The validity of daylight calculations in rights to light cases

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Abstract

The aim of this research was to discover whether it would be possible to justify an alternative measure of daylight sufficiency that would satisfy the requirement of a court and also be capable of being used in negotiations of compensation.

By testing the validity of the original research, which has underpinned the current methods without question since 1923 and, comparing this with alternative methods of measurement a new standard was developed which more accurately represents the value of daylight in a room. Further research and experimentation and testing confirmed the levels of illuminance required for sufficiency.

It is proposed that daylight calculation should, in future, be undertaken using a CIE overcast sky model, accounting for Lambert's formula. It is further proposed that the level of illuminance required should be equivalent to at least 25 Lux (0.5% Sky Factor) over at least half of the area of the room rather than the 1 foot-candle (10 Lux or 0.2% Sky Factor), which is currently used.

Using this new methodology, the practitioner will be better able to advise both the client and the court, where the degree of loss might be actionable.

Keywords

Easement, Prescription, Waldram, Rights to Light, Sky Factor, Illuminance, Calculation, CIE, Lamberts Rule, CIEL Diagram.

1. Introduction

This paper describes a completed research project towards the Professional Doctorate in the Built Environment at Anglia Ruskin University in which the aim was to reassess the basis upon which specialist surveyors advise both their clients and the courts when considering adequacy of daylight within a room.

The legal principles are clear in that a right to light can be acquired and that this right needs to be protected. The difficulty that has arisen is that the courts, rather than seeking to make the right absolute, have defined a standard of sufficiency, which was acceptable in the early twentieth century (Colls 1904) but now appears to bear little relationship to what is perceived to be an acceptable standard and they have accepted a methodology which has now been superseded by technology. Unfortunately, the experts who provide evidence in Court still rely upon this original methodology, despite the availability of alternative methods, in the sincere belief that this is what the Courts require as the standard of evidence and also because no-one has yet defined a more acceptable methodology, let alone one which might still be relevant in another hundred years.

What has to be appreciated and recognised when seeking to identify an appropriate alternative methodology is that the cases which reach the court are an insignificant percentage of the total number of cases being dealt with at any point in time and that the overwhelming majority of cases are dealt with through negotiated settlement of compensation. The decisions of the courts inform the processes used in establishing the likelihood of injunction and/ or the levels of compensation, the practitioners advise both the client in the first instance and the courts ultimately on the amount of daylight available, the degree of loss and the likely level of compensation that would be necessary to reduce or remove the risk of injunction or, alternatively, any changes that could be made to the design that would remove the risk.

The challenge therefore was to discover a scientific solution that will be acceptable to the courts, to assist their decision making process and will also be acceptable to other professionals in assessing the degree of loss, bearing in mind that they will have invested heavily in the technology based upon the original methodologies and will be reluctant to change unnecessarily.

From the foregoing, the four key objectives of this research can be defined as:

- To demonstrate that it is reasonable to assume a value of 500 foot-candles (5,000 Lux) for the illuminance provided by the unobstructed sky.
- To determine whether it is reasonable to state that a level of illuminance equivalent to 1 foot-candle (10 Lux) over half the area of the room is adequate for ordinary purposes.

- To test whether the Waldram diagram, in its present form, provides a realistic representation of the illuminance provided by the sky.
- To devise a better method of measurement either from existing alternatives or from a new paradigm.

It has long been accepted that the illuminance provided by the unobstructed sky, on all but the most overcast of days, will exceed 500 foot-candles or approximately 5,000 Lux. (Waldram 1925)

If the value should be significantly higher or lower then this would have a direct affect on the amount of illuminance that could be assumed to be available within a room by reference to its adequacy for ordinary purposes.

The BRE and others have undertaken much research into the amount of light available and for this part of the research it is proposed to compare the results of these previous researches to establish whether this level is achieved over a significant majority of the working year, comparable to the original assumptions.

