CHARTERED INSTITUTION OF BUILDING SERVICES ENGINEERS

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Working Plane Illuminance In Electrically Lit Spaces

1.0 Introduction

This paper offers practical guidance on the measurement of working plane illuminance. This criterion is given prominence in the CIBSE *Interior Lighting Code* 1994 and in other statutory and institutional recommendations and for this reason assumes importance for designers as the major form of installation appraisal. The range of information to be obtained from an installation is described. In addition guidance on the collection and recording of illuminance measurements is given including the use of standard pro-formas. Finally methods of analysis of the measurements are discussed. Many other aspects of lighting appraisal are not covered here including luminance and vertical illuminance.

2.0 Why Surveys Are Carried Out

The contractual conditions associated with the design of artificial lighting systems have focused attention on assessment of their performance. Often designers, their clients or potential tenants of a space, wish to check the accuracy of the calculated lighting level against that actually available in the space. In addition the duty of care imposed on employers, and others, means that the lighting conditions of the workplace must meet minimum standards. A failure to provide the minimum standard can have serious implications for the employer.

Where existing installations are appraised it is important to obtain accurate information concerning the age and maintenance of the installation. Although empty interiors are relatively straightforward, furnished interiors are likely to influence the position at which illuminance measurements can be taken. There may also be shadows on the plane where illuminance measurements are taken. The recent adoption of the maintained illuminance approach to lighting design has altered the earlier UK definition of Maintenance Factor. This change means that the average illuminance on the working plane before maintenance is to be carried out is greater than the maintained illuminance specified by the designer. The measurement of working plane illuminance can be used to assess whether installation performance meets specification. The average measured illuminance should never be lower than the average maintained illuminance.

3.0 Preparation For The Survey

It is important to plan in advance all aspects of the survey. This involves liaison with the client or occupier of the space to ensure access, often in the evening, and to ensure that thermal conditions in the test area are stable; checking of measuring equipment and preparation of means of recording the survey.

3.1 llluminance meters to BS 667:1985

There is a wide range of illuminance measurement equipment available for use in lighting surveys. Equipment can be purchased from a reputable company or may be hired for the period of the lighting survey. Light measuring equipment should be regularly calibrated, typically once a year. When the meter is used extensively, or the consequences of the results are critical, 6 monthly calibration is advised. When the meter has been dropped or subjected to extremes of heat or cold it is advisable to re-calibrate. All equipment should be regularly cleaned and batteries checked. Spare batteries should always be taken when carrying out a lighting survey.

There are two types of meter defined in BS 667 of different accuracy. Errors of measurement of ±10% may occur in Type P1, and ±15% may occur in Type P2. Normally a type P1 should be used for field measurement. The manufacturer will provide information concerning the temperature range over which the meter remains accurate. Although this will probably include most building interiors, specialist industrial processes may need extremes of temperature. Manufacturers of photo-voltaic cells can supply correction factors for illuminance measurements when the meter is used in operating temperatures which differ from a normal value. In many cases this is about 25ºC. Selenium photocells are more sensitive to high temperature than silicon photocells, where prolonged exposure to temperatures above 50ºC causes permanent damage. An illuminance meter is shown on Figure 1.

The meters measure the photon impact intensity on the surface of a photocell. The cell is able to use this energy to provide a small current which will vary in proportion to the photon impact intensity. Circuitry in the meter amplifies this signal and corrects it for the spectral sensitivity of the eye (V correction). The output can then be displayed as a reading calibrated in lux, usually on an LED display, but sometimes on a moving coil needle gauge. It is common for meters to be provided with a range of full-scale readings. The scale can be changed by control knobs or switches.

The meters are normally portable, hand-held and the photocell is usually attached to the amplifier by a flexible cable. This allows the photocell to be some distance from the person taking measurements, avoiding the risk of shadowing the photocell.

The photocell must be of the cosine corrected type. This is because when light is incident at less than 90º to the photocell surface, the response of the photocell must be modified by the cosine of the incident angle. This is achieved by a dome or disk of diffusing material being incorporated over the actual measuring cell.

The person making the measurements must be familiar with the use of the equipment. Time should be taken to read and understand the contents of the instruction book. Simple trial measurements are useful.

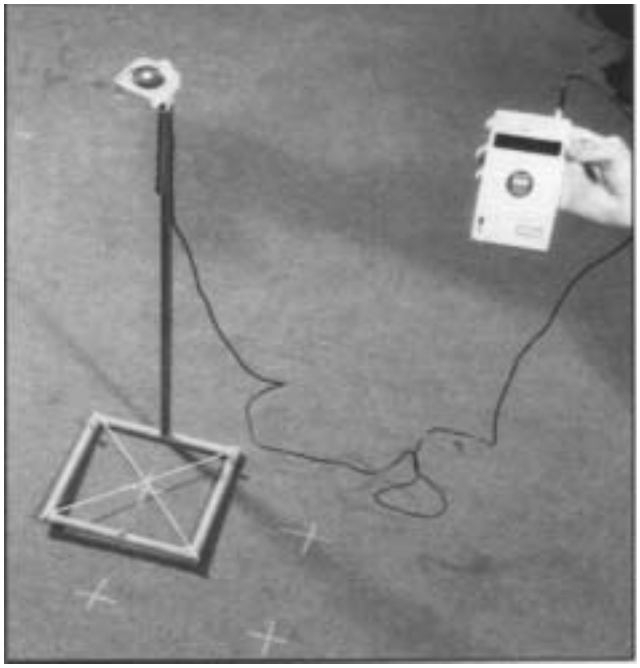

Figure 1

3.2 Other equipment

The other equipment needed for the survey may seem self evident but needs to be assembled and checked in advance if an abortive visit or wasted time is to be avoided.

A floor plan of the areas to be surveyed should be obtained from the client beforehand to allow consideration of the grid location. If reflected ceiling plans, showing the luminaire layout, and furniture layouts can be obtained then this will allow even more pre-planning to be carried out before the visit.

A long tape measure, at least 7-10 metres, is needed to lay out the measurement grid. The grid itself can be marked-out by string or chalk marks on the carpet (if allowed); otherwise brightly coloured sticky dots or labels are needed to mark the grid intersection points so as to allow quick and accurate location of the measuring cell. It is possible to buy packs of pre-numbered dots which may help in identifying and recording the readings.

If measurements are to be carried out over empty areas or between desks then a portable stand will be needed to ensure the measuring cell is located at the working plane height. This stand should be light but able to ensure that the measuring cell is horizontal and at the correct height for each reading. An example is shown in Figure 1.

Finally a clipboard or other firm writing surface, pens and paper should be obtained for the recording of the results. If proforma recording sheets, like that shown in Figure 2, are used then time is saved at the measuring site and the readings are more likely to be recorded without error. Where a comparison is to be made between calculated illuminance figures and those measured it will be necessary to estimate the actual room surface reflectances. This can be done by taking a BS colour matching chart and using it to obtain a match against the room surfaces. The chart will then give a reflectance figure that can be used for calculating corrections between the recorded illuminance figures and those calculated.

3.3 Preparation of test areas

Liaison with the client and/or the occupiers of the space before the visit is vital as all measurements relating to the performance of artificial lighting systems should, whereever possible, be taken at night. This may entail special security clearance or the attendance of the client's staff at the tests.

As the light output of lamps varies depending on their operating temperature, it is essential that the luminaires will have been operating under normal thermal conditions before measurements start. This may require, for example, both lighting and heating or air conditioning system to be switched on for long enough to achieve steady state conditions.

4.0 THE SURVEY ITSELF

Initially the proposed test areas must be checked to ensure that they are representative of the working area and that all lamps and equipment are working correctly. Stray light from surrounding rooms, spaces and through external windows should be minimised by use of blinds, curtains, etc. Any automatic lighting control or daylight linked controls should be set such that the output of the lamps is at full power and will not vary during the tests. All lighting in the area that would normally illuminate the area test grid should be operating. A failure to allow the lamps to reach their normal operating temperature before taking illuminance measurements will mean that initial readings will be low. Where lamps are known to be new they should be run for a minimum of 100 hours under normal operating conditions. A characteristic swirling pattern of light emission from the lamps may indicate that the lamps are new.

Where possible the line voltage supply to the lighting circuit should be monitored. Increases and decreases in lumen output are caused by variations in supply voltage. Record details of any control system and any special measuring or monitoring of the supply voltage or lamp output.

4.1 Setting out the test grid

The measurement grid should be positioned to cover a representative area of the working plane. This should be where there are no obstructions above the working plane which may reduce the measured levels. Since standard calculations and illuminance prediction are based on the assumption that there are no obstructions above the working plane, ensure that no screens, filing cabinets etc. are present in the measurement area.

