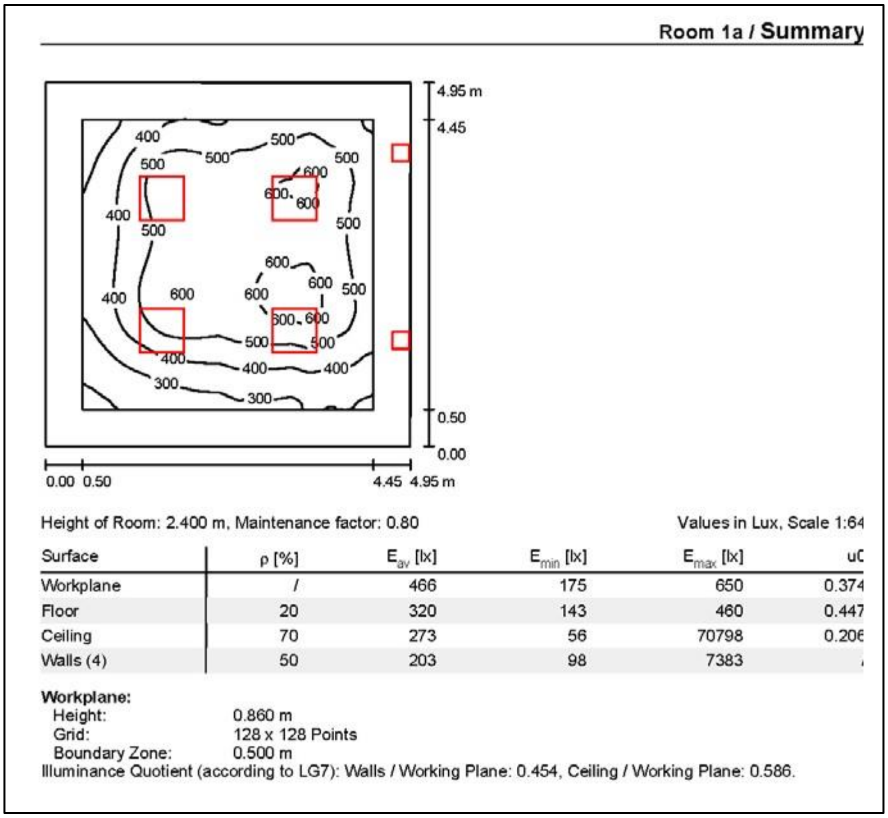
Room calculation in Dialux using 83%/78%/30% reflectance values.

As can be seen from Fig. 1.2 the average horizontal illuminance on the working plane is 342 lux using 70%/50%/20% reflectances. By increasing the reflectance values to 83%/78%/30% the illuminance value increases to 423 lux as shown in Fig. 1.3. This means that a variance (or inaccuracy) of + 23.6% can be experienced if standard reflectance values are used in the design instead of accurate figures.

**b. Obstructions to the Working Plane**

The majority of designs are carried out for an 'unobstructed working plane'. In practice, this is far from realistic, with a modern office having desks, filing cabinets, and chairs. Also, windows, doors, notice boards and blinds will affect the calculations. In industrial areas the addition of storage racking or machinery will in most cases reduce working plane illuminance levels by as much as 50%.

For the purposes of this report I have looked at a typical office and carried out a calculation as a standard room with no doors, windows or furniture installed. I then carried out the same calculation but with the objects added as a comparison. The results are as follows:




Height of Room: 2.400 m, Maintenance factor: 0.80

Values in Lux, Scale 1:64

| Surface | ρ [%] | $E_{av}$ [lx] | $E_{min}$ [lx] | $E_{max}$ [lx] | u0 |
|---|---|---|---|---|---|
| Workplane | / | 466 | 175 | 650 | 0.374 |
| Floor | 20 | 320 | 143 | 460 | 0.447 |
| Ceiling | 70 | 273 | 56 | 70798 | 0.206 |
| Walls (4) | 50 | 203 | 98 | 7383 | / |

**Workplane:**
Height: 0.860 m
Grid: 128 x 128 Points
Boundary Zone: 0.500 m
Illuminance Quotient (according to LG7): Walls / Working Plane: 0.454, Ceiling / Working Plane: 0.586.

**Fig. 2.1:**

Room calculation in Dialux without furniture, windows and doors.

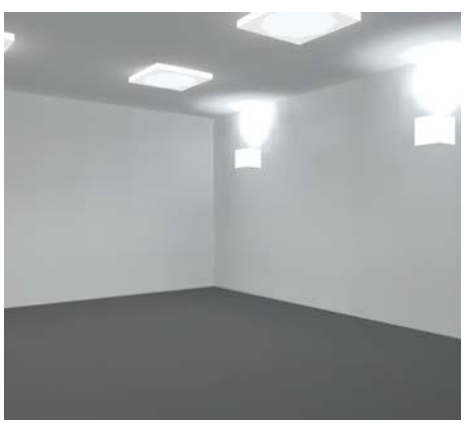
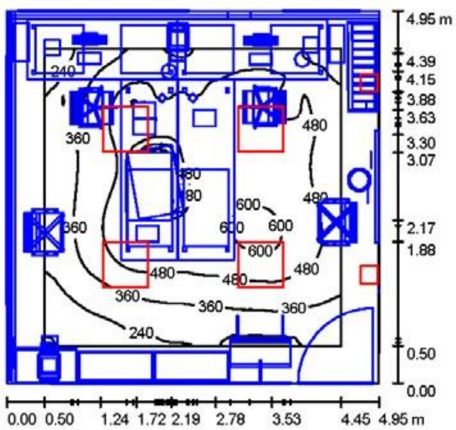


**Fig. 2.2:**

3D view from Dialux of unfurnished room, as calculated above.

Room 1 / **Summary**




Height of Room: 2.400 m, Maintenance factor: 0.80

Values in Lux, Scale 1:64

| Surface | ρ [%] | $E_{av}$ [lx] | $E_{min}$ [lx] | $E_{max}$ [lx] | u0 |
|---|---|---|---|---|---|
| Workplane | / | 429 | 75 | 628 | 0.175 |
| Floor | 20 | 141 | 2.86 | 366 | 0.020 |
| Ceiling | 70 | 256 | 17 | 65664 | 0.067 |
| Walls (4) | 50 | 95 | 3.69 | 7506 | / |

**Workplane:**
Height: 0.860 m
Grid: 128 x 128 Points
Boundary Zone: 0.500 m
Illuminance Quotient (according to LG7): Walls / Working Plane: 0.361, Ceiling / Working Plane: 0.599.

**Fig. 2.3:**

Room calculation in Dialux furnished with furniture, windows and doors.

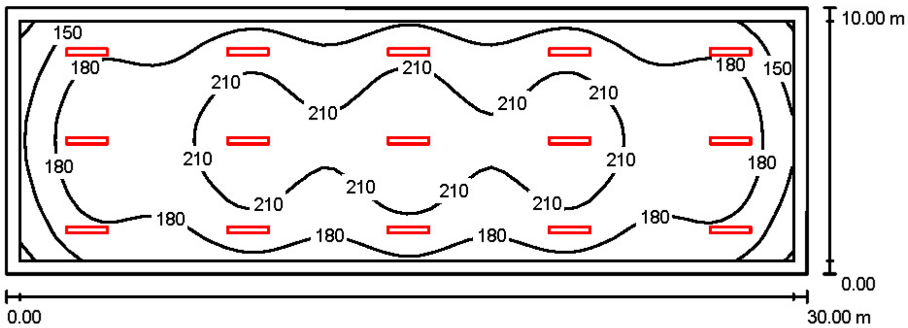
**Fig. 2.4:**

3D view from Dialux of furnished room, as calculated above.

The calculations show that an average horizontal illuminance at desk height of 466 lux is achieved in the unfurnished room, whilst a figure of 429 lux is achieved in the furnished room. This means that a variance of – 7.9% can be expected for office projects, when furniture and other objects are not taken into account.

This can be illustrated further if a similar calculation is carried out in an industrial area. The results are as follows:

**Warehouse Unobstructed / Summary**




Height of Room: 5.000 m, Mounting Height: 5.000 m, Maintenance factor: 0.80

Values in Lux, Scale 1:215

| Surface | ρ [%] | $E_{av}$ [lx] | $E_{min}$ [lx] | $E_{max}$ [lx] | u0 |
|---|---|---|---|---|---|
| Workplane | / | 192 | 114 | 233 | 0.593 |
| Floor | 20 | 185 | 97 | 233 | 0.523 |
| Ceiling | 30 | 38 | 31 | 50 | 0.811 |
| Walls (4) | 30 | 124 | 30 | 279 | / |

**Workplane:**
Height: 0.000 m
Grid: 64 x 32 Points
Boundary Zone: 0.500 m

| **UGR** | Lengthways- | Across | to luminaire axis |
|---|---|---|---|
| Left Wall | 24 | 23 | |
| Lower Wall | 25 | 24 | |
| (CIE, SHR = 1.00.) | | | |

Illuminance Quotient (according to LG7): Walls / Working Plane: 0.640, Ceiling / Working Plane: 0.196.

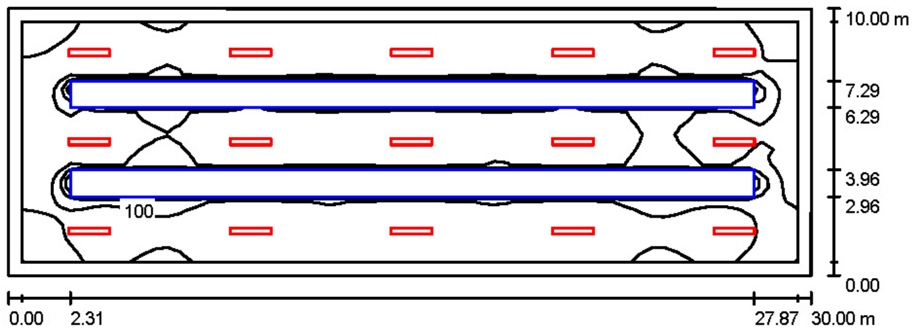
**Fig. 2.5:**

Warehouse calculation in Dialux with unobstructed working plane.

**Fig. 2.6:**

3D view of warehouse from Dialux of unobstructed working plane, as calculated above.

**Warehouse Obstructed / Summary**




Height of Room: 5.000 m, Mounting Height: 5.000 m, Maintenance factor: 0.80

Values in Lux, Scale 1:215

| Surface | ρ [%] | $E_{av}$ [lx] | $E_{min}$ [lx] | $E_{max}$ [lx] | u0 |
|---|---|---|---|---|---|
| Workplane | / | 105 | 38 | 119 | 0.360 |
| Floor | 20 | 85 | 2.75 | 124 | 0.032 |
| Ceiling | 30 | 23 | 6.18 | 54 | 0.267 |
| Walls (4) | 30 | 87 | 22 | 257 | / |

**Workplane:**

Height: 0.000 m
Grid: 64 x 32 Points
Boundary Zone: 0.500 m

Illuminance Quotient (according to LG7): Walls / Working Plane: 0.817, Ceiling / Working Plane: 0.220.

**Fig. 2.7:**

Warehouse calculation in Dialux with high level racking obstructing the working plane, which in this case is the floor.

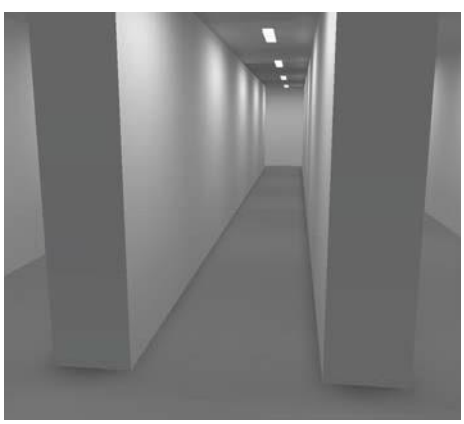


**Fig. 2.8:**

3D view of warehouse from Dialux showing the effect of high level racking, as calculated above.

From the calculations shown above the average horizontal illuminance at floor level reduces from 192 lux unobstructed to 105 lux with the shelving. This is a variance of – 45.3%, which is common within this type of area. The high variance can be illustrated logically by looking at a reference point at the centre of the room. With an unobstructed working plane the reference point receives light flux directly from all of the luminaires (Fig. 2.9). However, when the racking is in place the point receives flux directly only from a single row (Fig. 2.10). This reduces the direct component drastically, hence the high variable of 45.3 %.

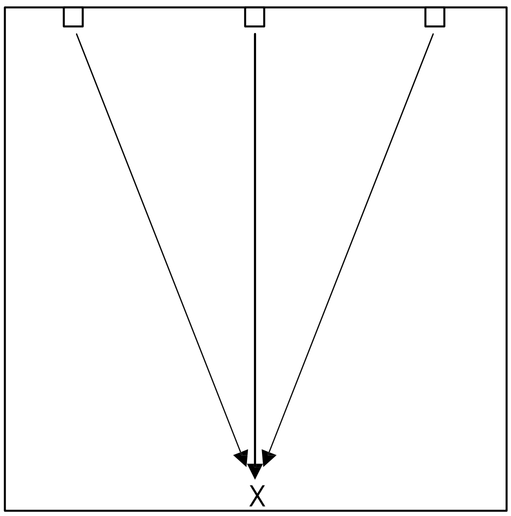



**Fig. 2.9:**

An unobstructed point on the working plane receives light from other luminaires.

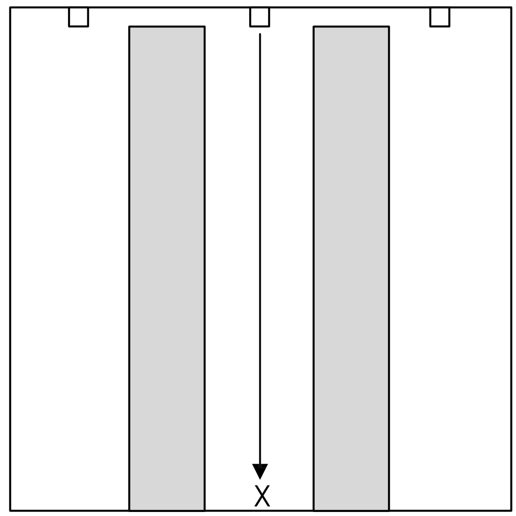



**Fig. 2.10:**

An obstructed point receives light from fewer luminaires.

It must be remembered that as computers become more sophisticated and programs more complex, the need to speed up calculations grows. In Dialux there is an option in the calculation menu to take furniture and objects out of the calculation itself. Whilst this may be useful in certain circumstances it must never be actioned when furniture is installed, and accurate results are required. In this case it would be far better to suffer a longer calculation time rather than inaccurate results. The vast majority of rooms we have to deal with in lighting design have obstructions in some form or other. If the higher value of variance was used in the evaluation process at the end of this report it would inevitably make computerised lighting design appear untenable. In addition, CAD drawings that I have received from clients for warehouse areas nearly always contain details of racking systems, if intended to be installed. Therefore, for the purpose of acceptability, I propose to use the office variance of -7.9% as being the norm for this section, as very few drawings received by my department detail office furniture positions.

**c. Maintenance Factor**

Computerised lighting design programs have within their construction the ability to select a maintenance factor. Usually this can be done by either choosing a finite value, or by letting the program calculate a value from a series of drop-down menu options. It is common practice in the UK for a maintenance factor or co-efficient of 0.8 to be used. In theory this means that the design is allowing for 20% more light to be provided initially, so that the average light levels throughout a maintenance cycle achieve the design level. The other option is to answer questions from drop-down menus to follow a course in accordance with EN12464-1[8] to reach a calculated value.

A maintenance factor is made up of several components:

$$MF = LLMF \times LSF \times LMF \times RSMF$$

Where $MF$ = maintenance factor or coefficient
$LLMF$ = lamp lumen maintenance factor
$LSF$ = lamp survival factor
$LMF$ = luminaire maintenance factor
$RSMF$ = room surfaces maintenance factor

The Lamp Lumen Maintenance Factor is taken from lamp manufacturers' data, and gives the percentage of initial lamp lumens after a particular number of hours use. In the 1970s and 1980s lamps were given an initial lumen value as well as a lighting design value (LDL) based on 2000hrs use. This LDL figure was intended to take into account lumen maintenance and survival statistics, so that the maintenance factor of 0.8 only represented losses due to dirt and wear and tear of the luminaires and room surfaces. However, LDL figures are no longer produced by lamp manufacturers, the computer design programs use initial lumens, yet the maintenance factor of 0.8 is still prevalent in design specifications.

Whilst it is true that the maintenance factor (or light loss factor in the US) should be calculated as accurately as possible to save energy, and therefore $CO_2$ emissions, it is still strictly speaking an estimate. It is a calculated guess at what the average horizontal illuminance on the room's working plane will be, at some time in the future, just before the lamps are changed and the luminaires cleaned.

It is necessary therefore to carry out a maintenance factor calculation using the information described in the CIBSE Code for Lighting 2006.
The parameters will be as follows:
A standard office area with Room Index of 2.5
Luminaires will be of an enclosed type, direct/indirect distribution
Lamps will be 35W T5 840
Annual burning hours will be 4000
Luminaires will be cleaned every 1 year
Lamps will be replaced every 3 years

The Lamp Lumen Maintenance Factor and Lamp Survival Factor can be found by refering to a standard table[9] (Fig. 3.1), which gives typical values expected from lamp manufacturers. However, to further accuracy, the published lumen maintenance graph (Fig. 3.2) and the published survival graph (Fig. 3.3) from Havells Sylvania for the 35W T5 840 lamp are to be used.

**Table 3.4** Typical lumen maintenance and lamp survival data

| | | Typical values of LLMF and LSF | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Operation time (1000 h) | | | | | | | | | | |
| | | 0.1 | 0.5 | 1.0 | 1.5 | 2.0 | 4.0 | 6.0 | 8.0 | 10.0 | 12.0 | 14.0 |
| Fluorescent multi- and tri-phosphor | LLMF | 1 | 0.98 | 0.96 | 0.95 | 0.94 | 0.91 | 0.87 | 0.86 | 0.85 | 0.84 | 0.83 |
| | LSF | 1 | 1 | 1 | 1 | 1 | 1 | 0.99 | 0.95 | 0.85 | 0.75 | 0.64 |
| Fluorescent halophosphor | LLMF | 1 | 0.97 | 0.94 | 0.91 | 0.89 | 0.83 | 0.80 | 0.78 | 0.76 | 0.74 | 0.72 |
| | LSF | 1 | 1 | 1 | 1 | 1 | 1 | 0.99 | 0.95 | 0.85 | 0.75 | 0.64 |
| Mercury | LLMF | 1 | 0.99 | 0.97 | 0.95 | 0.93 | 0.87 | 0.80 | 0.76 | 0.72 | 0.68 | 0.64 |
| | LSF | 1 | 1 | 1 | 1 | 0.99 | 0.98 | 0.97 | 0.95 | 0.92 | 0.88 | 0.84 |
| High-pressure sodium | LLMF | 1 | 1 | 0.98 | 0.97 | 0.96 | 0.93 | 0.91 | 0.89 | 0.88 | 0.87 | 0.86 |
| | LSF | 1 | 1 | 1 | 1 | 0.99 | 0.98 | 0.96 | 0.94 | 0.92 | 0.89 | 0.85 |
| High-pressure sodium, improved colour | LLMF | 1 | 0.99 | 0.97 | 0.95 | 0.94 | 0.89 | 0.84 | 0.81 | 0.79 | 0.78 | — |
| | LSF | 1 | 1 | 1 | 0.99 | 0.98 | 0.96 | 0.9 | 0.79 | 0.65 | 0.50 | — |

**Fig. 3.1:**

Typical lumen maintenance and survival factor values, taken from the CIBSE Code for Lighting: 2006

As can be seen in Fig. 3.2 the actual figure at 12000 hours is 0.91. This is somewhat different from the lower value of 0.84 from the table in Fig. 3.1, but is due in the main to recent advances in T5 lamp technology.

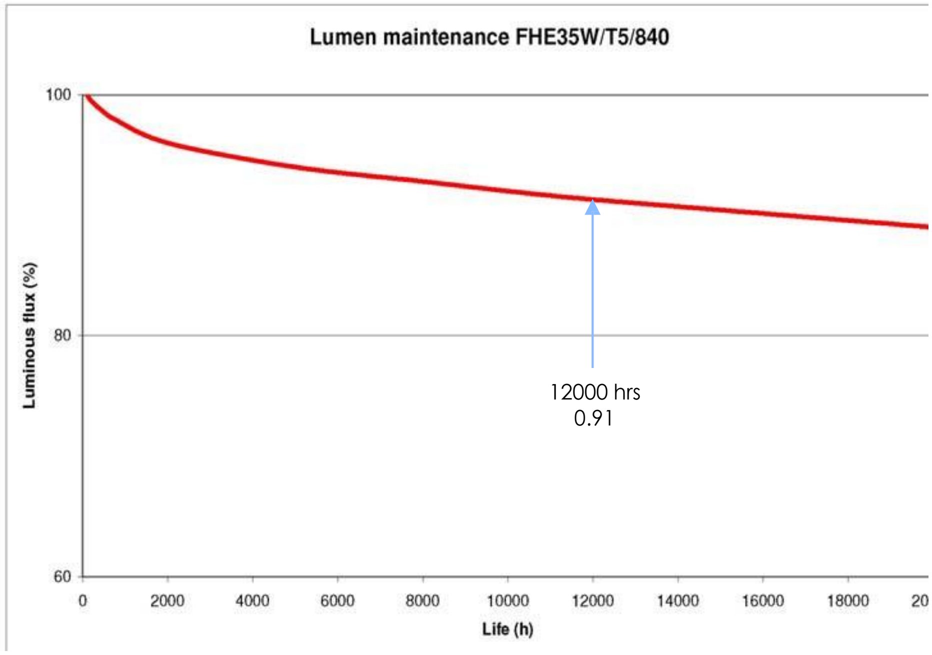



**Fig. 3.2:**

Lumen Maintenance graph for a Havells Sylvania 35W T5 840 lamp

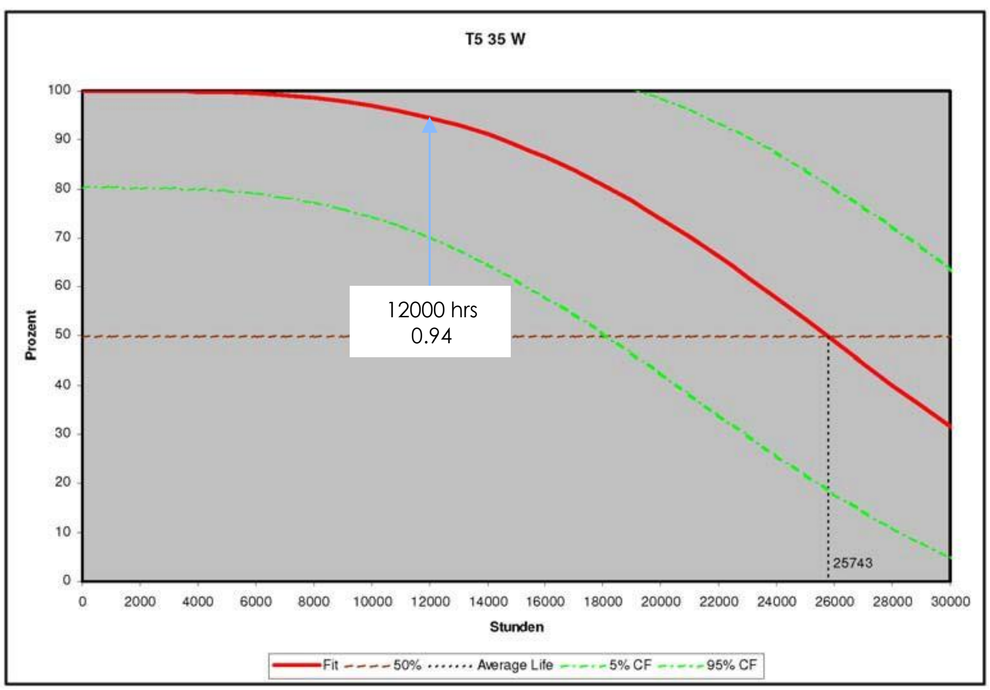



**Fig. 3.3:**

Lamp Survival graph for a Havells Sylvania 35W T5 840 lamp

From Fig. 3.1 we also obtain a value for Lamp Survival Factor of 0.75. By looking at the actual graph in Fig. 3.3 we read off a figure of 0.94, which again is significantly higher for similar reasons.

The Luminaire Maintenance Factor is now obtained by categorising the luminaire using Table 3.5[10] from the Code of Practice.

**Table 3.5** Luminaire categories and a list of typical locations where the various environmental conditions may be found

| Category | Description |
|---|---|
| A | Bare lamp batten |
| B | Open top reflector (ventilated self-cleaning) |
| C | Closed top reflector (unventilated) |
| D | Enclosed (IP2X) |
| E | Dustproof (IP5X) |
| F | Indirect uplighter |
| **Environment** | **Typical locations** |
| Clean (C) | Clean rooms, computer centres, electronic assembly, hospitals |
| Normal (N) | Offices, shops, schools, laboratories, restaurants, warehouses, assembly workshops |
| Dirty (D) | Steelworks, chemical works, foundries, welding, polishing, woodwork areas |

**Fig. 3.4:**

Luminaire categories for different environmental conditions

The particular luminaire chosen for the project falls under the category 'D' in Fig. 3.4, and the project room is 'Normal (N)'. If this information is used in Fig. 3.5, with a cleaning cycle of one year, a value of 0.82 is obtained.

**Table 3.6** Typical changes in light output from a luminaire caused by dirt deposition, for a number of luminaire and environment categories

| **Time between cleaning (years)** | | **0.5** | | | **1.0** | | | **1.5** | |
|---|---|---|---|---|---|---|---|---|---|
| Environment | C | N | D | C | N | D | C | N | D |
| Luminaire category | | | | | | | | | |
| A | 0.95 | 0.92 | 0.88 | 0.93 | 0.89 | 0.83 | 0.91 | 0.87 | 0.80 |
| B | 0.95 | 0.91 | 0.88 | 0.90 | 0.86 | 0.83 | 0.87 | 0.83 | 0.79 |
| C | 0.93 | 0.89 | 0.83 | 0.89 | 0.81 | 0.72 | 0.84 | 0.74 | 0.64 |
| D | 0.92 | 0.87 | 0.83 | 0.88 | 0.82 | 0.77 | 0.85 | 0.79 | 0.73 |
| E | 0.96 | 0.93 | 0.91 | 0.94 | 0.90 | 0.86 | 0.92 | 0.88 | 0.83 |
| F | 0.92 | 0.89 | 0.85 | 0.86 | 0.81 | 0.74 | 0.81 | 0.73 | 0.65 |
| **Time between cleaning (years)** | | **2.0** | | | **2.5** | | | **3.0** | |
| Environment | C | N | D | C | N | D | C | N | D |
| Luminaire category | | | | | | | | | |
| A | 0.89 | 0.84 | 0.78 | 0.87 | 0.82 | 0.75 | 0.85 | 0.79 | 0.80 |
| B | 0.84 | 0.80 | 0.75 | 0.82 | 0.76 | 0.71 | 0.79 | 0.74 | 0.79 |
| C | 0.80 | 0.69 | 0.59 | 0.77 | 0.64 | 0.54 | 0.74 | 0.61 | 0.64 |
| D | 0.83 | 0.77 | 0.71 | 0.81 | 0.75 | 0.68 | 0.79 | 0.73 | 0.73 |
| E | 0.91 | 0.86 | 0.81 | 0.90 | 0.85 | 0.80 | 0.90 | 0.84 | 0.83 |
| F | 0.77 | 0.66 | 0.57 | 0.73 | 0.60 | 0.51 | 0.70 | 0.55 | 0.65 |

**Fig. 3.5:**

Luminaire maintenance factor values

The final component is the Room Surface Maintenance Factor. The table for calculating this part is shown in Fig. 3.6 below:

**Table 3.7** Typical changes in the illuminance from an installation that occur with time due to dirt deposition on the room surfaces

| **Time between cleaning (years)** | | **0.5** | | | **1.0** | | | **1.5** | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Room size (K) | Luminaire distribution | C | N | D | C | N | D | C | N | D |
| Small (K = 0.7) | Direct | 0.97 | 0.96 | 0.95 | 0.97 | 0.94 | 0.93 | 0.96 | 0.94 | 0.92 |
| | Direct/indirect | 0.94 | 0.88 | 0.84 | 0.90 | 0.86 | 0.82 | 0.89 | 0.83 | 0.80 |
| | Indirect | 0.90 | 0.84 | 0.80 | 0.85 | 0.78 | 0.73 | 0.83 | 0.75 | 0.69 |
| Medium–large (K = 2.5–5.0) | Direct | 0.98 | 0.97 | 0.96 | 0.98 | 0.96 | 0.95 | 0.97 | 0.96 | 0.95 |
| | Direct/indirect | 0.95 | 0.90 | 0.86 | 0.92 | 0.88 | 0.85 | 0.90 | 0.86 | 0.83 |
| | Indirect | 0.92 | 0.87 | 0.83 | 0.88 | 0.82 | 0.77 | 0.86 | 0.79 | 0.74 |
| **Time between cleaning (years)** | | **2.0** | | | **2.5** | | | **3.0** | | |
| Room size (K) | Luminaire distribution | C | N | D | C | N | D | C | N | D |
| Small (K = 0.7) | Direct | 0.95 | 0.93 | 0.90 | 0.94 | 0.92 | 0.89 | 0.94 | 0.92 | 0.88 |
| | Direct/indirect | 0.87 | 0.82 | 0.78 | 0.85 | 0.80 | 0.75 | 0.84 | 0.79 | 0.74 |
| | Indirect | 0.81 | 0.73 | 0.66 | 0.77 | 0.70 | 0.62 | 0.75 | 0.68 | 0.59 |
| Medium–large (K = 2.5–5.0) | Direct | 0.96 | 0.95 | 0.94 | 0.96 | 0.95 | 0.94 | 0.96 | 0.95 | 0.94 |
| | Direct/indirect | 0.89 | 0.85 | 0.81 | 0.87 | 0.84 | 0.79 | 0.86 | 0.82 | 0.78 |
| | Indirect | 0.84 | 0.77 | 0.70 | 0.81 | 0.74 | 0.67 | 0.78 | 0.72 | 0.64 |

**Fig. 3.6:**

Room Surface maintenance factor values

From the Table 3.7 shown in Fig. 3.6 we look for the value which meets the parameters of the installation, namely luminaire cleaning period of 1 year, 'Normal' classification, direct/indirect distribution, and a Room Index of 2.5. Therefore, a value of 0.88 is obtained.

All of the component values have now been evaluated, and the complete maintenance factor can be calculated:

$$MF = LLMF \times LSF \times LMF \times RSMF$$

So:

$$MF = 0.91 \times 0.94 \times 0.82 \times 0.88$$

And:

$$MF = 0.617$$

This figure is very different from the standard coefficient of 0.8. Even if lighting design lumens (LDL) had been used and the maintenance factor comprised of the luminaire and room components only (LMF x RSMF), the result would still be 0.72, which is at variance with the 0.8 value.

However, the aim of this work is to find out what are the possible variances from standard practice, and although the lumen output should be considered, it rarely is in practice. In order that the variances are kept acceptable and meaningful, it is proposed that a variance of -10% is used.

## 2. Secondary Variables

### a. Linear Source Calculations

When a lighting design program such as Relux or Dialux carries out illuminance calculations it uses point source calculations:

$$E = \frac{I_\theta \cos^3\theta}{h^2}$$

However, point source calculations are only accurate when the height ($h$) is more than 5 times the length of the luminaire[12]. When the length is lower it is necessary to use a linear source formula to make the calculation accurate.

To compare a Dialux calculation using point source formula with a manual calculation using linear source formulae it is necessary to create a sample room which has been taken as 6m square with a ceiling height of 2.7m.

As we are looking at a comparison between 2 formulae basically, it is not necessary to consider reflected light, so all the room surfaces will have zero reflectance. The sample room will have 2 rows of 2 surface mounted fluorescent luminaires with prismatic controllers, Sylvania SYL Line 9141561, spaced symmetrically, and each housing twin 1500mm T5 35W tubes.

There will be 3 rows of 3 calculation points, arranged symmetrically also, and a working plane 0.85m above finished floor level:

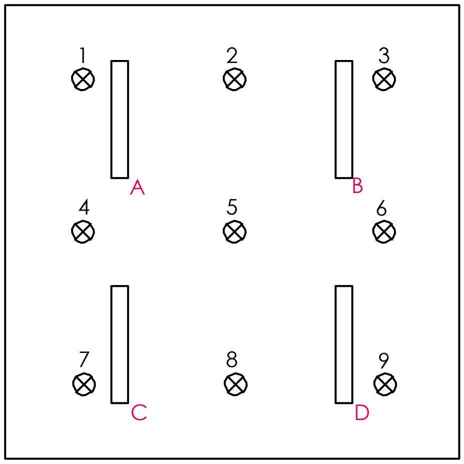
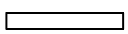



**Fig. 4.1:**

Sample room layout showing luminaires and calculation points

 Surface luminaire 2 x 58W T8

 Calculation point

It can be seen that all the calculation points lie away from the major axis of the luminaires, and in some cases they lie within the perpendicular boundary of the luminaire, and in some cases beyond. Therefore, two linear source calculations are necessary[13]:

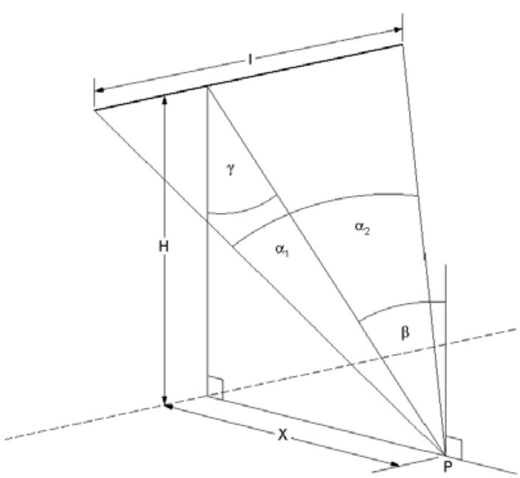



**Fig. 4.2:**

Drawing for calculation at a point within the boundary of a luminaire

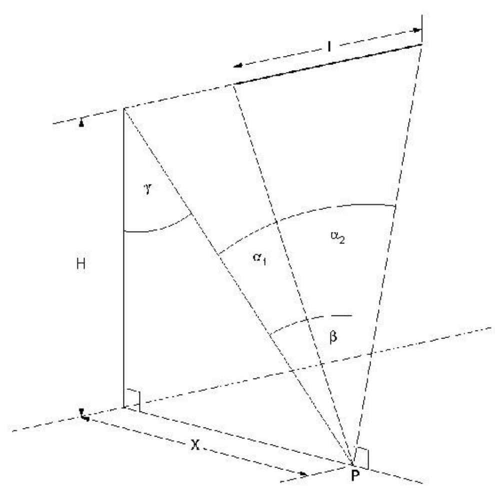



**Fig. 4.3:**

Drawing for calculation at a point outside the boundary of a luminaire

From the code of practice we obtain the respective equations:

$$[illegible] = \frac{[illegible]}{\cos [illegible]}$$

For the calculation at a point within the luminaire boundary, and

$$[illegible] = \frac{[illegible]}{\cos [illegible]}$$

Where the point is beyond the end of the luminaire.

So, for each of the 9 calculation points shown in Fig. 4.1 we need to carry out 4 linear source calculations, one for each luminaire, the sum of which will give the illuminance at that point.

Starting at Point (1) the first calculation involves luminaire A. Point (1) is 1m from the left wall and luminaire A is 1.5m away. Therefore the distance between them (X) is 0.5m. The height of the luminaire above the working plane (H) is (2.7m – 0.85m – 0.082m [luminaire depth]) which is 1.768m. The distance (D) is calculated as an hypotenuse from Fig. 4.2:

$[illegible] = \sqrt{0.5^{[illegible]} + 1.768^{[illegible]}}$ $\qquad$ $[illegible] = 1.837\text{m}$

$\tan [illegible] = \frac{0.5}{1.768}$ and $[illegible] = 15.8°$ As angle ([illegible]) = angle ([illegible]) in our situation,

Then: $[illegible] = 15.8°$ also.

Now $[illegible] = 1.5\text{m}$, the end of the luminaire to the top wall is 0.75m and from point (1) to top wall is 1.0m. Therefore $[illegible] = 0.25\text{m}$ and $[illegible] = 1.25\text{m}$.

$\tan [illegible] = \frac{[illegible]}{[illegible]}$ and $\tan [illegible] = \frac{[illegible]}{[illegible]}$

Then: $[illegible] = 7.7°$ and $[illegible] = 34.2°$

These angles are the respective angles for obtaining the aspect factors [illegible] and [illegible], both of them being in the parallel plane. We can obtain these values by interpolating table values for the particular luminaire. These values themselves were calculated from an Excel calculation program written by myself some years ago, and based on TM5[14]. The resultant sheets are shown on pages A10-A11 in the Appendix. The Aspect Factor table is as follows:

$AF_1$ angle □ 7.7°

$AF_2$ angle □ 34.2°

**Aspect Factors**

| Angle (degrees) | Parallel Plane | Perpendicular Plane |
|---|---|---|
| 0 | 0.000 | 0.000 |
| 5 | 0.087 | 0.004 |
| 10 | 0.172 | 0.015 |
| 15 | 0.255 | 0.033 |
| 20 | 0.335 | 0.058 |
| 25 | 0.407 | 0.089 |
| 30 | 0.472 | 0.123 |
| 35 | 0.529 | 0.159 |
| 40 | 0.576 | 0.195 |
| 45 | 0.611 | 0.227 |
| 50 | 0.637 | 0.256 |
| 55 | 0.656 | 0.280 |
| 60 | 0.669 | 0.300 |
| 65 | 0.677 | 0.316 |
| 70 | 0.682 | 0.327 |
| 75 | 0.684 | 0.336 |
| 80 | 0.686 | 0.342 |
| 85 | 0.686 | 0.345 |
| 90 | 0.686 | 0.346 |

**Fig. 4.4:**

Aspect factor table for the 9141561 Syl-Line luminaire

From the table we ascertain that: $AF_1 = 0.087$ □ $\frac{2.7(0.172 - 0.087)}{5}$

Therefore: $AF_1 = 0.133$

And: $AF_2 = 0.472$ □ $\frac{4.2(0.529 - 0.472)}{5}$

Therefore: $AF_2 = 0.520$

The intensity value, $I_\gamma$, can likewise be read off the table for the luminaire:

$\gamma$ angle □ 15.8°

**Luminous Intensity Values - (cd/1000 lm)**

| Gamma Angle (degrees) | Transverse Plane (0°) | Axial Plane (90°) |
|---|---|---|
| 0 | 286 | 286 |
| 5 | 284 | 284 |
| 10 | 279 | 280 |
| 15 | 276 | 276 |
| 20 | 271 | 269 |
| 25 | 254 | 246 |
| 30 | 254 | 235 |
| 35 | 246 | 209 |
| 40 | 233 | 174 |
| 45 | 220 | 141 |
| 50 | 202 | 112 |
| 55 | 172 | 88 |
| 60 | 161 | 68 |
| 65 | 139 | 48 |
| 70 | 110 | 34 |
| 75 | 79 | 25 |
| 80 | 54 | 16 |
| 85 | 50 | 6 |
| 90 | 51 | 0 |

**Fig. 4.5:**

Part of intensity table for the 9141561 Syl-Line luminaire

Therefore: $I_{\theta} = 276 + [illegible](271 - 276)$

And: $I_{\theta} = 275.2$ cd/klm

$= 275.2 \times 7.3$ cd

$= 2008.96$ cd

All the necessary values have now been acquired and can be put into the first line source calculation as follows:

$$E_{p1} = \frac{2008.96 \times (0.133 + 0.520) \times 0.962}{1.5 \times 1.837}$$

Therefore: $E_{p1} = 457.99$ lux

In a like manner $E_{p2}$ can be calculated. This time we get the following values:

Point (1) is 1m from the left wall and luminaire B is 4.5m away. Therefore the distance between them (X) is 3.5m. The height of the luminaire above the working plane (H) is (2.7m – 0.85m – 0.082m) which is 1.768m. The distance (D) is calculated as an hypotenuse from Fig. 4.2:

$D = \sqrt{3.5^2 + 1.768^2}$ $D = 3.92$m

$\tan\theta = \frac{3.5}{1.768}$ and $\theta = 63.20°$ As angle ($\theta$) = angle ($\beta$) in our situation,

Then: $\beta = 63.20°$ also.

Now $L = 1.5$m, the end of the luminaire to the top wall is 0.75m and from point (1) to top wall is 1.0m. Therefore $A = 0.25$m and $B = 1.25$m.

$\tan\alpha_A = \frac{0.25}{3.92}$ and $\tan\alpha_B = \frac{1.25}{3.92}$

Then: $\alpha_A = 3.65°$ and $\alpha_B = 17.69°$

These angles are the respective angles for obtaining the aspect factors $AF_A$ and $AF_B$, both of them being in the parallel plane. We again can obtain these values by interpolating table values for the particular luminaire. The Aspect Factor table is as follows:

**Aspect Factors**

$AF_1$ angle □ $3.65^{o}$

$AF_2$ angle □ $17.69^{o}$

| Angle (degrees) | Parallel Plane | Perpendicular Plane |
|---|---|---|
| 0 | 0.000 | 0.000 |
| 5 | 0.087 | 0.004 |
| 10 | 0.172 | 0.015 |
| 15 | 0.255 | 0.033 |
| 20 | 0.335 | 0.058 |
| 25 | 0.407 | 0.089 |
| 30 | 0.472 | 0.123 |
| 35 | 0.529 | 0.159 |
| 40 | 0.576 | 0.195 |
| 45 | 0.611 | 0.227 |
| 50 | 0.637 | 0.256 |
| 55 | 0.656 | 0.280 |
| 60 | 0.669 | 0.300 |
| 65 | 0.677 | 0.316 |
| 70 | 0.682 | 0.327 |
| 75 | 0.684 | 0.336 |
| 80 | 0.686 | 0.342 |
| 85 | 0.686 | 0.345 |
| 90 | 0.686 | 0.346 |

**Fig. 4.6:**

Aspect factor table for the 9141561 Syl-Line luminaire for $E_{1B}$ calculation

From the table we ascertain that $$AF_1 = 0.0 \;\square\; \frac{(3.65(0.087 - 0.0))}{5}$$

Therefore: $AF_1 = 0.064$

And: $$AF_2 = 0.255 \;\square\; (\frac{2.69}{5}(0.335 - 0.255))$$

Therefore: $AF_2 = 0.298$

The intensity value, $I_{\gamma}$, can likewise be read off the table for the luminaire:

**Luminous Intensity Values - (cd/1000 lm)**

$\gamma$ angle □ $63.2^{o}$

| Gamma Angle (degrees) | Transverse Plane (0°) | Axial Plane (90°) |
|---|---|---|
| 0 | 286 | 286 |
| 5 | 284 | 284 |
| 10 | 279 | 280 |
| 15 | 276 | 276 |
| 20 | 271 | 269 |
| 25 | 254 | 246 |
| 30 | 254 | 235 |
| 35 | 246 | 209 |
| 40 | 233 | 174 |
| 45 | 220 | 141 |
| 50 | 202 | 112 |
| 55 | 172 | 88 |
| 60 | 161 | 68 |
| 65 | 139 | 48 |
| 70 | 110 | 34 |
| 75 | 79 | 25 |
| 80 | 54 | 16 |
| 85 | 50 | 6 |
| 90 | 51 | 0 |

**Fig. 4.7:**

Part of intensity table for the 9141561 Syl-Line luminaire for $E_{1B}$ calculation

Therefore: $\square\ 161 \ \square\ \frac{\square}{\square}(139\ \square\ 161)$

And: $\square\ 146.92$ cd/klm

$\square\ 146.92\ \square\ 7.3$ cd

$\square\ 1072.52$cd

All the necessary values have now been acquired and can be put into the first line source calculation as follows:

$$\square = \frac{\dfrac{1072.52\ \square\ (0.064\ \square\ 0.298)\ \square}{0.451}}{1.5\ \square\ 3.92}$$

Therefore: $\square\ 29.78$ lux

In a similar manner $\square$ can be calculated, although this time we need to use the second calculation equation as the point is outside the boundary of the luminaire, as in Fig. 4.3.

Point (1) is 1m from the left wall and luminaire C is 1.5m away. Therefore the distance between them (X) is 0.5m. The height of the luminaire above the working plane (H) is (2.7m – 0.85m – 0.082m) which is 1.768m. The distance (D) is calculated as an hypotenuse from Fig. 4.3:

$\square\ \sqrt{0.5^{\square}\ \square\ 1.768^{\square}}$ $\square\ 1.837$m

$\tan \square\ \square\ \frac{0.5}{1.768}$ and $\square\ \square\ 15.8°$ As angle ($\square$) = angle ($\square$) in our situation,

Then: $\square\ \square\ 15.8°$ also.

Now $\square$ 1.5m, the end of the luminaire to the top wall is 3.75m and from point (1) to top wall is 1.0m. Therefore $\square$ 2.75m.

$\tan \square_{\square}\ \square\ \frac{\square}{\square}$ and $\tan \square_{\square}\ \square\ \frac{\square}{\square}$

Then: $\square_{\square}\ \square\ 56.26°$ and $\square_{\square}\ \square\ 66.62°$

These angles are the respective angles for obtaining the aspect factors $\square$ and $\square$, both of them being in the parallel plane. The Aspect Factor table is as follows:

**Aspect Factors**

AF₁ angle □ 56.26°

AF₂ angle □ 66.62°

| Angle (degrees) | Parallel Plane | Perpendicular Plane |
|---|---|---|
| 0 | 0.000 | 0.000 |
| 5 | 0.087 | 0.004 |
| 10 | 0.172 | 0.015 |
| 15 | 0.255 | 0.033 |
| 20 | 0.335 | 0.058 |
| 25 | 0.407 | 0.089 |
| 30 | 0.472 | 0.123 |
| 35 | 0.529 | 0.159 |
| 40 | 0.576 | 0.195 |
| 45 | 0.611 | 0.227 |
| 50 | 0.637 | 0.256 |
| 55 | 0.656 | 0.280 |
| 60 | 0.669 | 0.300 |
| 65 | 0.677 | 0.316 |
| 70 | 0.682 | 0.327 |
| 75 | 0.684 | 0.336 |
| 80 | 0.686 | 0.342 |
| 85 | 0.686 | 0.345 |
| 90 | 0.686 | 0.346 |

**Fig. 4.8:**

Aspect factor table for the 9141561 Syl-Line luminaire for $E_{1c}$ calculation

From the table we ascertain that $AF_1 = 0.656$ □ ሺ1.26ሺ0.669 – 0.656ሻሻ / 5

Therefore: $AF_1 = 0.659$

And: $AF_2 = 0.677$ □ ሺ1.62ሺ0.682 – 0.677ሻሻ / 5

Therefore: $AF_2 = 0.679$

The intensity value, $I_\gamma$, can likewise be read off the table for the luminaire:

**Luminous Intensity Values - (cd/1000 lm)**

γ angle □ 15.8°

| Gamma Angle (degrees) | Transverse Plane (0°) | Axial Plane (90°) |
|---|---|---|
| 0 | 286 | 286 |
| 5 | 284 | 284 |
| 10 | 279 | 280 |
| 15 | 276 | 276 |
| 20 | 271 | 269 |
| 25 | 254 | 246 |
| 30 | 254 | 235 |
| 35 | 246 | 209 |
| 40 | 233 | 174 |
| 45 | 220 | 141 |
| 50 | 202 | 112 |
| 55 | 172 | 88 |
| 60 | 161 | 68 |
| 65 | 139 | 48 |
| 70 | 110 | 34 |
| 75 | 79 | 25 |
| 80 | 54 | 16 |
| 85 | 50 | 6 |
| 90 | 51 | 0 |

**Fig. 4.9:**

Part of intensity table for the 9141561 Syl-Line luminaire for $E_{1C}$ calculation

Therefore: $I = 276 - (\ldots)(271 - 276)$

And: $I_{\theta} = 275.2$ cd/klm

$= 275.2 \times 7.3$ cd

$= 2008.96$cd

All the necessary values have now been acquired and can be put into the second line source calculation as follows:

$$E_{p} = \frac{\frac{2008.96 \times (0.679 + 0.659) \times 0.962}{}}{1.5 \times 1.837}$$

Therefore: $E_{p} = 14.03$ lux

In another similar manner $E_{p}$ can be calculated, and again we need to use the second calculation equation as the point is outside the boundary of the luminaire, as in Fig. 4.3.

Point (1) is 1m from the left wall and luminaire D is 4.5m away. Therefore the distance between them (X) is 3.5m. The height of the luminaire above the working plane (H) is (2.7m – 0.85m – 0.082m) which is 1.738m. The distance (D) is calculated as an hypotenuse from Fig. 4.3:

$D = \sqrt{3.5^2 + 1.738^2}$ $D = 3.908$m

$\tan\theta = \frac{3.5}{1.738}$ and $\theta = 63.60°$ As angle ($\theta$) = angle ($\alpha$) in our situation,

Then: $\alpha = 63.60°$ also.

Now $L = 1.5$m, the end of the luminaire to the top wall is 3.75m and from point (1) to top wall is 1.0m. Therefore $L = 2.75$m.

$\tan\beta_1 = \frac{\ldots}{\ldots}$ and $\tan\beta_2 = \frac{\ldots}{\ldots}$

Then: $\beta_1 = 35.13°$ and $\beta_2 = 47.40°$

These angles are the respective angles for obtaining the aspect factors $AF_1$ and $AF_2$, both of them being in the parallel plane. We again can obtain these values by interpolating table values for the particular luminaire. The Aspect Factor table is as follows:

**Aspect Factors**

| Angle (degrees) | Parallel Plane | Perpendicular Plane |
|---|---|---|
| 0 | 0.000 | 0.000 |
| 5 | 0.087 | 0.004 |
| 10 | 0.172 | 0.015 |
| 15 | 0.255 | 0.033 |
| 20 | 0.335 | 0.058 |
| 25 | 0.407 | 0.089 |
| 30 | 0.472 | 0.123 |
| 35 | 0.529 | 0.159 |
| 40 | 0.576 | 0.195 |
| 45 | 0.611 | 0.227 |
| 50 | 0.637 | 0.256 |
| 55 | 0.656 | 0.280 |
| 60 | 0.669 | 0.300 |
| 65 | 0.677 | 0.316 |
| 70 | 0.682 | 0.327 |
| 75 | 0.684 | 0.336 |
| 80 | 0.686 | 0.342 |
| 85 | 0.686 | 0.345 |
| 90 | 0.686 | 0.346 |

$AF_1$ angle □ $35.13^o$

$AF_2$ angle □ $47.40^o$

**Fig. 4.10:**

Aspect factor table for the 9141561 Syl-Line luminaire for $E_{1D}$ calculation

From the table we ascertain that $AF_1 = 0.529$ □ ጽ0.13ጽ0.576 – 0.529ኻኻ / 5

Therefore: $AF_1 = 0.530$

And: $AF_2 = 0.611$ □ ጽ2.4ጽ0.637 – 0.611ኻኻ / 5

Therefore: $AF_2 = 0.624$

The intensity value, $I_\gamma$, can likewise be read off the table for the luminaire:

**Luminous Intensity Values - (cd/1000 lm)**

| Gamma Angle (degrees) | Transverse Plane (0°) | Axial Plane (90°) |
|---|---|---|
| 0 | 286 | 286 |
| 5 | 284 | 284 |
| 10 | 279 | 280 |
| 15 | 276 | 276 |
| 20 | 271 | 269 |
| 25 | 254 | 246 |
| 30 | 254 | 235 |
| 35 | 246 | 209 |
| 40 | 233 | 174 |
| 45 | 220 | 141 |
| 50 | 202 | 112 |
| 55 | 172 | 88 |
| 60 | 161 | 68 |
| 65 | 139 | 48 |
| 70 | 110 | 34 |
| 75 | 79 | 25 |
| 80 | 54 | 16 |
| 85 | 50 | 6 |
| 90 | 51 | 0 |

$\gamma$ angle □ $63.60^o$

**Fig. 4.11:**

Part of intensity table for the 9141561 Syl-Line luminaire for $E_{1D}$ calculation

Therefore: $I_{\theta} = 161 + \frac{[illegible]}{[illegible]}(139 - 161)$

And: $I_{\theta} = 145.16\,cd/klm$

$= 145.16 \times 7.3\,cd$

$= 1059.67\,cd$

All the necessary values have now been acquired and can be put into the second line source calculation as follows:

$$E_{h2} = \frac{1059.67 \times (0.624 - 0.530) \times 0.445}{1.5 \times 3.908}$$

Therefore: $E_{h2} = 7.56$ lux

Direct illuminance levels have now been calculated at Point (1) from each of the four luminaires and a total value is obtained by adding them together:

$$E_{hT} = 457.99 + 29.78 + 14.03 + 7.56$$

$$E_{hT} = 509.36 \text{ lux}$$

So diagramatically:

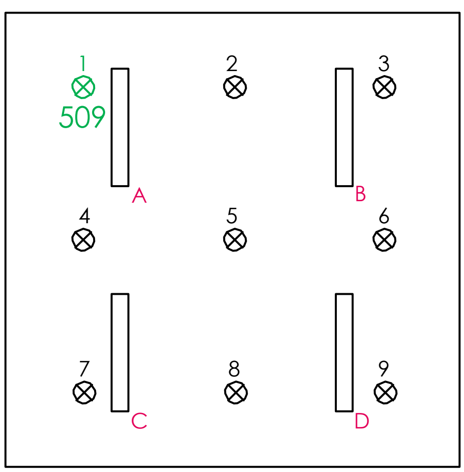



**Fig. 4.12:**

Calculated horizontal direct illuminance at Point (1)

But as the luminaire distribution is bi-symmetric, having symmetry in 0-180deg and 90-270deg planes at right angles to each other, then the calculated illuminance values at points 3, 7, and 9 will be identical. The following diagram illustrates the progress so far:

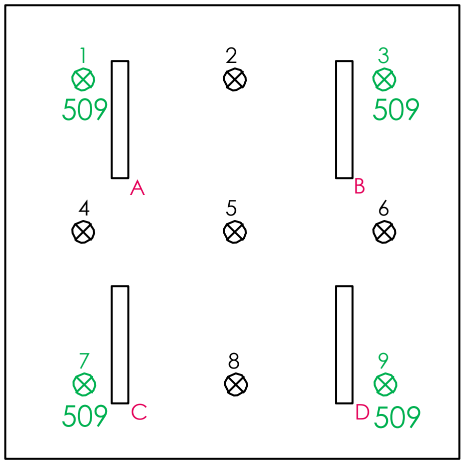



**Fig. 4.13:**

Calculated horizontal direct illuminance at Points (1) (3) (7) & (9)

If we now look at calculating the illuminance at Point (5), it is necessary to calculate using the second equation as the point is outside the luminaire boundary in each case.
This time we get the following values:

Point (5) is midway from either wall and therefore 3m from the left hand wall. Luminaire A is 1.5m away from the left hand wall. Therefore the distance between them (X) is 1.5m. The height of the luminaire above the working plane (H) is (2.7m – 0.85m – 0.082m) which is 1.738m. The distance (D) is calculated as an hypotenuse from Fig. 4.3:

$D = \sqrt{1.5^2 + 1.738^2}$ $\quad\quad$ $D = 2.30m$

$\tan\theta = \frac{1.5}{1.738}$ and $\theta = 40.80°$ As angle ($\theta$) = angle ($\beta$) in our situation,

Then: $\beta = 40.80°$ also.

Now $L = 1.5m$, the top end of the luminaire to a parallel plane with point (5) is 2.25m, and from the bottom end of the luminaire to a parallel plane with point (5) is 0.75m. Therefore $L_1 = 0.75m$, and $L_2 = 2.25m$.

$\tan\alpha_1 = \frac{0.75}{2.30}$ and $\tan\alpha_2 = \frac{2.25}{2.30}$

Then: $\alpha_1 = 18.06°$ and $\alpha_2 = 44.37°$

These angles are the respective angles for obtaining the aspect factors $AF_{\alpha_1}$ and $AF_{\alpha_2}$, both of them being in the parallel plane. We again can obtain these values by interpolating table values for the particular luminaire. The Aspect Factor table is as follows:

AF$_1$ angle □ 18.06°

AF$_2$ angle □ 44.37°

**Aspect Factors**

| Angle (degrees) | Parallel Plane | Perpendicular Plane |
|---|---|---|
| 0 | 0.000 | 0.000 |
| 5 | 0.087 | 0.004 |
| 10 | 0.172 | 0.015 |
| 15 | 0.255 | 0.033 |
| 20 | 0.335 | 0.058 |
| 25 | 0.407 | 0.089 |
| 30 | 0.472 | 0.123 |
| 35 | 0.529 | 0.159 |
| 40 | 0.576 | 0.195 |
| 45 | 0.611 | 0.227 |
| 50 | 0.637 | 0.256 |
| 55 | 0.656 | 0.280 |
| 60 | 0.669 | 0.300 |
| 65 | 0.677 | 0.316 |
| 70 | 0.682 | 0.327 |
| 75 | 0.684 | 0.336 |
| 80 | 0.686 | 0.342 |
| 85 | 0.686 | 0.345 |
| 90 | 0.686 | 0.346 |

**Fig. 4.14:**

Aspect factor table for the 9141561 Syl-Line luminaire for $E_{5A}$ calculation

From the table we ascertain that $AF_1 = 0.255 \square \frac{3.06(0.335 - 0.255)}{5}$

Therefore: $AF_1 = 0.304$

And: $AF_2 = 0.576 \square \frac{4.37(0.611 - 0.576)}{5}$

Therefore: $AF_2 = 0.607$

The intensity value, $I_\gamma$, can likewise be read off the table for the luminaire:

$\gamma$ angle □ 40.80°

**Luminous Intensity Values - (cd/1000 lm)**

| Gamma Angle (degrees) | Transverse Plane (0°) | Axial Plane (90°) |
|---|---|---|
| 0 | 286 | 286 |
| 5 | 284 | 284 |
| 10 | 279 | 280 |
| 15 | 276 | 276 |
| 20 | 271 | 269 |
| 25 | 254 | 246 |
| 30 | 254 | 235 |
| 35 | 246 | 209 |
| 40 | 233 | 174 |
| 45 | 220 | 141 |
| 50 | 202 | 112 |
| 55 | 172 | 88 |
| 60 | 161 | 68 |
| 65 | 139 | 48 |
| 70 | 110 | 34 |
| 75 | 79 | 25 |
| 80 | 54 | 16 |
| 85 | 50 | 6 |
| 90 | 51 | 0 |

**Fig. 4.15:**

Part of intensity table for the 9141561 Syl-Line luminaire for $E_{5A}$ calculation

Therefore: ☐ 233 ☐ (☐)(233 ☐ 220)

And: ☐ 235.08cd/klm

☐ 235.08 ☐ 7.3 cd

☐ 1716.08 cd

All the necessary values have now been acquired and can be put into the second line source calculation as follows:

$$E \; \square \; \frac{\frac{1716.08 \; \square \; (0.607 \; \square \; 0.304) \; \square}{0.757}}{1.5 \; \square \; 2.3}$$

Therefore: $E$ ☐ 114.09 lux

But again as the luminaire distribution, the luminaire layout, and positions of calculation points are all symmetric about the centre point (5), then the illuminance value just calculated will be the same from the other three luminaires.

Therefore:

$E$ ☐ 114.09 ☐

4 $E$ ☐ 456.36

lux

So diagramatically:

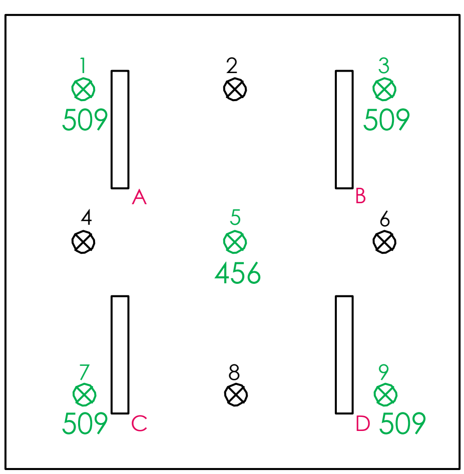



**Fig. 4.16:**

Calculated horizontal direct illuminance at Points (1),(3),(5),(7) & (9)

If we now look at calculating the illuminance at Point (4), again due to symmetric layout, we need only calculate values from luminaires A and B, and then double it to arrive at the total illuminance level.

This time we get the following values:

Point (4) is 1m from the left hand wall. Luminaire A is 1.5m away from the left hand wall. Therefore the distance between them (X) is 0.5m. The height of the luminaire above the working plane (H) is (2.7m – 0.85m – 0.082m) which is 1.768m. The distance (D) is calculated as an hypotenuse from Fig. 4.3:

$D = \sqrt{0.5^2 + 1.768^2}$ $D = 1.837\text{m}$

$\tan\theta = \frac{0.5}{1.768}$ and $\theta = 15.80°$ As angle ($\theta$) = angle ($\gamma$) in our situation,

Then: $\gamma = 15.80°$ also.

Now $L = 1.5\text{m}$, the top end of the luminaire A to a parallel plane with point (4) is 2.25m, and from the bottom end of the luminaire to a parallel plane with point (4) is 0.75m. Therefore $L_1 = 0.75\text{m}$, and $L_2 = 2.25\text{m}$.

$\tan\alpha_1 = \frac{0.75}{1.837}$ and $\tan\alpha_2 = \frac{2.25}{1.837}$

Then: $\alpha_1 = 22.21°$ and $\alpha_2 = 50.77°$

These angles are the respective angles for obtaining the aspect factors $AF_1$ and $AF_2$, both of them being in the parallel plane. We again can obtain these values by interpolating table values for the particular luminaire.

The Aspect Factor table is as follows:

$AF_1$ angle □ $22.21^o$

$AF_2$ angle □ $50.77^o$

**Aspect Factors**

| Angle (degrees) | Parallel Plane | Perpendicular Plane |
|---|---|---|
| 0 | 0.000 | 0.000 |
| 5 | 0.087 | 0.004 |
| 10 | 0.172 | 0.015 |
| 15 | 0.255 | 0.033 |
| 20 | 0.335 | 0.058 |
| 25 | 0.407 | 0.089 |
| 30 | 0.472 | 0.123 |
| 35 | 0.529 | 0.159 |
| 40 | 0.576 | 0.195 |
| 45 | 0.611 | 0.227 |
| 50 | 0.637 | 0.256 |
| 55 | 0.656 | 0.280 |
| 60 | 0.669 | 0.300 |
| 65 | 0.677 | 0.316 |
| 70 | 0.682 | 0.327 |
| 75 | 0.684 | 0.336 |
| 80 | 0.686 | 0.342 |
| 85 | 0.686 | 0.345 |
| 90 | 0.686 | 0.346 |

**Fig. 4.17:**

Aspect factor table for the 9141561 Syl-Line luminaire for $E_{4A}$ calculation

From the table we ascertain that $AF_1 = 0.335$ □ ሺ2.21ሺ0.407 – 0.335ሻሻ / 5

Therefore: $AF_1 = 0.367$

And: $AF_2 = 0.637$ □ ሺ0.77ሺ0.656 – 0.637ሻሻ / 5

Therefore: $AF_2 = 0.640$

The intensity value, $I_\gamma$, can likewise be read off the table for the luminaire:

$\gamma$ angle □ $15.80^o$

**Luminous Intensity Values - (cd/1000 lm)**

| Gamma Angle (degrees) | Transverse Plane (0°) | Axial Plane (90°) |
|---|---|---|
| 0 | 286 | 286 |
| 5 | 284 | 284 |
| 10 | 279 | 280 |
| 15 | 276 | 276 |
| 20 | 271 | 269 |
| 25 | 254 | 246 |
| 30 | 254 | 235 |
| 35 | 246 | 209 |
| 40 | 233 | 174 |
| 45 | 220 | 141 |
| 50 | 202 | 112 |
| 55 | 172 | 88 |
| 60 | 161 | 68 |
| 65 | 139 | 48 |
| 70 | 110 | 34 |
| 75 | 79 | 25 |
| 80 | 54 | 16 |
| 85 | 50 | 6 |
| 90 | 51 | 0 |

**Fig. 4.18:**

Part of intensity table for the 9141561 Syl-Line luminaire for $E_{4A}$ calculation

Therefore: $I = 276 - \frac{?.?}{?}(271 - 276)$

And: $I = 275.2 cd/klm$

$= 275.2 \times 7.3$ cd

$= 2008.96$ cd

All the necessary values have now been acquired and can be put into the second line source calculation as follows:

$$E = \frac{\frac{2008.96 \times (0.635 - 0.354) \times}{0.9622}}{1.5 \times 1.837}$$

Therefore: $E = 197.13$ lux

Now we need to calculate the illuminance at Point (4) from luminaire B. Point (4) is 1m from the left hand wall. Luminaire B is 4.5m away from the left hand wall. Therefore the distance between them (X) is 3.5m. The height of the luminaire above the working plane (H) is (2.7m – 0.85m – 0.082m) which is 1.768m. The distance (D) is calculated as an hypotenuse from Fig. 4.3:

$D = \sqrt{3.5^2 + 1.768^2}$ $D = 3.92$

$\tan \theta = \frac{3.5}{1.768}$ and $\theta = 63.20°$ As angle ([illegible]) = angle ([illegible]) in our situation,

Then: $\phi = 63.20°$ also.

Now $L = 1.5m$, the top end of the luminaire B to a parallel plane with point (4) is 2.25m, and from the bottom end of the luminaire to a parallel plane with point (4) is 0.75m. Therefore $L_1 = 0.75m$, and $L_2 = 2.25m$.

$\tan \alpha_1 = \frac{0.75}{3.92}$ and $\tan \alpha_2 = \frac{2.25}{3.92}$

Then: $\alpha_1 = 10.83°$ and $\alpha_2 = 29.86°$

These angles are the respective angles for obtaining the aspect factors $AF_{\alpha 1}$ and $AF_{\alpha 2}$, both of them being in the parallel plane. We again can obtain these values by interpolating table values for the particular luminaire.

The Aspect Factor table is as follows:

**Aspect Factors**

| Angle (degrees) | Parallel Plane | Perpendicular Plane |
|---|---|---|
| **0** | 0.000 | 0.000 |
| **5** | 0.087 | 0.004 |
| **10** | 0.172 | 0.015 |
| **15** | 0.255 | 0.033 |
| **20** | 0.335 | 0.058 |
| **25** | 0.407 | 0.089 |
| **30** | 0.472 | 0.123 |
| **35** | 0.529 | 0.159 |
| **40** | 0.576 | 0.195 |
| **45** | 0.611 | 0.227 |
| **50** | 0.637 | 0.256 |
| **55** | 0.656 | 0.280 |
| **60** | 0.669 | 0.300 |
| **65** | 0.677 | 0.316 |
| **70** | 0.682 | 0.327 |
| **75** | 0.684 | 0.336 |
| **80** | 0.686 | 0.342 |
| **85** | 0.686 | 0.345 |
| **90** | 0.686 | 0.346 |

$AF_1$ angle □ $10.83^o$

$AF_2$ angle □ $29.86^o$

**Fig. 4.19:**

Aspect factor table for the 9141561 Syl-Line luminaire for $E_{4B}$ calculation

From the table we ascertain that: $AF_1 = 0.172$ □ ፚ0.83ፚ0.255 – 0.172፛፛ / 5

Therefore: $AF_1 = 0.186$

And: $AF_2 = 0.407$ □ ፚ4.86ፚ0.472 – 0.407፛፛ / 5

Therefore: $AF_2 = 0.470$

The intensity value, $I_\gamma$, can likewise be read off the table for the luminaire:

**Luminous Intensity Values - (cd/1000 lm)**

| Gamma Angle (degrees) | Transverse Plane (0°) | Axial Plane (90°) |
|---|---|---|
| **0** | 286 | 286 |
| **5** | 284 | 284 |
| **10** | 279 | 280 |
| **15** | 276 | 276 |
| **20** | 271 | 269 |
| **25** | 254 | 246 |
| **30** | 254 | 235 |
| **35** | 246 | 209 |
| **40** | 233 | 174 |
| **45** | 220 | 141 |
| **50** | 202 | 112 |
| **55** | 172 | 88 |
| **60** | 161 | 68 |
| **65** | 139 | 48 |
| **70** | 110 | 34 |
| **75** | 79 | 25 |
| **80** | 54 | 16 |
| **85** | 50 | 6 |
| **90** | 51 | 0 |

$\gamma$ angle □ $63.20^o$

**Fig. 4.20:**

Part of intensity table for the 9141561 Syl-Line luminaire for $E_{4B}$ calculation

Therefore: $\square\; 161 \;\square\; (\ldots)(139 \;\square\; 161)$

And: $\square\; 146.92\,cd/klm$

$\square\; 146.92 \;\square\; 7.3\,cd$

$\square\; 1072.52\,cd$

All the necessary values have now been acquired and can be put into the second line source calculation as follows:

$$E \;\square\; \frac{\dfrac{1072.52 \;\square\; (0.470 \;\square\; 0.186) \;\square}{0.4509}}{1.5 \;\square\; 3.92}$$

Therefore: $E \;\square\; 23.36$ lux

But again as the luminaire distribution, the luminaire layout, and positions of calculation points are all symmetric about the centre point (5), then the illuminance value of $E \;\square\; E$ will be the same as for $E \;\square\; E$.

Therefore:

$$E \;\square\; 2(197.13) \;\square\; 2(23.36)$$

$$E \;\square\; 440.98 \text{ lux}$$

And as Point (6) is symmetric about the centre, the illuminance level there is the same as at Point (4), $E \;\square\; 440.98$ lux.

So diagramatically:

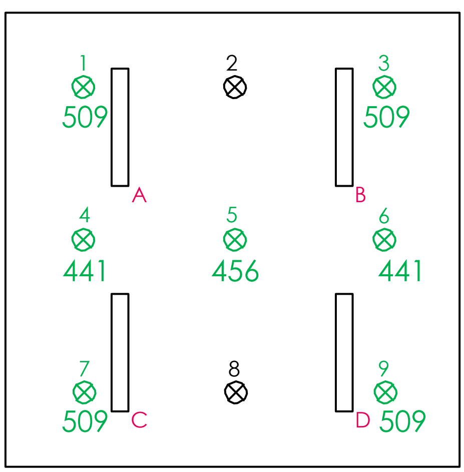



**Fig. 4.21:**

Calculated horizontal direct illuminance at Points (1),(3),(4),(5),(6),(7) & (9)

Now we need to calculate the illuminance at Point (2) from luminaire A. Point (2) is 3m from the left hand wall. Luminaire A is 1.5m away from the left hand wall. Therefore the distance between them (X) is 1.5m. The height of the luminaire above the working plane (H) is (2.7m – 0.85m – 0.082m) which is 1.768m. The distance (D) is calculated as an hypotenuse from Fig. 4.2:

$$D = \sqrt{1.5^2 \square 1.768^2} \qquad D = 2.32$$

$\tan\gamma \square \frac{1.5}{1.768}$ and $\gamma = 40.31^\circ$ As angle (γ) = angle (β) in our situation,

Then: $\beta = 40.31^\circ$ also.

Now L = 1.5m, the top end of the luminaire A to a parallel plane with point (2) is 0.25m, and from the bottom end of the luminaire to a parallel plane with point (4) is 1.25m. Therefore $L_1$ = 0.25m, and $L_2$ = 1.25m.

$\tan\alpha_1 \square \frac{0.25}{2.32}$ and $\tan\alpha_1 \square \frac{1.25}{2.32}$

Then: $\alpha_1 = 6.15^\circ$ and $\alpha_2 = 28.32^\circ$

These angles are the respective angles for obtaining the aspect factors $AF_1$ and $AF_2$, both of them being in the parallel plane. We again can obtain these values by interpolating table values for the particular luminaire. The Aspect Factor table is as follows:

**Aspect Factors**

| Angle (degrees) | Parallel Plane | Perpendicular Plane |
|---|---|---|
| 0 | 0.000 | 0.000 |
| 5 | 0.087 | 0.004 |
| 10 | 0.172 | 0.015 |
| 15 | 0.255 | 0.033 |
| 20 | 0.335 | 0.058 |
| 25 | 0.407 | 0.089 |
| 30 | 0.472 | 0.123 |
| 35 | 0.529 | 0.159 |
| 40 | 0.576 | 0.195 |
| 45 | 0.611 | 0.227 |
| 50 | 0.637 | 0.256 |
| 55 | 0.656 | 0.280 |
| 60 | 0.669 | 0.300 |
| 65 | 0.677 | 0.316 |
| 70 | 0.682 | 0.327 |
| 75 | 0.684 | 0.336 |
| 80 | 0.686 | 0.342 |
| 85 | 0.686 | 0.345 |
| 90 | 0.686 | 0.346 |

$AF_1$ angle $\square$ $6.15^o$

$AF_2$ angle $\square$ $28.32^o$

**Fig. 4.22:**

Aspect factor table for the 9141561 Syl-Line luminaire for $E_{2A}$ calculation

From the table we ascertain that: $AF_1 = 0.087 + \frac{1.15}{5}(0.172 - 0.087)$

Therefore: $AF_1 = 0.107$

And: $AF_2 = 0.407 + \frac{3.32}{5}(0.472 - 0.407)$

Therefore: $AF_2 = 0.450$

The intensity value, $I_\gamma$, can likewise be read off the table for the luminaire:

$\gamma$ angle = $40.31^o$

| Luminous Intensity Values - (cd/1000 lm) | | |
|---|---|---|
| Gamma Angle (degrees) | Transverse Plane (0°) | Axial Plane (90°) |
| 0 | 286 | 286 |
| 5 | 284 | 284 |
| 10 | 279 | 280 |
| 15 | 276 | 276 |
| 20 | 271 | 269 |
| 25 | 254 | 246 |
| 30 | 254 | 235 |
| 35 | 246 | 209 |
| 40 | 233 | 174 |
| 45 | 220 | 141 |
| 50 | 202 | 112 |
| 55 | 172 | 88 |
| 60 | 161 | 68 |
| 65 | 139 | 48 |
| 70 | 110 | 34 |
| 75 | 79 | 25 |
| 80 | 54 | 16 |
| 85 | 50 | 6 |
| 90 | 51 | 0 |

**Fig. 4.23:**

Part of intensity table for the 9141561 Syl-Line luminaire for $E_{2A}$ calculation

Therefore: $I_\gamma = 233 + \frac{0.31(220 - 233)}{5}$

And: $I_\gamma = 232.2$ cd/klm

$= 232.2 \times 7.3$ cd

$= 1695.06$ cd

All the necessary values have now been acquired and can be put into the second line source calculation as follows:

$$E_{2A} = \frac{1695.06 \times (0.450 - 0.107) \times 0.7626}{1.5 \times 2.32}$$

Therefore: $E_{2A} = 127.41$lux

Now we need to calculate the illuminance at Point (2) from luminaire C. Point (2) is 3m from the left hand wall. Luminaire A is 1.5m away from the left hand wall. Therefore the distance between them (X) is 1.5m. The height of the luminaire above the working plane (H) is (2.7m – 0.85m – 0.082m) which is 1.768m. The distance (D) is calculated as an hypotenuse from Fig. 4.3:

$D = \sqrt{1.5^2 + 1.768^2}$ $D = 2.32$

$\tan\gamma = \frac{1.5}{1.768}$ and $\gamma = 40.31^\circ$ As angle ($\gamma$) = angle ($\beta$) in our situation,

Then: $\beta = 40.31^\circ$ also.

Now L = 1.5m, the top end of the luminaire C to a parallel plane with point (2) is 2.75m, and from the bottom end of the luminaire to a parallel plane with point (2) is 4.25m. Therefore $L_1$ = 2.75m, and $L_2$ = 4.25m.

$\tan\alpha_1 = \frac{2.75}{2.32}$ and $\tan\alpha_1 = \frac{4.25}{2.32}$

Then: $\alpha_1 = 49.85^\circ$ and $\alpha_2 = 61.37^\circ$

These angles are the respective angles for obtaining the aspect factors $AF_1$ and $AF_2$, both of them being in the parallel plane. We again can obtain these values by interpolating table values for the particular luminaire. The Aspect Factor table is as follows:

**Aspect Factors**

| Angle (degrees) | Parallel Plane | Perpendicular Plane |
|---|---|---|
| 0 | 0.000 | 0.000 |
| 5 | 0.087 | 0.004 |
| 10 | 0.172 | 0.015 |
| 15 | 0.255 | 0.033 |
| 20 | 0.335 | 0.058 |
| 25 | 0.407 | 0.089 |
| 30 | 0.472 | 0.123 |
| 35 | 0.529 | 0.159 |
| 40 | 0.576 | 0.195 |
| 45 | 0.611 | 0.227 |
| 50 | 0.637 | 0.256 |
| 55 | 0.656 | 0.280 |
| 60 | 0.669 | 0.300 |
| 65 | 0.677 | 0.316 |
| 70 | 0.682 | 0.327 |
| 75 | 0.684 | 0.336 |
| 80 | 0.686 | 0.342 |
| 85 | 0.686 | 0.345 |
| 90 | 0.686 | 0.346 |

$AF_1$ angle = $49.85^o$

$AF_2$ angle = $61.37^o$

**Fig. 4.24:**

Aspect factor table for the 9141561 Syl-Line luminaire for $E_{2C}$ calculation

From the table we ascertain that: $AF_1 = 0.611 + \frac{4.85(0.637 - 0.611)}{5}$

Therefore: $AF_1 = 0.636$

And: $AF_2 = 0.669 + \frac{1.37(0.677 - 0.669)}{5}$

Therefore: $AF_2 = 0.671$

The intensity value, $I_\gamma$, can likewise be read off the table for the luminaire:

$\gamma$ angle $= 40.31^o$

| Luminous Intensity Values - (cd/1000 lm) | | |
|---|---|---|
| **Gamma Angle (degrees)** | **Transverse Plane (0°)** | **Axial Plane (90°)** |
| **0** | 286 | 286 |
| **5** | 284 | 284 |
| **10** | 279 | 280 |
| **15** | 276 | 276 |
| **20** | 271 | 269 |
| **25** | 254 | 246 |
| **30** | 254 | 235 |
| **35** | 246 | 209 |
| **40** | 233 | 174 |
| **45** | 220 | 141 |
| **50** | 202 | 112 |
| **55** | 172 | 88 |
| **60** | 161 | 68 |
| **65** | 139 | 48 |
| **70** | 110 | 34 |
| **75** | 79 | 25 |
| **80** | 54 | 16 |
| **85** | 50 | 6 |
| **90** | 51 | 0 |

**Fig. 4.25:**

Part of intensity table for the 9141561 Syl-Line luminaire for $E_{2C}$ calculation

Therefore: $I_\gamma = 233 + \frac{0.31(220 - 233)}{5}$

And: $I_\gamma = 232.2 \text{cd/klm}$

$= 232.2 \times 7.3 \text{ cd}$

$= 1695.06 \text{ cd}$

All the necessary values have now been acquired and can be put into the second line source calculation as follows:

$$E_{2C} = \frac{1695.06 \times (0.671 - 0.636) \times 0.7626}{1.5 \times 2.32}$$

Therefore: $E_{2C} = 13.00$ lux

But again as the luminaire distribution, the luminaire layout, and positions of calculation points are all symmetric about the centre point (5), then the illuminance value of $E_{2A} + E_{2C}$ will be the same as for $E_{2A} + E_{2C}$.

Therefore:

$$E_{h2} = 2(127.41) +$$

$$2(13.00) \quad E_{h2} =$$

$$280.82 \text{ lux}$$

And as Point (8) is symmetric about the centre, the illuminance level there is the same as at Point (2), $E_{h8} = 280.82$ lux.

So diagramatically:

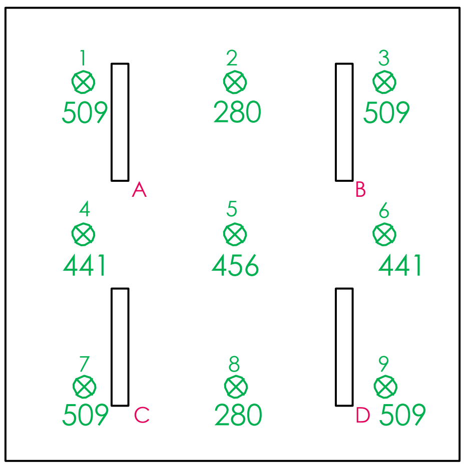



**Fig. 4.26:**

Calculated horizontal direct illuminance at all Points (1),(2),(3),(4),(5),(6),(7),(8) & (9)

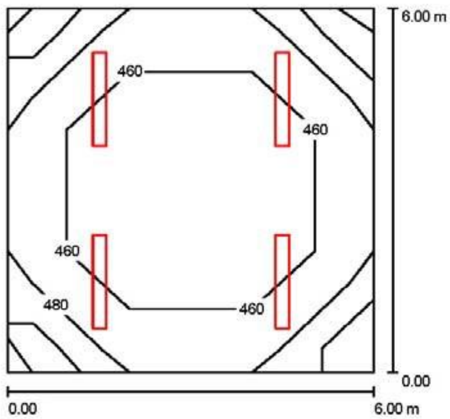
Therefore, the average horizontal direct illuminance at working plane height can now be obtained:

$$E_{h,ave} = \frac{509 + 280 + 509 + 441 + 456 + 441 + 509 + 280 + 509}{9}$$

$$E_{h,ave} = 437.11$$

A comparison must now be made with the results obtained by a computerised calculation. As we are only concerned with direct illuminance the reflectances of the individual room surfaces must be set to zero. In addition, no maintenance factor will be included as with the hand calculations.

Therefore if exactly the same information and parameters are put into Dialux the following results are seen:




Height of Room: 2.700 m, Mounting Height: 2.700 m, Maintenance factor: 1.00

Values in Lux, Scale 1:78

| Surface | ρ [%] | $E_{av}$ [lx] | $E_{min}$ [lx] | $E_{max}$ [lx] | u0 |
|---|---|---|---|---|---|
| Workplane | / | 467 | 423 | 509 | 0.906 |
| Floor | 0 | 339 | 152 | 433 | 0.448 |
| Ceiling | 0 | 64 | 1.05 | 921 | 0.016 |
| Walls (4) | 0 | 174 | 29 | 316 | / |

| **Workplane:** | | **UGR** | Lengthways- | Across | to luminaire axis |
|---|---|---|---|---|---|
| Height: | 0.850 m | Left Wall | 22 | 18 | |
| Grid: | 3 x 3 Points | Lower Wall | 22 | 18 | |
| Boundary Zone: | 0.000 m | (CIE, SHR = 1.00.) | | | |

Illuminance Quotient (according to LG7): Walls / Working Plane: 0.413, Ceiling / Working Plane: 0.149.

**Luminaire Parts List**

| No. | Pieces | Designation (Correction Factor) | Φ [lm] | P [W] |
|---|---|---|---|---|
| 1 | 4 | Syl-Line 2x35W T5 Syl-Line (1.000) | 7300 | 75.0 |
| | | Total: | 29200 | 300.0 |

**Fig. 4.27:**

Calculated results from sample room using Dialux Lighting Software

As can be seen on the summary sheet above (Fig. 4.27:) the average calculated illuminance with a measuring grid of 3 x 3 points is 467 lux. The same calculation done manually, as detailed above, gave a value of 437.11 lux. The inaccuracy of the computer program shows a variance of -6.4%, which is far too high not to be considered important by the program designers. This comparison shows that by going ‘back to basics’, using mathematical models developed around the middle of the last century, we should not assume that computers produce very accurate results. The saying that ‘the output from computers is only as good as the input’ is particularly true in this instance.

**b. Mathematical Engine Accuracy**

When a computer carries out mathematical calculations, values are stored in memory locations for future use within the program. These values can be determined to a particular accuracy by the number of decimal places used, as well as being either rounded 'up' or 'down'. If the calculations use numbers stored in this way it is obvious that as more steps are taken, the less accurate the values become.

To exemplify this particular variance I have entered exactly the same input information and luminaire type into both DIALux and Relux design programs. The parameters comprise of a single room with the following criteria:

| | |
|---|---|
| Dimensions: | 6m x 6m |
| Height of room: | 2.7m |
| Height of working plane: | 0.85m |
| Surface reflectances: | 70%; 50%; 20% |
| Boundary zone: | 0.0m |
| Maintenance Factor: | 0.8 |
| Calculation Grid: | 32 x 32 points |
| Luminaire type: | Syl-Line 2x35W T5 |
| Total Luminous Flux: | 29200 lumens |
| Number of luminaires: | 4 |
| Array: | Symmetrical within room |
| Furniture or objects: | None |

The calculation results are shown overleaf. Fig. 5.1 is the Summary sheet from the DIALux program, and Fig. 5.2 is the Result Overview sheet from the Relux program.

The DIALux summary shows an average horizontal illuminance over an unobstructed working plane 0.85m from finished floor level of 463 lux, whilst the same value in the Relux summary shows a value of 442 lux. If the assumption is made that neither of these values is exactly correct, then it is necessary to compare the variance from the midpoint. The mean of the two values is 452.5 lux, and the results from DIALux and Relux show their variances therefore as being + 2.35% and - 2.35% respectively.

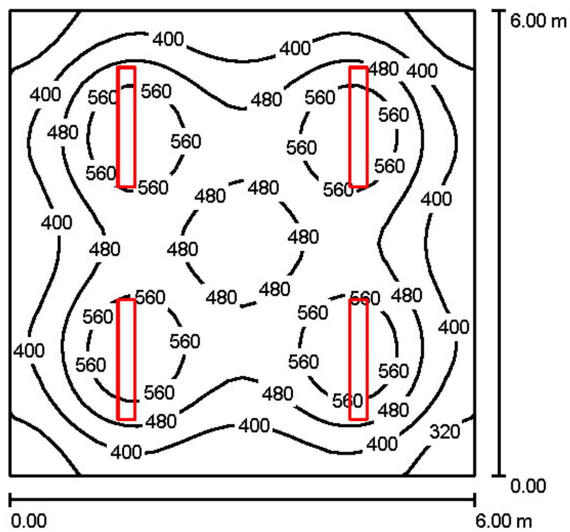
This variance is not insignificant when the total variance is evaluated later in the report.

Technical Memorandum 28 from the CIBSE[21] looks at a possible system for benchmarking lighting design software. It looks at an "Expectation of Error" band for standard calculations whereby variances of calculated values to measured values are expected to lie. The conclusion is that a variance of mean ±13.4% is expected on direct point illuminance, whilst only mean ±7.6% is expected on average illuminance. These are quite substantial variances which many will not be aware of.

Whilst these expected variances have been established within the tests carried out for TM28, they relate to possible variances in all lighting design software, of which there are numerous types in the marketplace. In this report I am concerned primarily with the maximum variance possible, within the confines of normal practice. As normal practice in the UK is to use either Relux or Dialux software, then the variance calculated in this report is taken from values calculated by only these two programs. The actual variance is then calculated from a mean between the two results.

I believe that the values calculated this way give a more realistic variance value in practice, than by taking the values straight from TM28.

**Sample Room with reflectance / Summary**




Height of Room: 2.700 m, Mounting Height: 2.700 m, Maintenance factor: 0.80 — Values in Lux, Scale 1:78

| Surface | ρ [%] | $E_{av}$ [lx] | $E_{min}$ [lx] | $E_{max}$ [lx] | u0 |
|---|---|---|---|---|---|
| Workplane | / | 463 | 258 | 647 | 0.558 |
| Floor | 20 | 386 | 253 | 462 | 0.654 |
| Ceiling | 70 | 152 | 84 | 840 | 0.551 |
| Walls (4) | 50 | 240 | 140 | 356 | / |

**Workplane:**
Height: 0.850 m
Grid: 32 x 32 Points
Boundary Zone: 0.000 m

| **UGR** | Lengthways- | Across | to luminaire axis |
|---|---|---|---|
| Left Wall | 21 | 17 | |
| Lower Wall | 21 | 17 | |

(CIE, SHR = 1.00.)

Illuminance Quotient (according to LG7): Walls / Working Plane: 0.530, Ceiling / Working Plane: 0.328.