If the required illuminance should be significantly higher or lower than 1 foot-candle then this would have a direct affect on the perceived adequacy for ordinary purposes, or if the requirement were for the whole of the room to benefit from at least this level of illuminance then this too would affect the perceived adequacy.

The jury experiment is used to assess the appropriate level of illuminance for ordinary use and these results are then related to the experiments using a physical room and theoretical models to determine whether the required levels can be achieved if at least 50% of the room receives at least that level of illuminance.

Whilst the Waldram diagram is used, most often, to determine relative change of illuminance, many situations rely upon the absolute definition of the well-lit area of a room. If the diagram is not sufficiently accurate, then the well-lit area may be misrepresented. The experiments in the physical room and using the theoretical models will compare reality with existing theory and with the revised diagram developed using an overcast sky model rather than a uniform sky model to assess whether the existing methodology approximates reality to an acceptable level or whether the new diagram is in fact more accurate.

Any new method must be usable and acceptable by the fellow professionals and ultimately by the Courts. By canvassing opinion of a focus group and careful consideration of the alternatives including the use of the overcast sky model, it is intended to identify whether a new method could be adopted which provides both a more accurate representation of reality and, at the same time, remains easy to use as the present methodology.

2 Historical Context

A Right to Light is a negative easement which, commonly, can be acquired in one of three ways, by use since time immemorial (prescription under common law), prescription by lost modern grant, or under the Prescription Act 1832 (prescription by statute), the breach of which is considered to be a Nuisance and is governed by the law of tort, the remedies for which are Injunction and/or Damages

The basic requirements, for an easement to exist, were defined in *Re Ellenborough Park [1956] Ch131*

- There must be a dominant and servient tenement,
- The easement must accommodate the dominant tenement,
- The dominant and servient tenements must be owned by different persons; and
- The easement must be capable of forming the subject matter of a grant.

A tenement is a legal interest in the land or property such as the freehold or leasehold ownership and, in the context of Rights to Light, the owner of the dominant tenement has the right to the passage of light across the land of the owner of the servient tenement. Where the right exists, the servient owner may not cause any obstruction to the light passing over his land, to the extent that it deprives the dominant owner of sufficient light for ordinary use. In this way the benefit of the easement accommodate the dominant owner.

The definition of sufficient light is discussed later in this paper but at this point it is necessary to explain that the light has to pass through an aperture to a room forming part of the dominant tenement and not just to fall on the bare land. Thus the amount of light entering the room is what has to be measured for sufficiency.

If the tenements are owned by the same person then an easement cannot be created for the legal interest of that owner but may be created where there are other interests involved such as a leaseholder where the freeholder owns both properties but only occupies one of them.

A right to light might also be granted by one owner to another, without relying upon the forms identified above, in a legal agreement such as a deed of sale.

It is important, however, to recognise that the law evolves over time and in this respect the law dealing with ‘Rights to Light’ is no exception and there are many landmark cases to which practitioners refer for precedent. In addition to this, the Law Commission have previously issued their consultation paper No 186, which looked at Easements, Covenants and Profits à Prendre. This consultation process has now concluded and the results are awaited but it is a possibility that they may lead to changes in connection with the prescriptive acquisition of a right to light.

The following are some of the relevant events/ cases in chronological order up to the present day.

Table 1: Significant Legal Milestones in Rights to Light Cases

Date	**Event**	**Significance**
1275	The Statute of Westminster 1189 Time immemorial	Established in the principle that a benefit that had been enjoyed for longer than could be remembered by a living person should be enjoyed as of right.
1832	The Prescription Act	Set the period of enjoyment as 20 years in rights to light cases.
1866	Dent v. Auction Mart Co	Scientific evidence used and judge referred to adverse affect of artificial light
1904	Colls v Home & Colonial Stores	Established principle of sufficiency according to ordinary use.
1921	Charles Semon and Company, Limited v. Bradford Corporation	Court decision consistent with Waldram methodology. Expert's advice accepted.
1927	Horton's Estate Ltd v James Beattie Ltd	Established no special measure to be used for tasks and consistent with Waldram methodology.
1930	Price v. