This paper continues the debate started by M Pitts and continued by Paul Chynoweth in previous editions of Structural Survey

Introduction

It is accepted by most Rights to Light practitioners that Percy Waldram devised the first convenient way to measure the relative value of the light from the sky, for use in Rights to Light cases and whilst this is an oversimplification of events, it is quite clear that but for his efforts the majority of practitioners would not be where they are today. However, in devising the well recognised system of droop charts and contour lines he used methods and made assumptions which are today being questioned in many quarters.

This paper examines the origins of some of those assumptions and whether they might be wrong.

The Current Debate

The concern amongst many practitioners is that the method of calculation of daylight in rights to light cases is no longer valid {{1 Chynoweth,Paul 2005; }}. The need to establish a new standard and method of calculation is driven firstly by the recognition that daylight is important to the normal use of a building, and that this daylight must be of a level which is currently acceptable, and secondly by a recognition that with modern technology there is the opportunity to make far more sophisticated measurements than was possible at the time of Waldram's original research.

Waldram's Methods and Assumptions

Whilst, in theory at least, the right to light can be traced back to time immemorial it is only in more recent times that the Courts have taken the view that the amount of light only has to be sufficient for the needs of the ordinary person *Colls v Home & Colonial Stores 1904* A.C.203 {{34 1904; }}and, since the early twentieth century, for the purposes of rights to light calculations, the amount of daylight within a room has been measured using the Waldram diagram to assess the area of sky visible from a series of points within a room at 850 mm above floor level. The diagram assumes that the value of the light from the skydome is 500 Lumens and that therefore 1 Lumen of light is provided by 0.2% of the skydome and that, provided 1 Lumen of light, from the sky is available to over half the area of the room that the room should be well lit for ordinary purposes. It should be noted however that it is for the Courts to decide if this is true and that practitioners only use these methods to advise the Court or to negotiate compensation.

Even though most computerised methods for performing the calculation do not use the Waldram diagram, they still measure the area of skydome visible at each point and if any of the above, or the other assumptions, used by Waldram and others, is flawed then the whole basis of assessment needs to be re-examined.

This paper examines the following assumptions:

- that total Sky Luminance for the dome is 500 Lumens
- a Uniform Sky can be assumed for the purposes of these calculations
- Lamberts Formula can be used to define the adjustment factor for low angle light and that there needs to be an equal adjustment to the chart for the value of light from a higher altitude
- the Waldram Diagram can be adjusted to 20 units in height and 25 units in width so that a grid of 500 equal squares can be used without affecting the result

- the appropriate height for the measurement of available light is 850 mm above floor level
- 1 Lumen of light is adequate
- it is appropriate to ignore window frames and glazing
- internal reflectance should be ignored

Some of these will prove to be easier to justify than others and in some cases, it may be impossible to justify the assumptions under any circumstances.

Total Sky Luminance for the Sky Dome is 500 Lumens

There are many examples of publications where Waldram and others have referred to the value of luminance from the sky being assumed, for the purposes of rights to light calculations, to be 500 Lumens. There is also considerable evidence available from respected commentators, over the years, which confirm the doubts that this assumption is correct.

It is obvious to any observer that the light receivable from the sky is variable and, according to Technical Paper No.17 on Illumination Research entitled 'Seasonal Variation of Daylight Illumination' published by HMSO, in 1928 for the Department of Scientific and Industrial Research {{18 }}, the outdoor illumination from the whole sky, at that time, varied between a value of less than 500 Lumens in December to about 3,750 Lumens in June or July). This analysis also showed that the value of the light during the day at various times of the year remains within a relatively small range and thus, for their purposes, it was deemed acceptable to take a mean figure for the variation of 500 to 3500 between mid-winter and mid summer.

This paper also gave examples to demonstrate that the solar illumination at noon is very similar to the illumination from the whole sky and only slightly above it in intensity and, whilst the sun is not considered important in rights to light calculation, it has to be recognised this might have an affect on any measurement process.

In 1925, Percy Waldram published his paper in the Journal of the Royal Institution of British Architects, which was read before the RIBA on Monday 20th April 1925 and was entitled 'The Natural and Artificial Lighting of Buildings'.{{13 Waldram,P.J. 1925; }}

On page 9 he reproduced the graphic representation of the results from the Home Office Report on Factory Lighting 1914 showing the Seasonal Variations of Noon Daylight and the Diurnal Variations of Daylight, Midsummer, Equinoxes, and Midwinter.

The values given represent the apparent brightness of a white card lying horizontally under an unobstructed sky and he stated that this would be double what would be recorded if the card were laid on a window cill where it could only receive half the amount of light. (This of course is a dramatic oversimplification and the direction of the sun would affected the amount of light available even for an overcast sky).

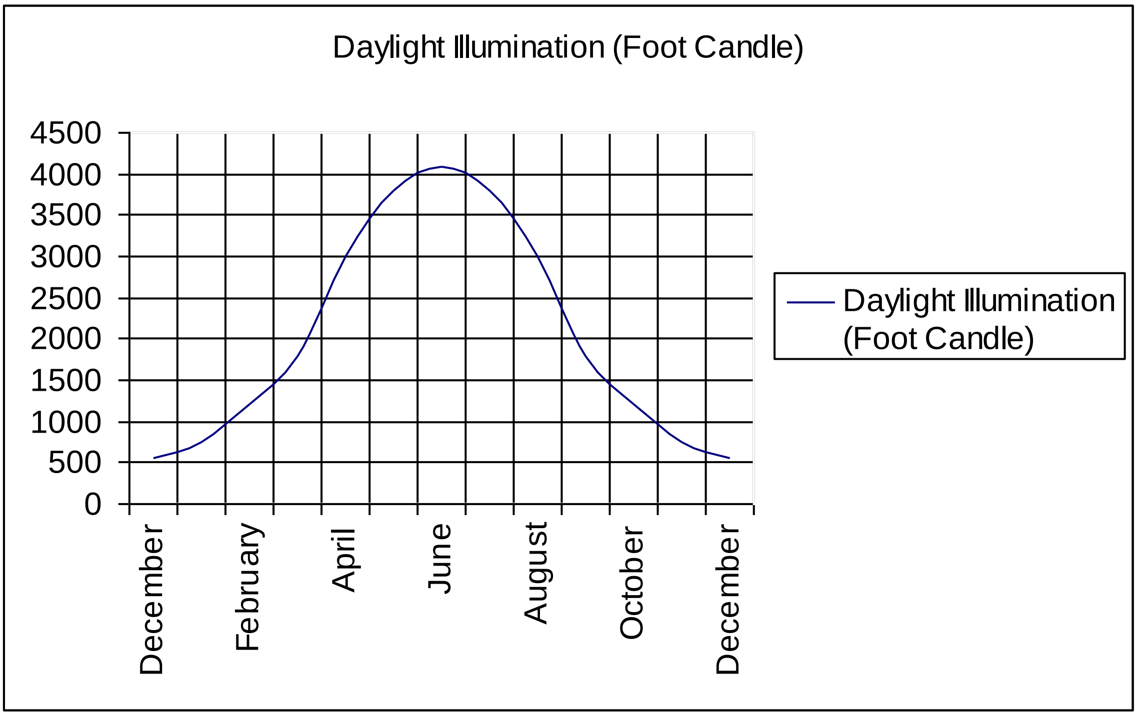

Figure 1
Seasonal Variations of Noon Daylight

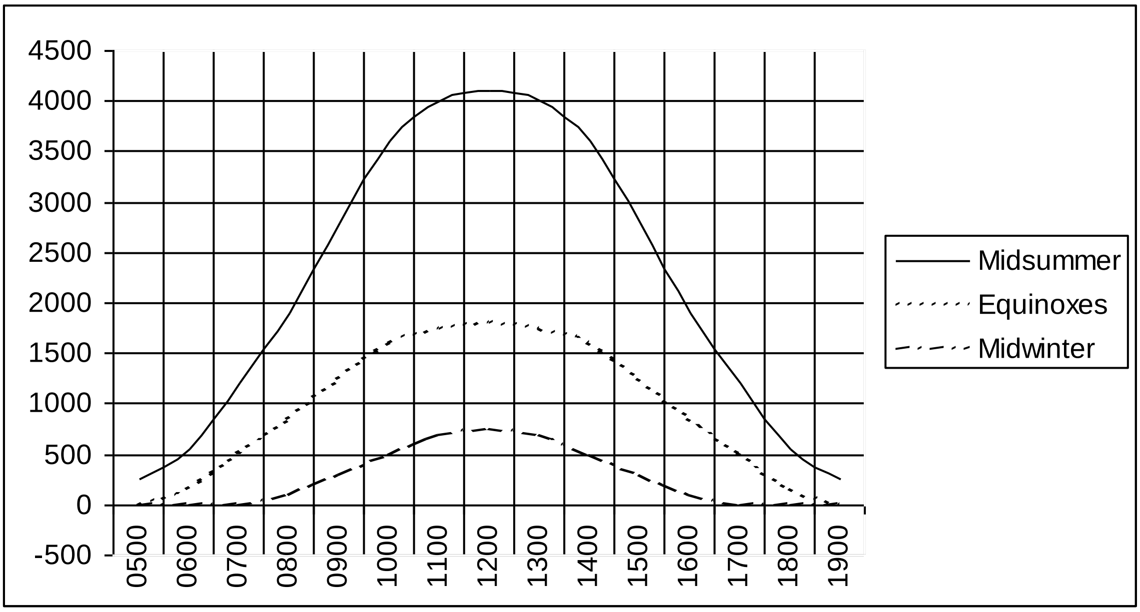

Figure 2
Diurnal Variations of Daylight, Midsummer, Equinoxes and Midwinter.

Waldram then compared the combined results of a full year's observation at Teddington, with the values in the Home Office report and, whilst emphasising that he believed it to be an exceptional year in Teddington, it is quite clear that the combined results significantly exceed the predicted values.

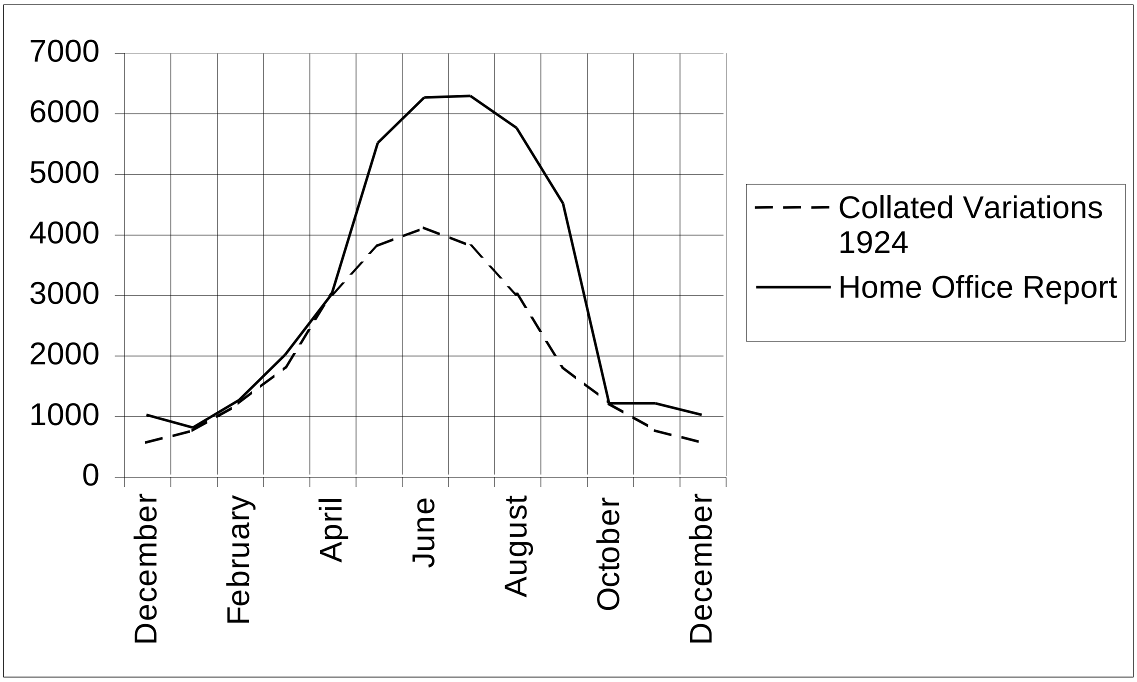

Figure 3

Seasonal Variations of Noon Daylight, Teddington 1924

At page 14 of his paper, Waldram observed that it is necessary to determine the proportion of light admitted through the windows on a moderately dull day but not abnormally so, when people would not reasonably expect to have enough light for ordinary purposes. He went on to state that he had, for some years, adopted a reading of 500 foot candles as representing the amount of light from the sky on an ordinary wet day in spring or autumn, in the country rather than in a town or city. He also stated that it is rarely exceeded throughout the day in winter in towns.

As a matter of mathematical interest, there are unexplained errors of up to 0.08 Kilolux in each of his averages but the average annual diffuse illuminance was around 18 -29 Kilolux during the working day.

According to his tables, the diffuse illuminance value of 500 Lumens, or approximately 5000 Lux was exceeded over 83.5% of the year at Bracknell and 84.1% of the year at Kew .

In 1979, Hunt, D.R.G. of the Building Research Establishment (BRE) analysed the illuminance records for Kew and Bracknell for the 10 year period from 1964 to 73 which he produced in his paper CI SfB 1976 (N11){{30 Hunt,D.R.G 1979; }}. The tables, which he included, provided an analysis of the percentages of various working years, months and hours for which given illuminances occurred and were exceeded.

Previously the published data which had been used for daylighting calculations had been based on recordings made between 1933 and 1939 which were summarised in the {{31 (2nd Edition July 1972).;}} Illuminating Engineering Society's (IES) Technical Report No 4 Daytime Lighting in Buildings (2nd Edition July 1972).

Hunt {{30 Hunt,D.R.G 1979; }} stated in his introduction that since these original calculations were undertaken, the atmospheric conditions had changed considerably owing to such things as the Clean Air Act 1956 and that the average number of hours of bright sunshine in Central London had increased by 75% over the years (although less so in the outer suburbs).

It might also be argued that since his data is now in excess of thirty years old it may be similarly inaccurate but it does provide a useful starting point for comparison between the levels achieved and those used by Waldram and others in the earlier research.

Hunt proposed that the most straightforward way to make the comparison between the 1964 to 1973 data and the 1933 to 1939 data was to look at the working day being between 09.00 and 17.30 hours British Summer Time (BST) which was in operation from April to October as this was the working year used in the IES Report. The results for Kew and Bracknell over the period 1964 to 1973 were, in fact, very similar. (Figure 4)

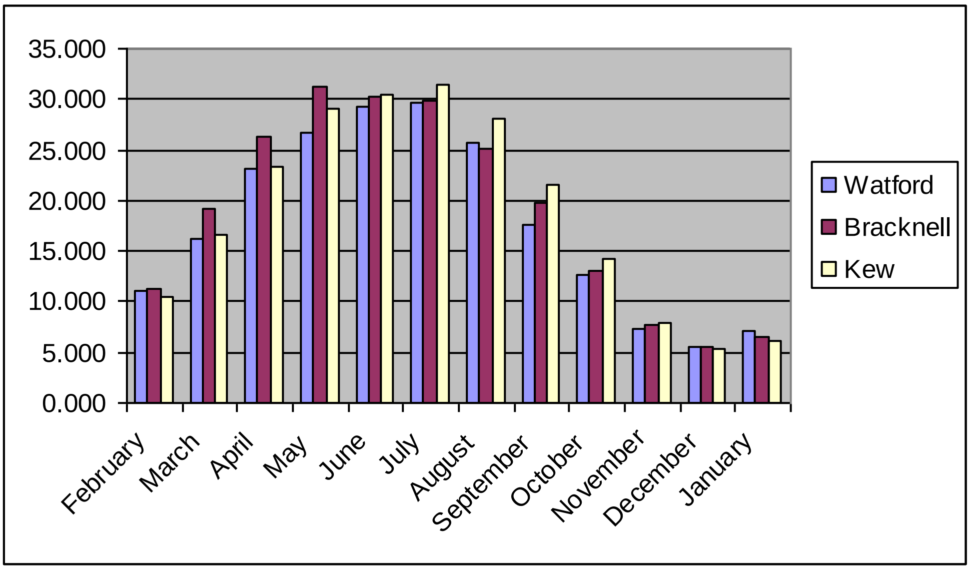

Figure 4 Comparison of mean illuminance for calendar months

Figure 4 also includes the averages taken from the information provided by P J Littlefair{{33 Littlefair,P.J. 1984; }} tables 44 and 45) in which he recorded readings during 1981 for diffuse and solar illuminance between April and October and demonstrated that in this period the diffuse horizontal illuminance of the sky peaked at around 70 Kilolux with the average around 15 Kilolux i.e. for 50% of the time between 9 a.m. and 5 p.m. between April and October, the horizontal diffuse illuminance exceeded 15 Kilolux and for 96.6 percent of that time exceeded 0.5 Kilolux or 50 Lumens. 500 Lumens was achieved for 85.7 percent of the time. (Figure 5 below)

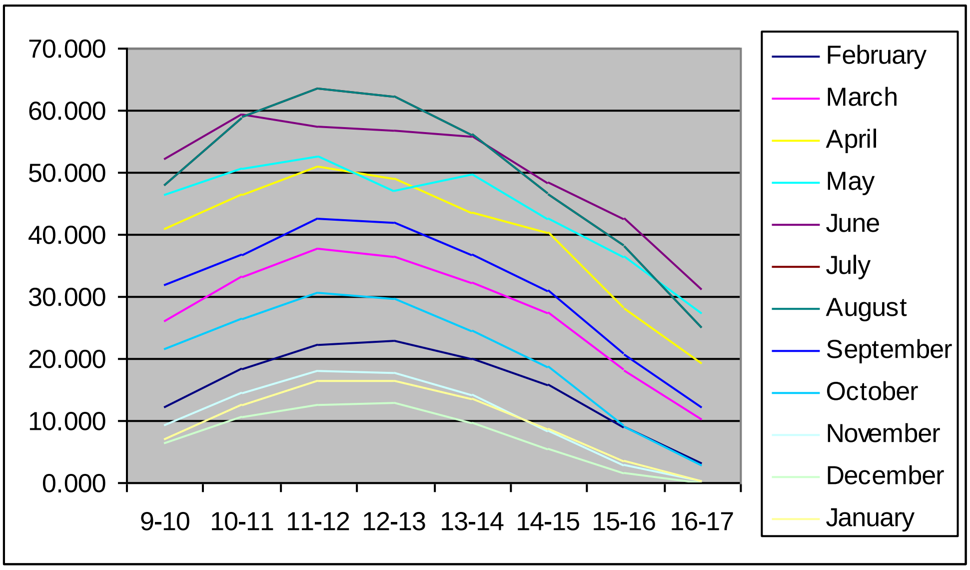

Figure 5

If it can be assumed that the exceptionally dull days, to which Waldram referred, are those which fall outside the 85% or thereabouts then Waldram's use of the 500 Lumens would appear to be justified although it is in fact neither a minimum nor an average.

Uniform Sky

It was once accepted that the light from a grey sky could be considered to be uniform from horizon to zenith but the Commission Internationale de L'Eclairage (CIE) in 1955 adopted a non uniform sky model which is now referred to as the CIE Sky, in which different values are attached to the light receivable at different elevations with the "norm" at about 42.5 degrees.

{{13 Waldram,P.J. 1925; }}Waldram p5 stated that 'in towns the zenith sky is nearly always brighter than sky nearer to the horizon where the light from the sky has to pierce a greater thickness of smoke belt. He stated that it was of even more importance that obstructing buildings almost invariably block out sky from low angles and so the light through the upper panes of glass provided the most sky visibility and it was this that was the dominating factor in natural illumination.

However, iIn the section of the paper entitled Principles of Measuring Daylight, Waldram{{13 Waldram,P.J. 1925; }} commented that because the difference between the amount of daylight externally and the amount of light internally can be different by several hundred times, a uniform sky should be adopted since, with a sky that is uniformly bright, the ratio between the external light and the internal will remain constant at all times.

Anstey {{5 Anstey,B. 1963; }}summarised the value of sky brightness by angle of altitude in the form of a table (Figure 6 below) which is not dissimilar to the CIE sky which predicts that the luminance at the zenith will be three times that at the horizon.

Average angle of altitude of patch of visible sky	Sky Brightness Factor
5	0.50
10	0.58
20	0.72
30	0.86
40	0.98
50	1.09
60	1.17
70	1.24
80	1.27

Figure 6

It has been observed that, in rights to light cases, this variation from zenith to horizon could be important in that different patches of sky whilst of the same area, would offer different amounts of illumination and that this might be significant however Walsh JWT {{19 Walsh J W T; }} maintained that the change in daylight conditions in a room was more relevant than the actual conditions.

In 1993, Littlefair P J published a BRE Information paper entitled measuring daylight (11/93){{32 Littlefair,P.J. 1993; }}. He referred in his introduction to the then new Health and Safety Workplace Regulations recognising that workplaces should, as far as practicable, receive sufficient natural light and that, as a result of this, BRE had carried out a programme of daylight measurements at its Garston site.

The study which they undertook formed part of the International Daylight Measurement Programme of the Commission Internationale de l'Eclairage (CIE) and took place in sites throughout the UK and Europe. Daylight illuminances and solar radiation were recorded for every minute during daylight hours, using sensors on horizontal and vertical planes and also using a sun tracking device. It was also the first time in the UK that the measurements included sky luminance distribution using a specialised scanner which scanned the sky every 15 minutes between July 1991 and December 1992. What was interesting was that they stated that they had used this to supplement (compare and contrast) readings which they had taken previously between 1981 and 1985. There is no available commentary on whether the new results justified or contradicted the earlier results.

Littlefair {{32 Littlefair,P.J. 1993; }}stated, in respect of daylight calculations that, under overcast conditions, the sky luminance is more stable and that as a consequence the CIE overcast sky is used as it gives a good approximation of a uniformly and heavily overcast sky but there is no direct evidence in this document that the statement has actually been verified.

It appears therefore that the uniform sky was adopted as a mathematical simplification that is surely no longer justified

The Use of Lamberts Formula for Adjustment of the Chart

Waldram{{13 Waldram,P.J. 1925; }} p5 stated that in towns the zenith sky is nearly always brighter than sky nearer to the horizon where the light from the sky has to pierce a greater thickness of smoke belt. He therefore advocated an adjustment to the value of the light from the sky at various angles of altitude.

The adjustment which he used was, it is said, based on Lambert's formula which recognised that diffuse reflection redirects light equally in all directions and is common for dull surfaces{{6 Waldram,P.J. 1923; }}. The formula is usually stated as:

$E = p\ E0\cos(\theta)$

Where p describes how dull/ shiny the surface is, E0 is the intensity of the light source and θ is the angle between the light direction and the surface normal. However, the formula used by Waldram was not just applied to low altitude light but also to light from the zenith and the rationale for this is discussed below.

In 'The Science of Daylight', Chapter 5 entitled 'Daylight Calculations by Graphical Methods' {{19 Walsh J W T; 1961 }}, there is a discussion of the 'Unit-Sphere Principle' which describes the relationship between the illumination on the horizontal plane due to a small element of sky, the luminance of that element and its angle of elevation or altitude at the point where the illumination is measured. (Figure 7)

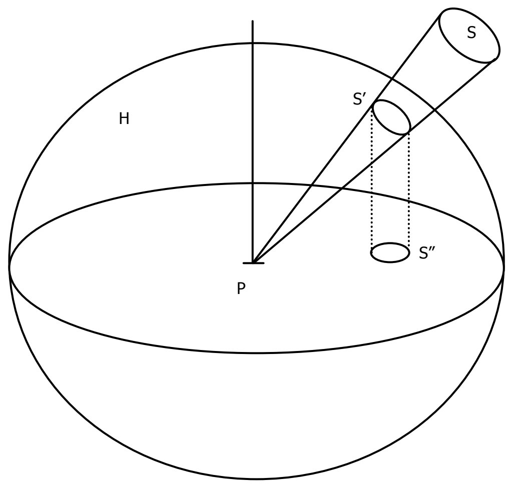

Figure 7 The principle of the unit sphere

The mathematics involves the use calculus but in simple terms, the illumination at point P due to the light received from S is proportional to the luminance of S and the area of S". (Figure 8)

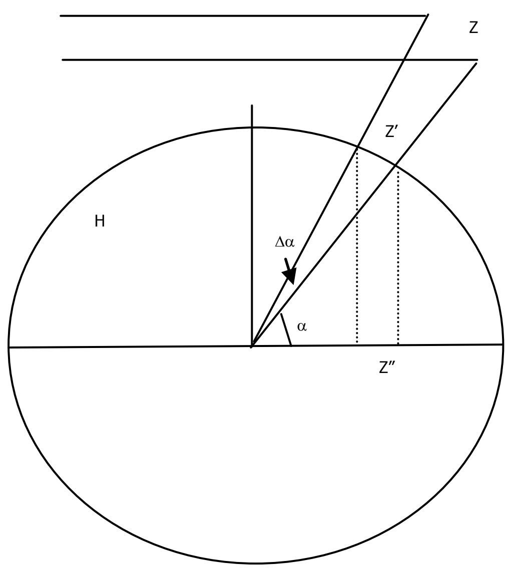

Figure 8 The illumination from an element of sky

According to Walsh, "If *Z is a very narrow zone of sky of angular breadth $\Delta\alpha$ and constant angle of altitude α then Z' is a zone of H whose breadth is $\Delta\alpha$. Its inclination to the vertical is α and so Z" is an annulus whose breadth is $\Delta\alpha$ Sin α and radius Cos α. If S is a small section of Z whose angular breadth projected onto the horizontal plane through P, is $\Delta\beta$, the area of S" is $\Delta\alpha$. Sin α multiplied by $\Delta\beta$ Cos α, i.e. it is ½ Sin 2α. $\Delta\alpha$. $\Delta\beta$."*

This calculation then leads on to the calculation which justifies the rectangular diagram described by Waldram. "*The network constructed with abscissae proportional to β but with co-ordinates in which the distance between two adjacent divisions ($\alpha \underline{+} \Delta\alpha$) is proportional to $\Delta\alpha$ multiplied by Sin 2α, then areas on the network are proportional to the values of illuminance produced by the corresponding areas of sky of uniform illuminance. The scale of the abscissae is uniform so that the abscissa corresponding to any angle β is proportional to β while the ordinate corresponding to any given angle of α is proportional to*

$\int_0^\alpha$ *Sin 2α $d\alpha$ which converts to 1-Cos 2α ,*"

This produces the chart at Figure 9 although in practice the results are converted such that the maximum value of the ordinates is 1 rather than 2 (since 1-Cos 180 = 2), for comparison with other similar methods but the ratios remain the same.

According to both Walsh and Waldram, the contraction at the bottom of Figure 9 indicates the gradual decrease in illumination produced by the sky at low angles of elevation owing to the fact that the light then reaches the working plane very obliquely, the contraction at the top expresses the fact that the area of the sky above any given attitude diminishes rapidly as this angle approaches 90 degrees but why this diminution should be symmetrical is not explained, nor is the apparent conflict with the accepted principle that light through a horizontal roof light will provide adequate daylight in most circumstances, except by reference to the sill ratio.

In this form, the diagram is 180 degrees in width and 90 degrees in height and the angular adjustment at the top and the bottom of the chart. i.e. the reduction in distance between the lines, is balanced by the increase in distance between the lines around the centre of the chart.

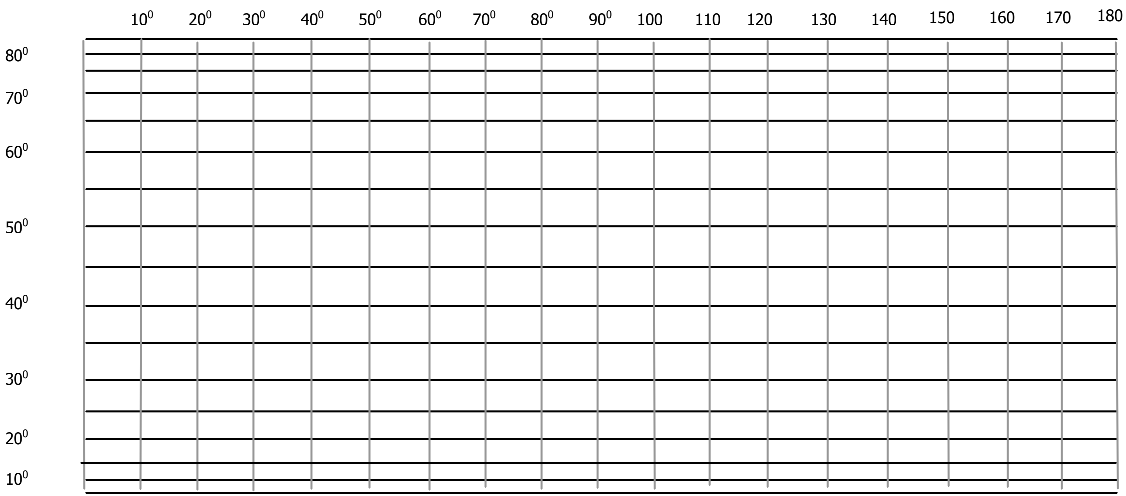

Figure 9 Original Waldram Diagram

Many practitioners are not aware of the principles behind the Lambert Formula and it is worth explaining here that, in theory, ideal diffuse reflectors reflect light according to *Lambert's cosine law*, (sometimes called Lambertian reflectors). Lambert's law states that the reflected energy from a small surface area in a particular direction is proportional to the cosine of the angle between that direction and the surface normal. Lambert's law determines how much of the *incoming* light energy is reflected and relies upon the principle that the amount of energy that is reflected in any one direction is constant in this model and thus the reflected intensity is independent of the viewing direction. The intensity does however depend on the light source's orientation relative to the surface, and it is this property that is governed by Lambert's law. The diagram below (Figure 10) shows how, as the angle of incidence nears the horizontal, the amount of light reflected is reduced.

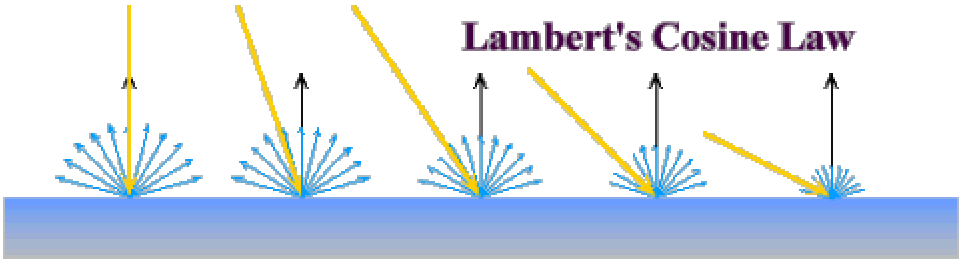

Figure 10

Note however the difference between Lambert's Formula and that used by Waldram. In fact the adjustment used by Waldram and described by Walsh, bears little resemblance to Lambert's Formula other than the use of the cosine.

The rationale for the adjustment to the upper altitudes on the chart is possibly difficult to follow but in essence, the adjustment is only necessary because the representation is on a flat piece of paper as a rectangle. The adjustment would not be necessary if the measurements were made on a sphere and is not necessary in computerised systems that use the ray method.

It is also debatable whether the adjustment applies to the lower levels as it could be argued that when reading we do not lay the newspaper flat on the work surface but generally hold it at an angle thus benefiting from the horizontal light to a greater degree.

It appears that the application of Lambert's Formula to the light from all angles of altitude was merely a convenience since there is no evidence in any publication of there being a justification that the adjustment at upper altitudes should be the same as the lower altitudes.

Adjustment of chart to 20 units in height and 25 units in width

The original chart at figure 9 does not deal with the change in vertical angle as the point being considered deviates either side of the perpendicular and so the formula has to be applied to a 'droop chart' which is the better known version of the Waldram diagram and is based upon the principle of the Mercator projection. The idea being that the adjusted flat projection of the half hemisphere of the sky which would provide light to an unobstructed window sill would provide equal values of light per square inch anywhere on the diagram.

If the sky dome were considered without making the adjustment outlined above, then the height of each point would be defined by the formula Arctan (Tan (α) x Cos(β)) where α = the angle of elevation above the horizontal and β= the horizontal angle either side of the perpendicular. This is then combined with the formula which produced the chart at figure 9 and adjusted to fit the 20 units by 25 units overall size which is used in the published form of the Waldram Diagram to produce the diagram at Figure 11.

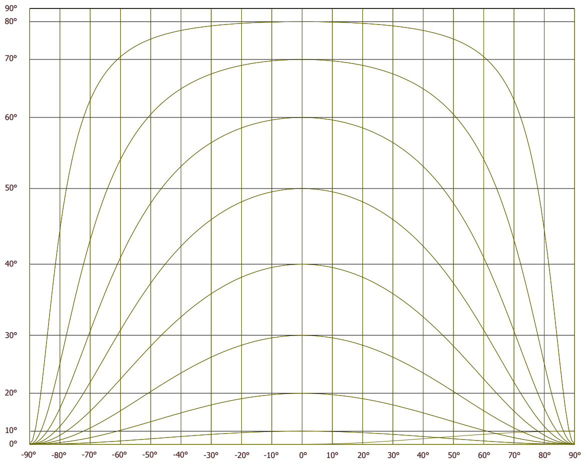

Figure 11

When a window is plotted onto the Waldram diagram it occupies an area proportional to the area of the chart. The easiest method of checking whether the relative area is affected is by plotting a window onto a chart of the original dimensions (180 x 90) and to measure the chart area and the window area. The chart can then be squeezed electronically to replicate the 25 x 20 format and the same measurements taken. If the ratio between window area and chart remains the same for each version then there is no affect.

The charts below show this in action. Figure 12 is a representation of half the width of the chart, with a window plotted on. Figure 13 is the same chart with compressed width.

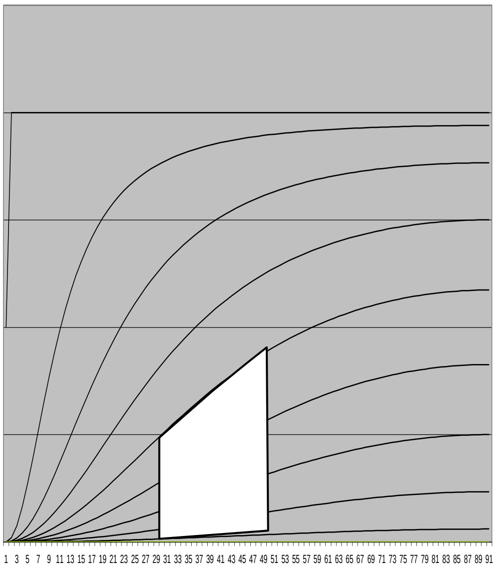

Figure 12

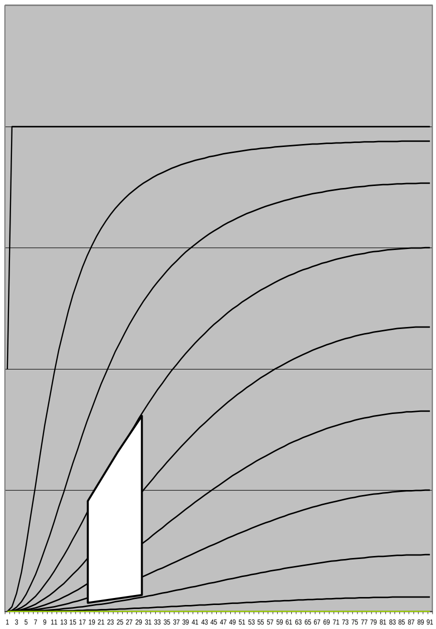

Figure 13

By measuring and calculating the area of the chart and the area of the window in each case it can be demonstrated that the window represents the same proportion of the chart no matter what shape or size the chart becomes. The only risk to accuracy would be if the user tried to employ an incorrectly sized squared grid to calculate the area of the window.

Height of Work Surface 850 mm

Littlefair {{32 Littlefair,P.J. 1993; }}quoted the accepted practice of measuring the daylight factor and stated that the working plane should be at 850 mm for houses and factories and at 700 mm for offices and this may have some relevance since in rights to light cases the level is always assumed to be 850 mm.

Most office desks, kitchen worktops and tables are no more than about 750 mm, in height; In addition, when using computers or reading, the surface being viewed is nearer to the vertical than the horizontal.

There appears to be little justification for the use of the 850 mm. If one refers to the original research by Waldram and others for the Illumination Research Council, there is mention of reading a copy of the Times and of working at a desk in offices that are now part of the Ministry of Defence (Waldram P J and J M 1923), (Taylor A K 1931). If as is likely, the desk level was at around 2 feet 6 inches (762 mm) above floor level then the people who participated in the research will have either been reading the Times laid flat on the surface or raised at an angle to take advantage of the light. If laid flat then it could be suggested that Lambert's Formula might well apply but that the readings should start at 762 mm above floor level. If the paper was held at an angle then it is possible that the optimum reading height might be 850 mm above floor level but Lambert's Formula would not apply.

1 Lumen is adequate

Despite considerable research there does not appear to be a definitive statement, as to the required level of natural light for ordinary purposes, from any profession other than Rights to Light Surveyors. Various bodies including CIBSE have established what they believe to be adequate levels for lighting for various purposes but these all include and rely upon artificial lighting. The psychologists all agree that daylight is necessary and the opticians will advise that adequate lighting is necessary and that some of that lighting should be daylight.

Looking back at the original research, it appears that the researchers adopted a phenomenological approach whereby a "jury" of people were asked to establish where in a room there was sufficient light from the sky for them to be able to work and this was plotted as a contour line on a plan of the room from which a level of light was calculated. {{6 Waldram,P.J. 1923;15 Taylor,A.K. 1931; }}. The charts produced at that time show various contours produced by each member of the jury together with a contour indicating the 'no sky line' i.e. the line representing the series of points in the room from which the last remnant of sky visibility disappears. What is not explained is why the 'no sky line' contour is nearer the window than some parts of the contours described by jury members.

Recent publications describe how the use of the standard does not appear to be based on empirical investigations. It appears, for example, from a review of relevant archive material that the values used may have been established by an extrapolation of absolute levels of illumination and that the 'jury' approach was employed more as a means of substantiating a predetermined value. {{1 Chynoweth,Paul 2005; }}.

In the Journal of the Royal Institution of British Architects which documented the presentation by Waldram, {{13 Waldram,P.J. 1925; }}, there is also documented the responses of persons present including Walsh who did not agree with Waldram that people could manage with less daylight than artificial light and he pointed out that, where Waldram mentioned the figure of one foot-candle as being probably satisfactory for clerical work in daylight, the recommended intensity for artificial light was three times that figure. Walsh went on to state that the idea of minimum illumination of one foot-candle being satisfactory, probably arose from the fact that it was used only for a brief period when the light was failing i.e. at twilight and it does appear that the 1 Lumen was always considered to be very much a minimum figure rather than being adequate by any standards.

Ignore window frames and glazing

It appears that window frames and glazing are ignored for one of two obvious reasons. Firstly the effect was difficult to model and secondly in legal terms, it would be possible to place an unfair burden on the servient owner by adopting thicker window frames and less translucent glass. However this fails to recognise that the lighting levels being predicted will always be lower as a result of even the smallest frames and the most translucent glass. Indeed, these will have affected the results of the original jury research.

It is arguable therefore that the value of light from the sky should be modified downwards to represent an average reduction factor.

Indeed in calculations of daylight for planning purposes, it is a requirement that the frames and translucency be taken into account and various computerised models use a 15% reduction for frames and 15% for glazing, as default values. Very obviously this would have a significant effect on the values being reported in rights to light calculations.

Ignore internal reflectance

Modern methods of calculating Daylight, as opposed to the methods used for Rights to Light calculation, include those which have been set out in BRE Digests 309 and 310 in 1986 and then in BS 8206: Part 2 and The BRE digest by Littlefair (1998) but these methods are used only for Planning purposes and are not considered to be valid in Rights to Light cases. In fact there are several differences worthy of consideration. For planning purposes the calculation of the average daylight factor takes into account the internal reflectance as well as the reduction in light through glazing and the effect of the window frame and glazing bars discussed above.

The rationale for ignoring internal reflectance is similar to that of ignoring window frames and glazing in that an occupant whose walls are dark wooden panels would suffer more from a reduction in the amount of sky visibility and thus place a greater burden on the person wishing to cause the reduction. Added to that is the argument that the calculations are intended to measure relative values and thus the starting point does not matter. This makes sense in Law but, in terms of the establishment of an adequate level of illumination, there is a question that must remain unanswered. When the original research took place involving the jury, what were the internal finishes? Unfortunately this is not documented. Imagine if the rooms were wooden panelled then internal reflectance may well have been low and thus the jury were using mainly the external direct light to mark their contour. If the rooms were painted or decorated in a lighter colour then they would have benefited from internal reflectance and would this have been valid if the purpose of the exercise was to determine what amount of sky was required to provide sufficient light.

Conclusions

Total Sky Luminance for the dome is rarely as low as 500 Lumens but this is a reasonable figure if it is intended to represent all but the most overcast of days.
The only justification for using a Uniform Sky appears to be mathematical. The CIE sky whilst still only theoretical provides a better model for assessment of available light from any given altitude.
There appears to be no justification for the use of Lamberts Formula or any other factor if the sky is considered to be uniform except to represent the skydome on a flat piece of paper. For computerised systems, the value of the light at any altitude or orientation can be modelled much more accurately.
There appears to be no reason why, when using the Waldram Diagram, that it cannot be adjusted to any dimensions including 20 units in height and 25 units in width so that a grid of 500 equal squares can be used without affecting the resulting ratio.
In the absence of evidence of the rationale for assuming that the appropriate height for the measurement of available light is 850 mm above floor level, there appears to be no justification for the use of this height. If the height used were reduced to 750 mm then there is the possibility that Lambert's Formula could be used to adjust the illuminance from the sky relative to its effectiveness at desk top level.
Nowhere is there any justification in support of 1 Lumen of light being adequate. Even those commentators of the time who may have been familiar with working by candle light disputed the adequacy for anything but very short periods of time.
There is however a perfectly reasonable justification in legal terms for ignoring window frames, glazing and internal reflectance, provided always that a reasonable allowance is made for the resultant reduction.

5163 words?

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