The spacing of the grid points must be different to that of the lumjnaires in all directions. In other words the grid points must not, for instance, fall below rows of luminaires in every fourth row. The best way to achieve this is to choose an origin point half a metre from a wall and mark-off the rows of the grid at an interval that is not similar to the luminaire grid. The columns of grid points can then be set-out at a spacing that again is
different to the luminaire rows, e.g. if the luminaires are spaced 1200mm apart in one direction and 1800mm in the other the measurement grid could be chosen as 1100mm by 1100mm, although it is not necessary to have a square measuring grid.

Where the measured illuminance is to be compared to the illuminance predicted by a computer program then the measurements should be taken at the same grid point spacing as the predictions.

To accurately determine the illuminance on the working plane, the greater the number of measurement points the better. This will account for any wide variations of illuminance in calculation of the average. Unfortunately the time taken for the measurements may become

uneconomical since a law of diminishing returns, in terms of accuracy, also applies. There is thus a need to compromise on the number of measurement points to produce an acceptable accuracy for the average illuminance.

The CIBSE *Code for Interior Lighting* 1994 recommends that an interior, or a representative area, is divided into a number of equal areas which should be as square as possible. The illuminance at the centre of each area is measured and the mean calculated. This gives an estimate of the average illuminance. The minimum number of measurement points is related to the Room Index of the room or space and is shown in Table 1. This is taken from The CIBSE *Code for Interior Lighting* 1994 to obtain a measured value for average illuminance with an error of ±10% compared to that obtainable with a very large number of measurement points, using a Type P1 meter. (The ±10% meter and other system or environmental inaccuracies are additional factors)

Table 1: Number of measurement points required to determine average work plane illuminance

Room Index	Number of points
Below 1	9
1 and below 2	16
2 and below 3	25
3 and above	36

The CIBSE *Code* 1994 recommends that measurements be taken at least 0.5m away from walls or fixed obstructions such as columns or partitions and this must be taken into account in positioning the grid points. The grid can be marked out on the floor with chalk or adhesive tape or sticky labels used to mark the grid intersections. One corner point should be identified as the origin of the grid and the rows and columns labelled to aid recording of the measurements.

Re-entrant room shapes may be treated as separate, smaller rectangular areas. Thus a room of 25m by 20m with a 10m by 10m re-entrant portion at one corner may be considered as two areas of 20m by 15m and 10m by 10m, see Figure 3.

4.2 Recording Information

The following general information should be recorded:

Date and time of test
Floor and area being measured
Those in attendance at the tests

The following should be obtained from the room:

Room Name/Reference Number
Plan Size
Floor to ceiling height and ‘desk’ height
Measurement grid and position
Size, shape and position of furniture, machinery and other room contents.

Luminaires:

Positions relative to measurement grid (mark lightly on grid plan).

Type/make, size, number of lamps electrical rating, control gear mounting arrangement and orientation height if different from ceiling height.

Maintenance features: flicker, hum. broken diffusers, etc.
Maintenance regime: cleaning, relamping schedule, when last cleaned, approximate burning hours.

Reflection factors of surfaces (if required).

Take photographs where possible. These can be useful when considering the appearance effects of an installation and the type and nature of the room contents. Do not use a flash camera. The influence and relationship of daylight within the space should be noted. A scale plan, and possibly cross section, should be produced to show the position of the measurement grid, luminaires and room contents.

4.3 Checking the illuminance meter
Before use the illuminance meter should be checked for:
Battery condition
Most recent calibration date
Signs of wear/tear/damage
Cleanliness. Particularly the cosine correction surface of the illuminance meter
Correct functioning of control switches
Providing readings at all scale ranges
The meter reads zero when the cell is completely covered

4.4 Taking and Recording Measurements
When readings are stable then measurements can begin. Readings need to be taken at the working plane height used in the design calculation, or at the actual height if surveying an existing installation. This can be achieved using a portable stand, see Figure 1, which supports the cell at the required height and inclination (usually horizontal) over the grid intersection points set out on the floor of the room. All persons, except the light measurement team, should be excluded from the room in order to avoid shadowing or reflecting light on to the photocell.

Each measurement point can be described by a grid reference, letters and numbers as shown on Figure 1. The measurements at each grid intersection point must be recorded and an example of a typical pro-forma record sheet is shown as Figure 2. Care must be taken not to shadow the photocell when making measurements. This may require the person moving the photocell to crouch below the working plane level. It is convenient to have a second person recording the readings called out by the person moving the photocell.

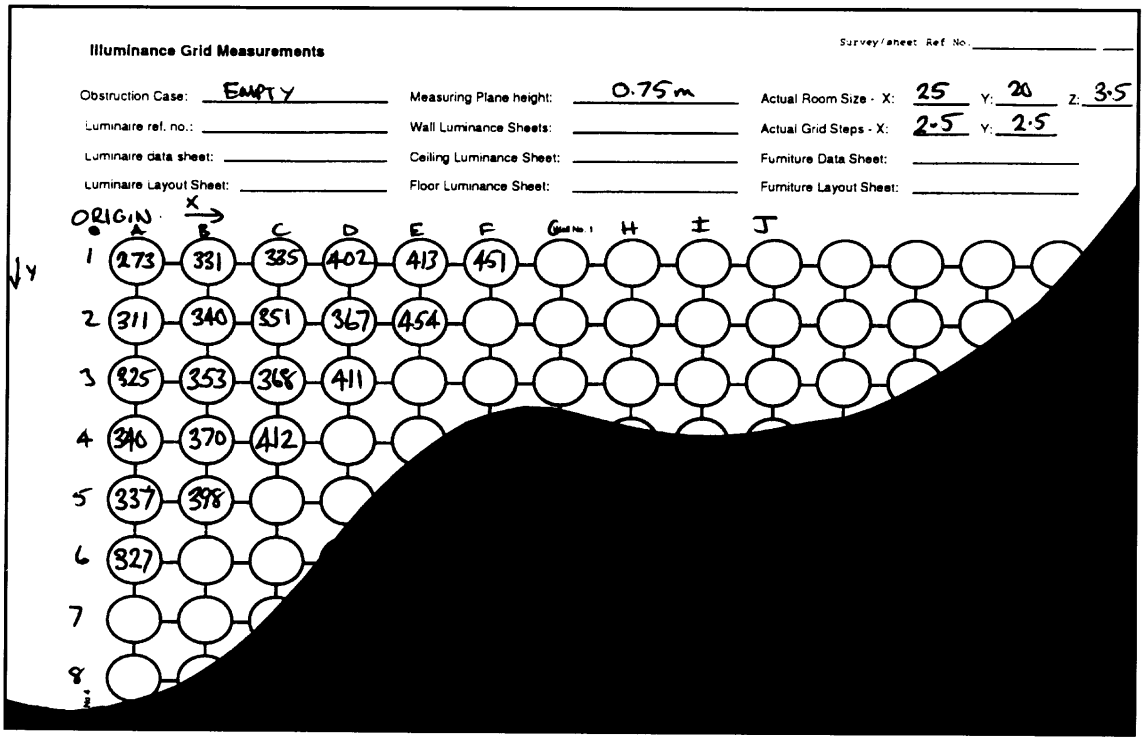

Figure 2

5.0 Analysis of the Results

5.1 Average Illuminance and Diversity

The average illuminance is, strictly speaking, weighted in relation to the area of the grid 'squares', but since each of these is the same size, a simple arithmetic average of the measured values will suffice.

The illuminance diversity can be found by locating the minimum and maximum illuminance values on the grid of measured points and calculating the ratio of minimum to maximum values.

The results can be compared with those recommended in the CIBSE *Code for Interior Lighting* 1994. Any comparison must take account of the age and maintenance of the installation. This is particularly important when considering Maintained Illuminance.

5.2 Comparison of measurements and predictions

There is also a range of other factors associated with light output variation and illuminance measurement which will need to be considered when practical measurements are to be compared to computer predictions. These include room surface reflectance, mains voltage variation, lamp operating temperature, characteristics of the control gear and the lumen output of the lamps. These factors will influence the relative accuracy of the measured values when compared to computer predictions, although the input to the computer program may permit the use of the actual condition factors present at the time of the survey.

5.3 Task uniformity measurement and calculation.

A small amount of additional measurement and associated calculation is necessary if illuminance uniformity over task areas is to be checked. Where the task locations are known,

measurements on a 0.25m fine grid should be made over the task and immediate surround at a number of representative positions. Where tasks may be located at any point over the core area it is necessary to check uniformity at points of maximum and minimum illuminance on the coarse grid and at least one other point. It is recommended that the number of fine grids is twice that of the room index of the space, e.g. for a large room with an index of 4 then 8 fine grids should be selected and checked. The measurements are positioned using a 0.25m fine grid located so that one corner of the task area coincides with a coarse grid point, see Figure 3. Measurements are made at each fine grid point as described above. Uniformity is calculated using the area weighted arithmetic average of the measurement points within the task area and the minimum fine grid point illuminance value in that area. Uniformity can be found from the ratio of minimum illuminance to average illuminance in a given task area.