**Luminaire Parts List**

| No. | Pieces | Designation (Correction Factor) | Φ [lm] | P [W] |
|---|---|---|---|---|
| 1 | 4 | Syl-Line 2x35W T5 Syl-Line (1.000) | 7300 | 75.0 |
| | | Total: | 29200 | 300.0 |

Specific connected load: 8.33 W/m² = 1.80 W/m²/100 lx (Ground area: 36.00 m²)

**Fig. 5.1:**

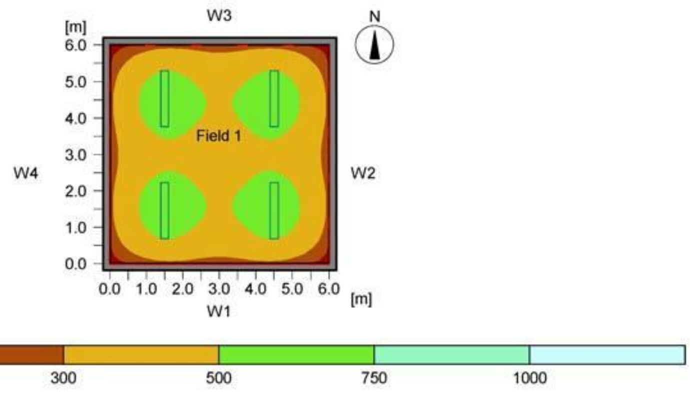
Calculated results from sample room using Dialux Lighting Software

| | | |
|---|---|---|
| Object | : | Engine Accuracy |
| Installation | : | Sample Room |
| Project number | : | Engine Accuracy |
| Date | : | 06.05.2009 |

# 1 Room 1

## 1.1 Summary, Room 1

### 1.1.1 Result overview, Reference plane 1




**General**

| | |
|---|---|
| Calculation algorithm used | Average indirect fraction with light colours |
| Height of evaluation surface | 0.85 m |
| Height of luminaire plane | 2.70 m |
| Maintenance factor | 0.80 |
| Total luminous flux of all lamps | 29200 lm |
| Total power | 300 W |
| Total power per area (36.00 m²) | 8.33 W/m² (1.88 W/m²/100lx) |

**Illuminance**

| | | |
|---|---|---|
| Average illuminance | Eav | 442 lx |
| Minimum illuminance | Emin | 170 lx |
| Maximum illuminance | Emax | 633 lx |
| Uniformity g1 | Emin/Em | 1:2.59 (0.39) |
| Uniformity g2 | Emin/Emax | 1:3.72 (0.27) |

**Type No.\Make**

| Type | No. | Make | |
|---|---|---|---|
| | | **EULUMDAT/2 LMAN=CONCORD:MARLIN LIGHTING;;LFAM=NONE;;LDTX=CONCORD.DTX/Syl-Li** | |
| 1 | 4 | Order No. | : Syl-Line 2x35W T5 |
| | | Luminaire name | : Syl-Line |
| | | Equipment | : 2 x SLI 35W T5 0 W / 3650 lm RGB 1.00 1.00 1.00 |

**Fig. 5.2:**

Calculated results from sample room using Relux Lighting Software

**c. Lamp Temperature**

A T8 fluorescent lamp produces maximum light output when the ambient temperature is 25˚C.[15] The modern range of T5 (16mm) tubes however have their maximum light output at an ambient temperature of 35˚C. Whilst this latter temperature can be easily achieved with careful luminaire design of an enclosed fixture, there is today popular use of these lamps in open style units using louvres and wire guards. It is therefore necessary now to look at the effect on T5 lamp light output when they are running in lower ambient temperatures.

The light output at both ambient temperatures is shown in Fig. 6.1, which is an extract from SYLVANIA Data Sheet 51P-5689C for FHE35W/T5 lamps. The full data sheet is shown in the Appendix on pages A12 and A13.

**PHOTOMETRIC DATA:**

| COLOUR | No. | Luminous Flux maximum [2)] (34...38 °C) (lm) | Luminous Flux nominal value [1)] (25 °C) (lm) | CRI (Group) | Colour temp. (K) | Energy Efficiency Class | ILCOS-Code |
|---|---|---|---|---|---|---|---|
| **LUXLINE plus COLOURS** | | | | | | | |
| HOMELIGHT DELUXE | 827 | 3650 | 3320 | 1B | 2700 | A | FDH-35/27/L/P-G5-16/1450 |
| WARM WHITE DELUXE | 830 | 3650 | 3320 | 1B | 3000 | A | FDH-35/30/L/P-G5-16/1450 |
| WHITE DELUXE | 835 | 3650 | 3320 | 1B | 3500 | A | FDH-35/35/L/P-G5-16/1450 |
| COOL WHITE DELUXE | 840 | 3650 | 3320 | 1B | 4000 | A | FDH-35/40/L/P-G5-16/1450 |
| DAYLIGHT DELUXE | 865 | 3400 | 3095 | 1B | 6500 | A | FDH-35/65/L/P-G5-16/1450 |

**Fig. 6.1:**

Extracted table from SYLVANIA Data Sheet 51P-5689C showing luminous flux at 35°C and 25°C

The table value for a colour 840 lamp with an ambient temperature of 35°C is 3650 lumens. Likewise for 25°C this value is reduced to 3320 lumens. The result is that a design calculation is reduced by -9% in practice. This result is typical in many practical situations where open luminaires are used. Also when T5 lamps are used in enclosed luminaires with very low ambient temperatures, such as cold stores. This situation is made worse if the operating times are relatively short, which will not allow the ambient temperature surrounding the lamp to warm up.

**d. Voltage Fluctuation**

A linear T5 fluorescent lamp such as the one detailed in the previous paragraph operates on a high frequency electronic ballast. As technology has advanced over recent years the electronic circuitry in the majority of modern units compensates for variations in supply voltage, thereby ensuring a constant light output from the lamp. This is illustrated in Fig. 7.1 below, which shows lamp power versus input voltage for 4x14W T5 electronic ballasts from various manufacturers.

However, if a T8 triphosphor fluorescent lamp is used on a switch start circuit with an electromagnetic ballast, then the light output will be affected by variations in mains input voltage.

The allowed variance in mains voltage in the UK is governed by Statutory Instrument 2002 No. 2665, and is known as "The Electricity Safety, Quality and Continuity Regulations 2002"[16]. This declares the mains voltage in the UK to be 230V. From 1st January 2004 the mains supply should be 230V (-6%, +10%), 50Hz (±1%); i.e. a range of 216.2 – 253V. This replaces the UK's former specification which was 240V (±6%); i.e. a range of 225.6 – 254.4V.

Therefore, if we look at Fig. 7.2, the top curve represents a colour 840 lamp. The rated lumen output at 240V is 5200 lumens. The lumen output at 216.2V is 4800 lumens, and at 253V is 5710 lumens. This represents a light output variance of -7.7% to +9.8%.

However, as wirewound ballast circuits are becoming much less common in the UK, and the fact that we have assumed the use of popular modern T5 technology throughout the rest of the report, it would be totally inaccurate to include these variances in the summary. Therefore, the variance for HF electronic circuits of ±0% must be used instead.

It must be borne in mind that if a calculation was being made using T8 lamps with wirewound ballasts then the variance calculated above would indeed affect the accuracy of results.

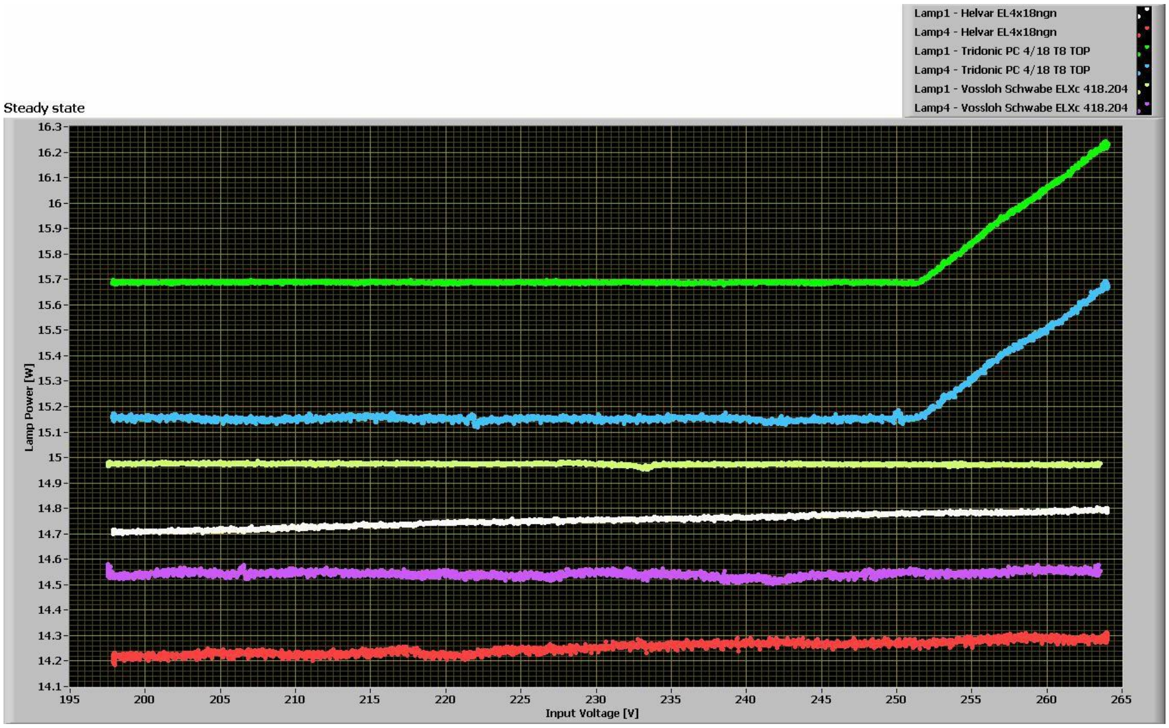



**Fig. 7.1:**

Graph showing lamp power for 4x14W T5 fluorescent tubes at varying input voltage, for various control gear manufacturers

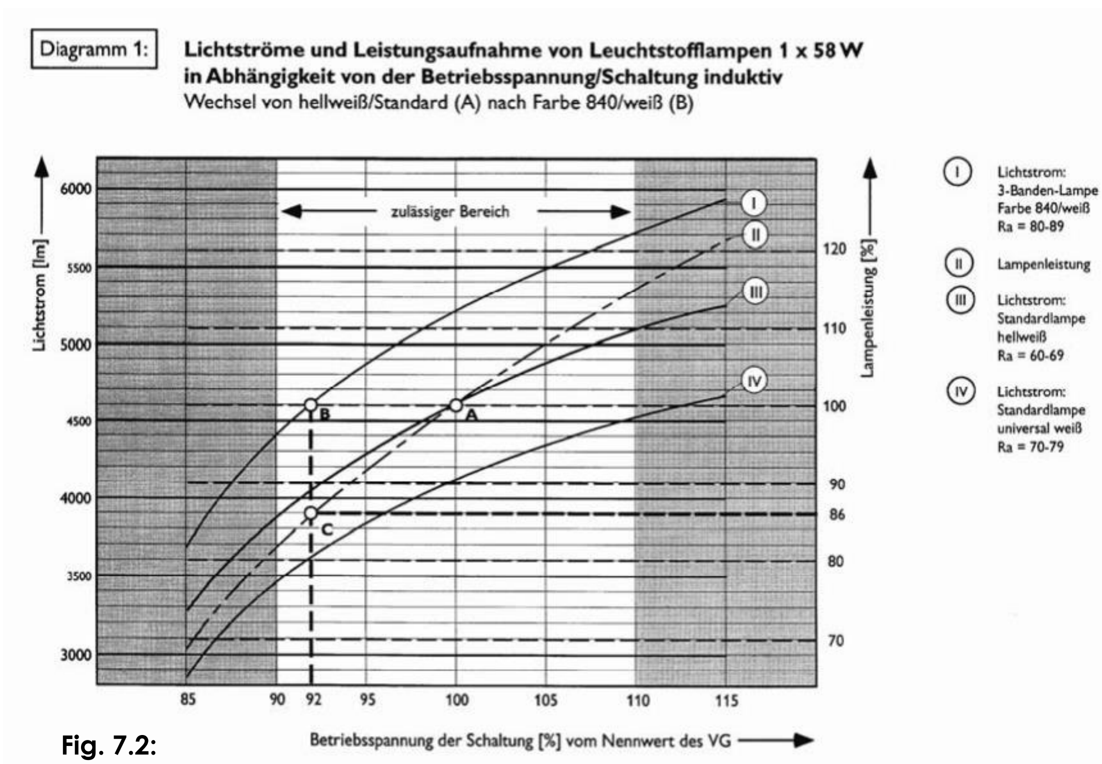



**Fig. 7.2:**

Graph showing lumen output at varying input voltage for various types of Sylvania T8 fluorescent tubes on wirewound ballasts

**e. Light Meter Accuracy**

When a lighting design has been installed it can be checked for conformity by the use of a portable light meter. As with any measuring apparatus the meter itself has an inbuilt inaccuracy due to many reasons, two of which are the quality of components and quality of construction.

Therefore, as one would expect, the accuracy of those meters at the cheaper end of the marketplace tends to be lower. Generally speaking, they will have a quoted accuracy of ±5%. It therefore follows that as the meters become more expensive the accuracy increases. These higher cost units will generally have a certified accuracy of ±3%.

To illustrate this point Fig. 8.1 below shows an extract from an on-line catalogue from Radio Spares Electronics. It can be seen that the 5% variance is evident on the cheaper meters, but improves as they become more expensive.

| RS Stock No. | Description | Order Quantity | Priced As | Availability | Range Type | Data Sheet | RoHS Status | Manufacturer | Manufacturers Part No. | Minimum Light Level | Maximum Light Level | Resolution | Sensor Type | Accuracy |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 506-9644 | ISO-TECH 1332 digital Light Meter | 1 Add to order | Each 1+ £61.80 | Check live availability | Stocked range | | | ISO-TECH | | 20lux | 200000lux | 0.1 Lux | - | ±3% ±0.5% for <10000lux ±4% ±10 Digits for >10000lux |
| 292-363 | Testo 540 Light Meter | 1 Add to order | Each 1+ £93.00 | Check live availability | Stocked range | | | Testo | 0560 0540 | - | - | 1 Lux (0 to 19,999 Lux); 10 Lux (20,000 to 99,999 Lux) | - | - |
| 327-6402 | RS-232 cable for testo 545 light meter | 1 Add to order | Each 1+ £29.70 | Check live availability | Stocked range | | | Testo | 0409 0178 | - | - | - | - | - |
| 439-1108 | Spare sensor for lux meter | 1 Add to order | Each 1+ £23.50 | Check live availability | Stocked range | | | Lutron | PROBE FOR 180-7133 (LX-105) | - | - | - | - | - |
| 459-7788 | ISO-TECH 1337 light meter LCD display | 1 Add to order | Each 1+ £79.00 | Check live availability | Stocked range | | | ISO-TECH | | 0 | 20000lux | 0.01 Lux | Silicon Photodiode | ±3% ±5 Digits |
| 442-0357 | ISO-TECH 1335 light meter with bar graph | 1 Add to order | Each 1+ £92.00 | Check live availability | Stocked range | | | ISO-TECH | | 0 | 400000lux | 0.01 Lux | Silicon Photodiode | ±3% ±5 Digits |
| 540-8207 | ISO-TECH RS-01 light meter | 1 Add to order | Each 1+ £81.00 | Check live availability | Stocked range | | | ISO-TECH | | 50lux | 50000lux | 0.01 Lux | Silicon Photodiode | ±3% |
| 180-7133 | Lux meter with light type selection | 1 Add to order | Each 1+£112.00 | Check live availability | Stocked range | | | RS | | 0 | 50000lux | 1; 10; 100 Lux | Photo Diode, Correction Filter | ±4% +2 Digits |
| 330-6963 | Testo 545 handheld digital light meter | 1 Add to order | Each 1+£258.75 | Check live availability | Stocked range | | | Testo | 0560.0545 | 0 | 100000lux | 1; 10 Lux | Silicon Photodiode | 8%, 5% |
| 331-7389 | Comsoft 3 Professional Software | 1 Add to order | Each 1+£215.00 | Check live availability | Stocked range | | | Testo | 0554 0830 | - | - | - | - | - |

You are seeing 1 - 10 of 10 results.



**Fig. 8.1:**

Extract from web page of Radio Spares showing attributes of various light meters, dated 6th June 2009

It should be assumed that when an installation is being checked on-site by a consulting engineer, architect, or some other professional person, a higher quality light meter is being used, therefore the lower variance of ±3% will be accepted as being the norm for the purposes of this report.

**f. Lamp Lumen Output**

All lamps are complicated items and none more so than modern T5 fluorescent tubes. They are manufactured using automated machinery within very small tolerances, yet no two lamps are identical.

When a lamp is first developed it is given a lumen output which it is expected to give out in the majority of production items. However, even with modern accurate machinery and chemical dosage, tolerances are such that the lumen output of individual lamps will vary plus or minus the rated value.

The standard for performance specifications of double-capped fluorescent lamps is BSEN 60081. In the section relating to photometric characteristics it states that "The initial reading of the luminous flux of a lamp shall be not less than 92% of the rated value".[17] This means that production lamps can have an actual lumen output 8% less that that stated in the data sheet, and indeed that value included in a photometric file using that particular lamp. The term 'Initial Reading' as explained in the above document, is the value measured at the end of the 100 hour ageing period.

Therefore, it is possible that the scheme we have been using throughout this report, with a system of 35W T5 840 linear fluorescent lamps, could yield only 460 lux when calculating for 500 lux just from this variance alone. In addition, the Standard above also states that "The lumen maintenance of a lamp shall be not less than 92% of the rated lumen maintenance value at any time in it's life". [18] This means that an additional variance can occur during calculation of the Maintenance Factor described on page 19. However, if the table as illustrated from the CIBSE Code for Lighting is used, the Lamp Lumen Maintenance Factor (LLMF) is obtained by a rational value, so if the variance is used in this section it need not be changed in the other. That would give a false variance value which is not what is wanted.