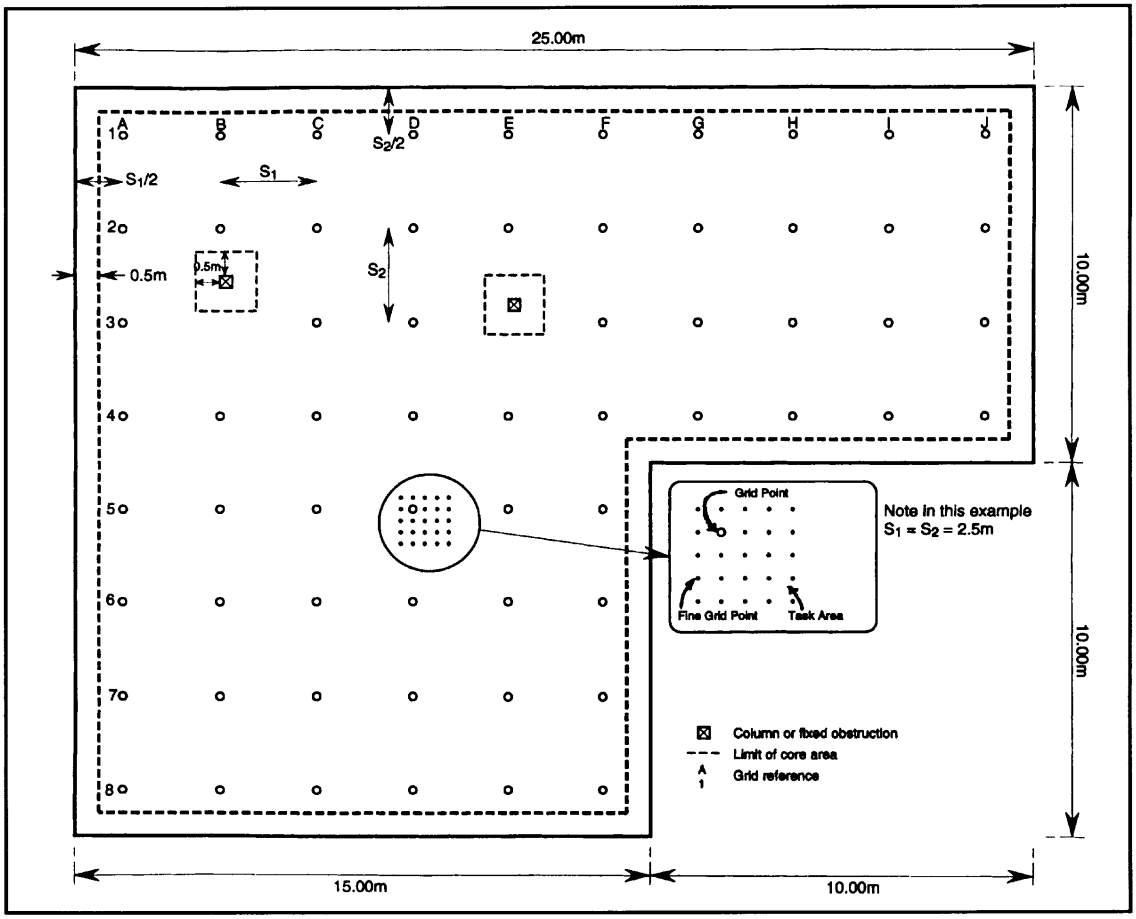

Figure 3

6.0 Summary

Although the collection of illuminance data from a room is straightforward, it is important to be systematic and thorough. It is worth spending time on establishing a measurement grid which does not compromise accuracy and does take into account CIBSE, or other, recommendations. Note features of the lighting system. Many interiors are lit by several different lamps and/or luminaires. Use well maintained and recently calibrated equipment. Light measurement surveys can take some time to complete, but always try to complete the task in one visit. Returning later after a partial survey may mean that lamps have failed, furniture may have been moved or the room temperature may have altered.

The measurements from the survey can be compared to those predicted by the design, although the relative accuracy of this comparison must be based on all of the parameters used as input to the design.. A thorough and rigorous use of the procedure described here and a Type P1 meter, should produce measured readings of the average illuminance with an error of ± 10% when compared to the actual illuminance. This will normally be sufficiently accurate for the appraisal of general lighting schemes under field conditions.

The authors wish to acknowledge the assistance provided by Paul Ruffles in preparing this Factfile.

Bibliography:

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British Standards Institution, 1985, BS 667, Specification for portable photoelectric photometers.