**g. Fixture Photometric Measurement**

When photometric tests are carried out on fixtures/luminaires, they are tested in accordance with BS 5225 Part 1:1975 and BSEN 13032 Part 1:2004.

There are numerous variances and anomalies which can occur during a photometric test. If we assume that the tests are carried out by a competant and registered laboratory in accordance with the above standards, then it is only normal variances which need be considered. Laboratory conditions such as stabilised power supply, temperature and humidity control, photocell and associated apparatus calibration, and stray light control will all have been looked at in depth. However, there will be variances associated with the linearity and spectral response of the photometer. The accuracy of the photocell to a given illuminance should not deviate significantly over the working range of angles of incidence. The measured value should only vary with the cosine of the incidence angle. Any error shall not exceed 1% at incidence angles between $0^{\circ}$ and $20^{\circ}$ to the normal, or 5% at any other angle.[19] In addition, the spectral sensitivity of the photocell should resemble the CIE photopic luminous efficiency function, known as the $V(\lambda)$ curve.[20] The difference between corresponding ordinates at any wavelength from 400nm to 680nm shall not exceed 5% of the normalised ordinate at 555nm, which is the peak of the photopic curve. This can especially occur when the components of a light fixture such as a lens or filter change the spectral distribution of the light source.

These accepted variances in the accuracy of a photometer reading, when combined, relate to an overall possible variance of ±9.75%. Although it is unlikely that this extreme condition would occur, it must nevertheless be taken into consideration when assessing computerised design results.

## Conclusion

The purpose of this report from the outset was to look at all the possible variables which could affect the accuracy of the results from computerised lighting design. The primary variables which are due directly to the input of assumptions made by the designer, together with secondary variables which are due to inconsistancies outside the designer's control, form a variance band in which the true result lies. The diagram below in Fig. 11.1 illustrates this variance band, and will show the results once the values have been added.

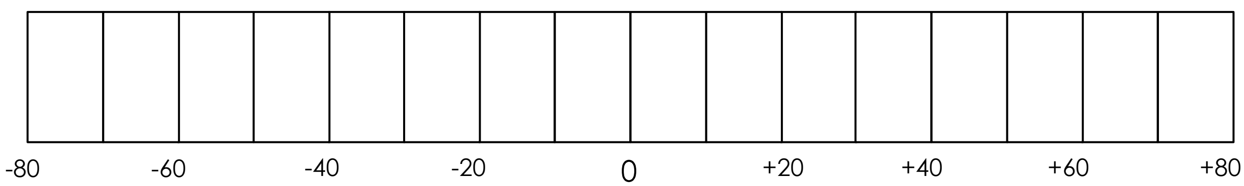



**Fig. 11.1:**

Diagram to show the possible variance from a True Result Norm (0) as a percentage

The resultant variances from the report are as follows:

| Variable | Negative Variance | Positive Variance |
|---|---|---|
| Reflectance Values | 0% | 23.6% |
| Obstructions to Working Plane | 7.9% | 0% |
| Maintenance Factor | 10% | 0% |
| Linear Source Calculations | 6.4% | 0% |
| Mathematical Engine Accuracy | 2.35% | 2.35% |
| Lamp Temperature | 9% | 0% |
| Voltage Fluctuation | 0% | 0% |
| Light Meter Accuracy | 3% | 3% |
| Lamp Lumen Output | 8% | 0% |
| Fixture Photometric Measurement | 9.75% | 9.75% |

From the variance table above we can calculate a total negative variance as follows:

$$V_{TN} = 1-((1-0.079)\text{x}(1-0.1)\text{x}(1-0.064)\text{x}(1-0.0235)\text{x}(1-0.09)\text{x}(1-0.03)\text{x}(1-0.08)\text{x}(1-0.0975))$$

$$\therefore V_{TN} = 1-(0.921 \text{ x } 0.9 \text{ x } 0.936 \text{ x } 0.9765 \text{ x } 0.91 \text{ x } 0.97 \text{ x } 0.92 \text{ x } 0.9025)$$

$$V_{TN} = 1 - 0.555$$

$$V_{TN} = 0.445 = 44.5\%$$

Likewise, a similar calculation for total positive variance is carried out as follows:

$$V_{TP} = 1-((1-0.236)\text{x}(1-0.0235)\text{x}(1-0.03)\text{x}(1-0.0975))$$

$$\therefore V_{TP} = 1-(0.764 \text{ x } 0.9765 \text{ x } 0.97 \text{ x } 0.9025)$$

$$V_{TP} = 1 - 0.653$$

$$V_{TP} = 0.347 = 34.7\%$$

These values can then be shown graphically on the variance diagram:

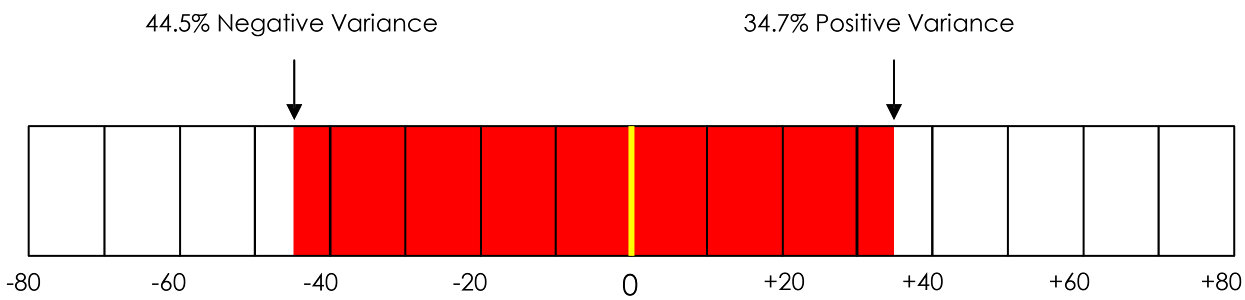



**Fig. 11.2:**

Diagram to show the resultant negative and positive variances from a True Result Norm (0) as a percentage

It is now important to realise the implications of the results. On the variance diagram in Fig. 11.2 above, the true average horizontal illuminance value will fall somewhere within the red shading.

This means that if a normal rectangular office is calculated and designed to an average level of 500 lux, and the array of luminaires is then installed, the resultant room once occupied will show a reading on a light meter which lies somewhere between 277 lux and 673 lux. Unfortunately, these figures make a mockery of illuminating engineering from a scientific or mathematical perspective, yet prove beyond doubt that lighting is not a precise science. Suffice it to say that any method of lighting calculation, whether it be by hand using the Lumen Method or by the use of sophisticated computerised design software, is not to be treated as finitely accurate. The results are at best only an indication of what a room will look like, and should not be relied upon per se.

This having been said, a qualified and competent lighting design engineer will evaluate the possibilities of error during the design process, input information as accurately as he or she can, and try to err on the positive side when possible. In this vein it is imperative that a disclaimer should be included with any calculations to explain that inaccuracies can and will occur.

Therefore, as mentioned in the introduction to this report, it appears that my tutor back in 1979 was totally correct in stating "If the measured results of a lighting design are within 20% of the calculated value then you have done well".

**Evaluation & Reflection**

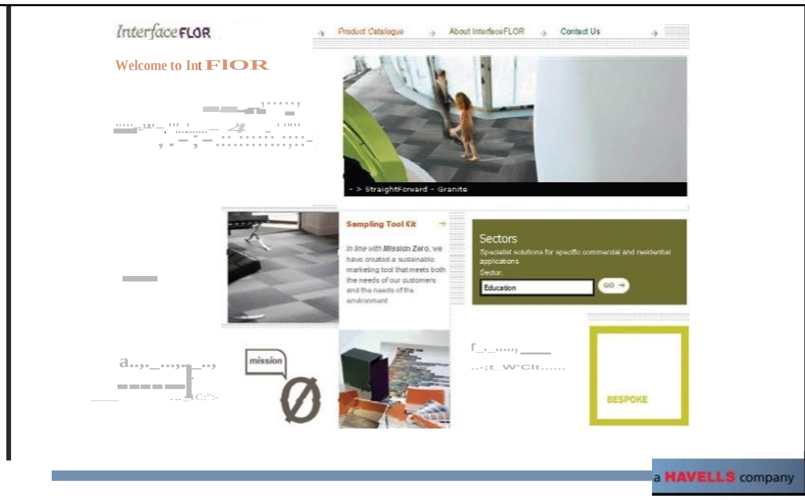
The report has covered I believe every aspect of computerised lighting design where a possible variance exists. One area which has not been investigated is the possibility of error within the program mathematics due to mistakes. This would have to be checked with a programmer working on the software, as it is not possible to check on the outside of the program. Generally speaking, the report has not considered mistakes at all, as these cannot be within the bounds of this report.

Whilst the results and conclusions have been stated, it would be reasonable to stand back and question whether the results from a recent design are that far out. The answer most certainly will be 'No'. The report has looked at possible errors, and linked the maximum errors down a certain path. In practice, the chances of high variances occurring on top of each other (or even at the same time) are very small.

Yes, it is possible that each variance is present to some degree, but only in smaller amounts. For example, I can understand a photometer having a variance of 1%, and indeed a lamp output being down by 1%, but not much more with modern technology. Having worked closely with lamp engineers in a modern lamp factory laboratory, and having seen photometric test results from batches over a 12 month period it is amazing how consistently accurate the lumen outputs from actual lamps are. Therefore, it is my opinion that those parameters covered by 'Secondary Variables' in practice may jointly account for a variance of ±5%. It is the variances from 'Primary Variables', those caused by user input, which will be the major cause of any discrepancies in expected results. The design process as described in the CIBSE/SLL Code of Practice should therefore be followed to the letter to try and minimise any variance. Ask questions about surface finishes, about ceiling types, carpet manufacturers, obstructions to the working plane, and accurate cleaning cycles so that your parameters are as near to reality as is practical.

With the best will in the world and accurate information, I would expect my designs to be accurate to ±10%. Therefore, if a specification requires an average maintained horizontal illuminance of 200 lux minimum, then a designed value of 220 – 230 lux is what I would aim for. There is no substitute for following a well tried design process, using tried mathematical models, and being as conscientious as possible. To enable any lighting engineer to do this it is important that they consider going "Back to Basics".

Appendix A




The conversation was very interesting, and he advised me that the most popular plain carpet tile for offices is their Palette 2000 range. Unfortunately there are 80 different colours in the range making for a very varied choice. I asked him if he had reflectance values for these 80 tiles and yes they had just completed their spectrometric testing. So, lets have a look at what we get for our 20% reflectance!

O NEXT SHEET


Here we have 4 commonly used carpet tile colours. Can anyone tell me which is the tile with a reflectance of 20%?

0 CLICK

0 CLICK

0 CLICK

0 CLICK

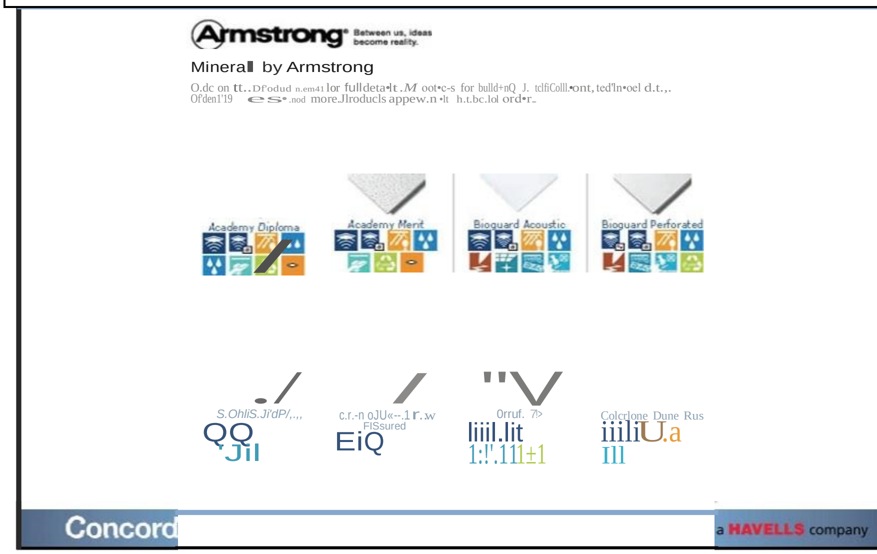
Those are the values which I find totally amazing. My conclusion from this research is that we as lighting engineers should be looking at more realistic parameters to apply to our designs. We should quite reasonably be able to use 30 to 40% floor reflectances and be fully justified.

But lets look just a little deeper at our typical office scenario.

0 NEXT SHEET


From the opening page on the website we need to look at the most popular ceiling. A mineral tile in a suspended 24mm grid.

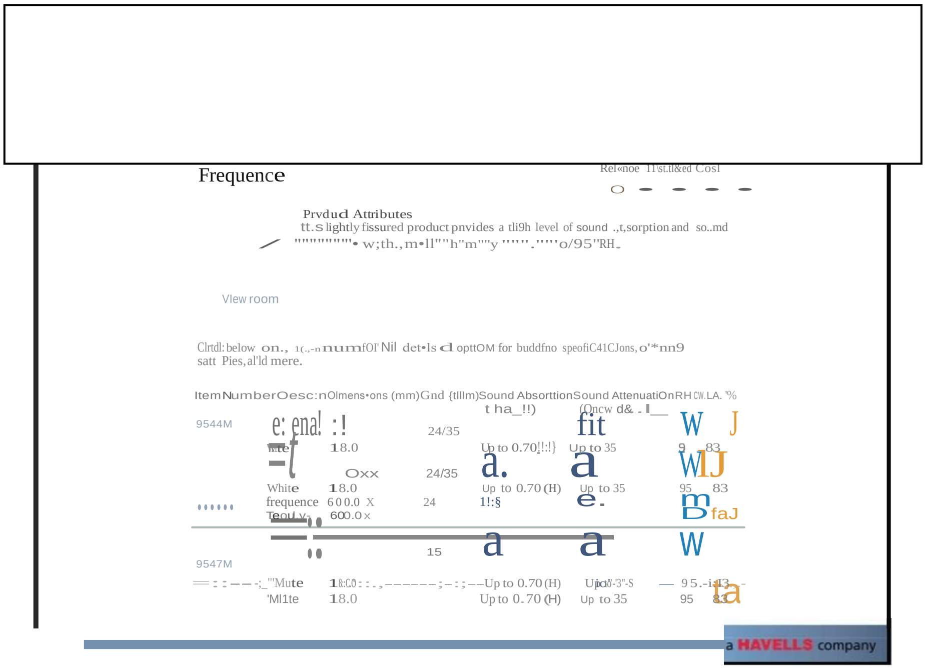
O CLICK




We now see the different ranges available. The most common type for offices is a range called "Frequency".

So lets have a look at that page.

O CLICK

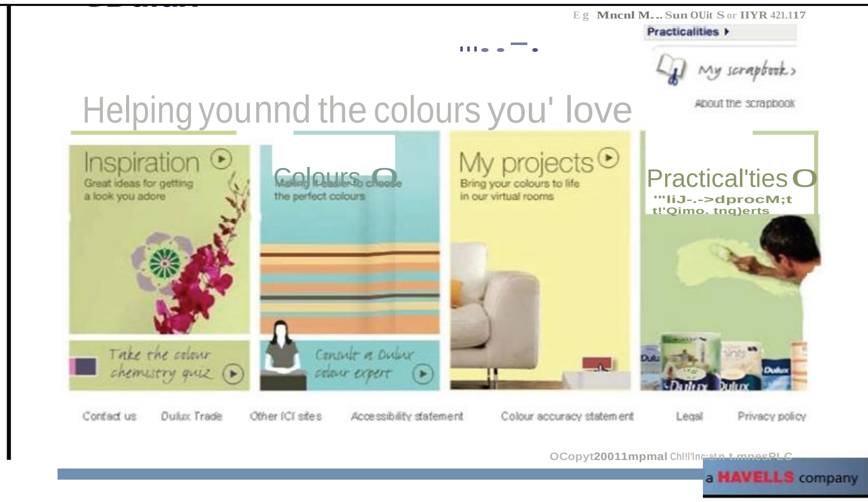



You can see that there are 4 types of Frequence tile, with different shapes or sizes, but it is the finish that we are interested in, and they all have a reflectance of 83%.

Therefore. we have justification in using 80% ceiling reflectance for a practical design scenario.

Next item to look at then is paint for the walls, as most new builds have an emulsion finish. Dulux is the market leader here. so lets visit their website.

O CLICK




Unfortunately, I was unable to get the information I wanted from their website, and had to resort to sending them an email.

I asked for the light reflection value for "Matt Emulsion Magnolia".

I got an email back very quickly as follows:

O CLICK


SYLVANIA

DULUX PAINTS

[redacted]
Sett by traq_ttley@ra..com
22105120071201

To dwtd holmes@ooncorctNrtm.com

Sl.b11tt Ra: FromN tel P41lfilt'W'•bt

Mr Holmes

Thank you for your e-mail enquiry.

The IR\1fa da:ss1crange MC Jnohis 78

Tncy Utir-1
CWU.tt AcM-(Ouh.a Trade)
Techo.eal AdmceCentre.
ICIPUUs.
Wnh.ua Rotd.
SII}DS,
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a HAVELLS company

So there we have it, a reflectance factor of 78%. A big difference to the 50% we have always been used to!

So lets go back to our table.

O CLICK

Enter the name of the room, select L-shaped room and afterwards define the orientation.

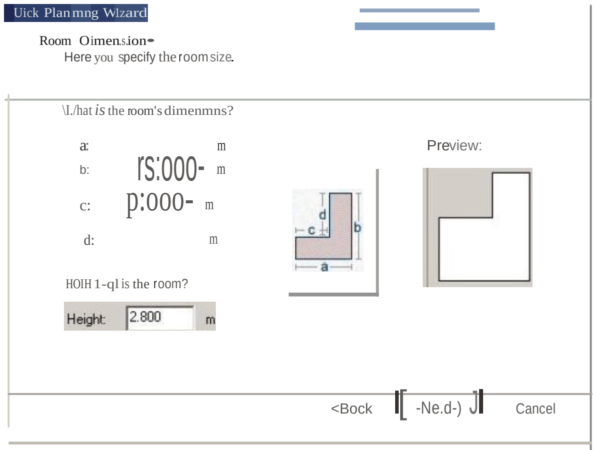



Fig 20 Working with Wizards – Room Dimensions

Specify the *Room's Dimension* and the *Room Height.* Which wall symbolizes each letter a to d is displayed on the drawing.

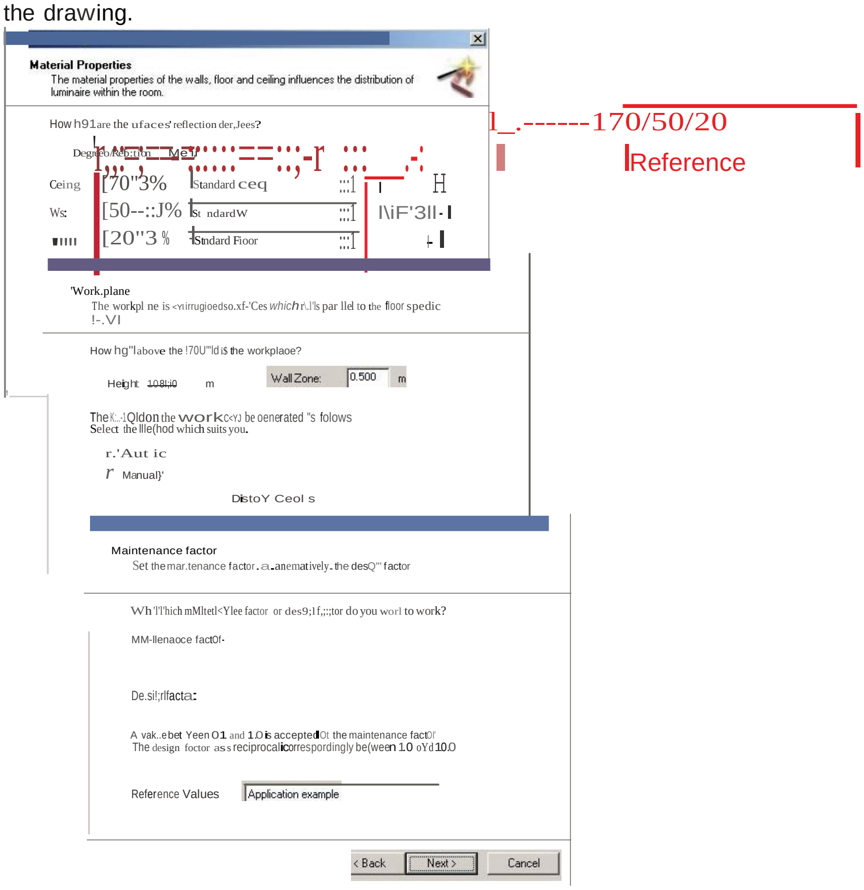


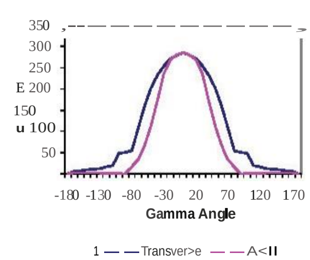

Fig 21 Working with Wizards – Reflection, Work plane, Maintenance Factor

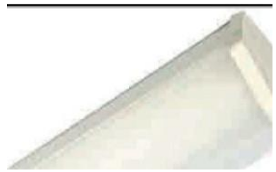
# Syi-Line

2 x 35W version

## Description:

Slim surface mounted T5 luminaire with prismatic controller, HF electronic gear.



Dimensions (Inmm):

Physical Length – 1540
**Luminous Length – 1500**

D

Physical Height – 82
**Luminous Height – 51**

Physical Width – 215
**Luminous Width – 215**

| Conversion Terms: | Lamp | UF&PC |
|---|---|---|
| 9141561 | 2 x 35W T5 linear Fluo | 1.00 |

## Utilisation Factors - UF(F)

Floor Reflectance - 20%   SHR NOM= 1.50

| Reflectances C | W | F | Room Index 0.75 | 1.00 | 1.25 | 1.50 | 2.00 | 2.50 | 3.00 | 4.00 | 5.00 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 0.70 | 0.50 | 0.20 | 0.51 | 0.58 | 0.64 | 0.69 | 0.75 | 0.79 | 0.81 | 0.85 | 0.88 |
| | 0.30 | | 0.45 | 0.52 | 0.58 | 0.63 | 0.69 | 0.74 | 077 | 0.81 | 0.84 |
| | 0.10 | | 040 | 0.47 | 054 | 058 | 065 | 0.70 | 073 | 078 | 0.82 |
| 050 | 0.50 | 0.20 | 0.49 | 0.56 | 0.61 | 0.65 | 0.71 | 0.74 | 077 | 0.80 | 0.82 |
| | 0.30 | | 0.44 | 0.50 | 0.56 | 0.60 | 0.66 | 0.70 | 073 | 077 | 0.80 |
| | 0.10 | | 040 | 0.46 | 0.52 | 056 | 063 | 067 | 0.70 | 075 | 0.77 |
| 030 | 0.50 | 0.20 | 0.47 | 0.53 | 058 | 0.62 | 067 | 0.70 | 0.72 | 0.75 | 0.78 |
| | 0.30 | | 0.42 | 0.48 | 0.54 | 0.58 | 0.63 | 0.67 | 0.70 | 0.73 | 0.76 |
| | 0.10 | | 0.39 | 0.45 | 0.50 | 054 | 060 | 064 | 067 | 071 | 0.74 |
| 0.00 | 0.00 | 0.00 | 0.36 | 0.42 | 047 | 051 | 0.56 | 0.59 | 0.62 | 065 | 0.68 |
| BZ Class | | | 4 | 4 | 4 | 4 | 4 | 4 | 5 | 5 | 5 |
| OF(F) | | | 036 | 0.42 | 0.47 | 0.51 | 0.56 | 0.59 | 0.62 | 0.65 | 0.68 |
| DF(W) | | | 0.43 | 0.38 | 0.33 | 0.29 | 0.24 | 0.20 | 0.18 | 0.14 | 0.12 |
| OF(C) | | | 0.08 | 0.08 | 0.08 | 0.08 | 0.08 | 0.08 | 0.08 | 0.08 | 0.08 |
| OF(V) *Cylindrical* | | | 0.06 | 0.08 | 0.10 | 0.12 | 0.15 | 0.17 | 0.18 | 0.21 | 0.23 |
| DF(S) *Scalar* | | | 0.10 | 0.12 | 0.15 | 0.16 | 0.19 | 0.21 | 0.22 | 0.25 | 0.26 |

Flux Fraction Ratio = 0.11
SHRMAX 1.63
SHR MAX(TR) 1.97

CIE Flux Code = 48 78 1 93 90 88
Light Output Ratio 0.88
Downward LOR 0.79

## Luminous Intensity Values- (cd/1000 lm)

| Gamma Angle (degrees) | Transverse Plane (00) | Axial Plane (90°) |
|---|---|---|
| | 286 | 286 |
| | 284 | 284 |
| 10 | 279 | 280 |
| 15 | 276 | 276 |
| 20 | 271 | 269 |
| 25 | 254 | 246 |
| 30 | 254 | 235 |
| 35 | 246 | 209 |
| 40 | 233 | 174 |
| 45 | 220 | 141 |
| 50 | 202 | 112 |
| 55 | 172 | 88 |
| 60 | 161 | 68 |
| 65 | 139 | 48 |
| 70 | 110 | 34 |
| 75 | 79 | 25 |
| 80 | 54 | 16 |
| 85 | 50 | 6 |
| 90 | 51 | 0 |
| 95 | 56 | |
| 100 | 48 | |
| 105 | 36 | |
| 110 | 19 | |
| 115 | 16 | |
| 120 | 17 | 2 |
| 125 | 14 | 2 |
| 130 | 12 | 2 |
| 135 | 12 | 2 |
| 140 | 11 | 2 |
| 145 | 10 | 3 |
| 150 | 10 | 3 |
| 155 | 9 | 3 |
| 160 | 8 | 3 |
| 165 | 7 | 3 |
| 170 | 7 | 3 |
| 175 | 6 | 3 |
| 180 | 0 | 0 |

## Aspect Factors

| Angle (degrees) | Parallel Plane | Perpendicular Plane |
|---|---|---|
| | 0.000 | 0.000 |
| | 0.087 | 0.004 |
| 10 | 0.172 | 0.015 |
| 15 | 0.255 | 0.033 |
| 20 | 0.335 | 0.058 |
| 25 | 0.407 | 0.089 |
| 30 | 0.472 | 0.123 |
| 35 | 0.529 | 0.159 |
| 40 | 0.576 | 0.195 |
| 45 | 0.611 | 0.227 |
| 50 | 0.637 | 0.256 |
| 55 | 0.656 | 0.280 |
| 60 | 0.669 | 0.300 |
| 65 | 0.677 | 0.316 |
| 70 | 0.682 | 0.327 |
| 75 | 0.684 | 0.336 |
| 80 | 0.686 | 0.342 |
| 85 | 0.686 | 0.345 |
| 90 | 0.686 | 0.346 |

## Luminance Distribution (cd/11¥/klm)

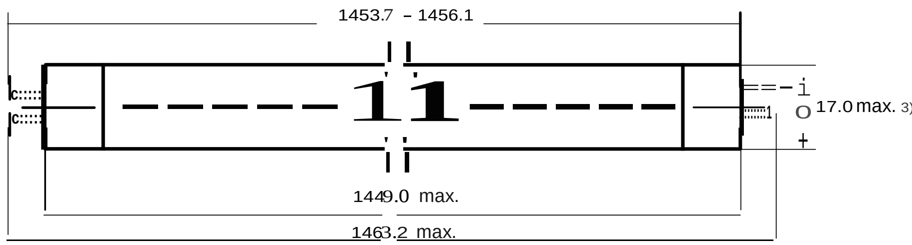
| Angle (degrees) | Transverse Plane | Axial Plane |
|---|---|---|
| 45 | 780 | 598 |
| 50 | 760 | 519 |
| 55 | 695 | 454 |
| 60 | 708 | 398 |
| 65 | 676 | 328 |
| 70 | 604 | 282 |
| 75 | 502 | 266 |
| 80 | 411 | 240 |
| 85 | 479 | 164 |

The Utilisatim Factor table, BZ values, and Distributim Factors (F) (W) & (C) have been calculated in accordance >Mth CIBSE Technical Memorandum No.5 (1980) from data tested >Mthout a ceiling board. The UF values need to be corrected using the appropriate conversion factor. The Distributim Factcrs for c indrical and scalar illuminance have been calculated using data provided by Dr. A. R.Bean.



Photometric Data Sheet Reference: CMD-9141561

DIMENSIONS lmm> : Nominal dimensions: 1450 x 16




Cap: G5 ( IEC 61-1 sheet 7004-52-5)

3) The maximum measure for the diameter includes out of round ofthe bulb and eccentricity versus the lamp axis.

| ELECTRICAL DATA | | NOMINAL VALUE | MIN. | MAX. |
|---|---|---|---|---|
| Frequency | (kHz) | | 20 | 26 |
| Lamp nominal wattage | rtf) | 35 | | |
| Lamp rated wattage | rtf) | 35.5 | | |
| Lamp operating voltage | M | 205.0 | 185.0 | 225.0 |
| Lampe current | (rnA) | 175 | | |
| CATHODE CHARACTERISTICS | | | | |
| Test current | (rnA) | 160 | | |
| Resistance of each cathode | (Q) | 40 | 30 | 50 |

| OPERATING CONDITIONS | | NOMINAL VALUE | MIN. | MAX. |
|---|---|---|---|---|
| Ballast type | | electronic | | |
| Cap rim temperature | (oC) | | | 120 |
| Lamp ambient temperature | (oC) | | -15 | 50 |
| Burning position | | horizontal or vertical, stamped side down | | |
| LAMP LIFE* | | | | |
| Average life (50% failure) | (h) | | 24000 | |
| Minimum individual life | (h) | | 14 000 | |

| | | | |
|---|---|---|---|
| Issued by | SLI LIchtsysteme | DATA SHEET | Specification No.: 51P-5689 C |
| Date | 04.05.1999 | | Supersedes : 51P-5689B 21.11.04 |
| Revision Date | 14.02.2007 | | Page 1 of 2 |

*SLI reserves the right to change data and specifications without notice.*
*Data for guidance only.*

PHOTOMETRIC DATA:

| COLOUR | No. | **Luminous** Flux **maximum 2)** (34.38°C) (1m) | Luminous Flux **nominal value** 1) (25 °C) (lm) | CAI (Group) | **Colour** temp. (K) | Energy **Emciency** Class | ILCOS-Code |
|---|---|---|---|---|---|---|---|
| **LUXLINE plus COLOURS** | | | | | | | |
| HOMELIGHT DELUXE | 827 | 3650 | 3320 | 18 | 2700 | A | FDH-35127/LIP-G5-16/1450 |
| WARM WHITE DELUXE | 830 | 3650 | 3320 | 18 | 3000 | A | FDH-35/30/LIP-G5-16/1450 |
| WHITE DELUXE | 835 | 3650 | 3320 | 18 | 3500 | A | FDH-35/35/LIP-G5-16/1450 |
| OOOL WHITE DELUXE | 840 | 3650 | 3320 | 18 | 4000 | A | FDH-35/40/LIP-G5-16/1450 |
| DAYLIGHT DELUXE | 865 | 3400 | 3095 | 18 | 6500 | A | FDH-35/65/LIP-G5-1611450 |

ATTENTION· Lamps comply with the requirements of IEC/EN 60081 and IEC/EN 61195. respectively.
The electronic ballast for lamp operation must comply with IECJEN 60929.
• Life test according to IECJEN 60081. Annex C. life-time under evaluation.

1) **Measured after 100h at 413V, with a frequenzy of 20-26kHz, constant current and a resistance of 1200C as reference** ballast at 25°C.

2) **The maximum luminous nux under optimal conditions (34...38°C) Is calculated by the luminous nux at 25°C at reference conditions and a factor F=0.91 (maximum luminous flux = nominal luminous flux / F).**

| Issued by : SLI Lichtsysteme<br>Date 04.05.1999<br>Revision Date : 14.02.2007 | **DATA SHEET** | Specification No. : 51P-5689C<br>Supersedes : 51P-5689B 21.11.04<br>Page 2 of 2 |
|---|---|---|

## References


1. Henderson, S.T., & Marsden, A.M., 1972. *Lamps and Lighting.* 2nd ed. London: Edward Arnold (Publishers) Ltd. p. 405
2. Henderson, S.T., & Marsden, A.M., 1972. *Lamps and Lighting.* 2nd ed. London: Edward Arnold (Publishers) Ltd. p. 406
3. Henderson, S.T., & Marsden, A.M., 1972. *Lamps and Lighting.* 2nd ed. London: Edward Arnold (Publishers) Ltd. p. 407
4. Bean, A.R., & Simons, R.H., 2001. *Lighting Engineering: Applied Calculations.* Oxford: Butterworth Heinemann. p. 190
5. Society of Light & Lighting, 2002. *Code for Lighting*. Oxford: Butterworth Heinemann. Section 2.4.3.
6. International Standards Office, 2008. *EN12464-1:2008 Light and Lighting: Lighting of Indoor Work Places,* Brussels: ISO. Section 4.2.
7. DIAL GmbH., 2009. *DIALux User Manual Version 4.7: The Software Standard for Calculating Lighting Layouts.* Ludenscheid, Germany: DIAL GmbH. Fig21, p. 27.
8. European Standard, 2008. *EN12464-1:2008 Light and Lighting: Lighting of Indoor Work Places,* Brussels: ISO. Section 4.9.
9. Society of Light & Lighting, 2002. *Code for Lighting*. Oxford: Butterworth Heinemann. Table 3.4. p. 87.
10. Society of Light & Lighting, 2002. *Code for Lighting*. Oxford: Butterworth Heinemann. Table 3.5. p. 88.
11. Society of Light & Lighting, 2002. *Code for Lighting*. Oxford: Butterworth Heinemann. Table 3.7. p. 89.
12. Bean, A.R., & Simons, R.H., 1968. *Lighting Fittings: Performance and Design.* Oxford: Pergamon Press Ltd. p. 2.
13. Society of Light & Lighting, 2006. [CD Version] *Code for Lighting*. Oxford: Butterworth Heinemann. Section: Formulae for Line Source Calculations.
14. CIBSE Technical Memorandum No. 5, 1980. *Calculation of Utilisation Factors.* London: CIBSE Publications.

15. Henderson, S.T., & Marsden, A.M., 1972. *Lamps and Lighting.* 2nd ed. London: Edward Arnold (Publishers) Ltd. pp. 226-227.

16. *The Electricity Safety, Quality and Continuity Regulations 2002.* SI 2002/2665, London: HMSO.

17. British Standards Institution, 2003. *BSEN 60081:2003 Double-capped Fluorescent Lamps – Performance Specifications.* Milton Keynes: BSI. Section 1.5.6. p. 8.

18. British Standards Institution, 2003. *BSEN 60081:2003 Double-capped Fluorescent Lamps – Performance Specifications.* Milton Keynes: BSI. Section 1.5.7. p. 8.

19. British Standards Institution, 1975. *BS 5225:Part 1:1975 Specification for Photometric Data for Luminaires.* Milton Keynes: BSI. Section 14(f). p. 9.

20. British Standards Institution, 1975. *BS 5225:Part 1:1975 Specification for Photometric Data for Luminaires.* Milton Keynes: BSI. Section 14(e). p. 9.

21. CIBSE Technical Memorandum No. 28, 2000. *Benchmarking Lighting Design Software*. London: CIBSE Publications.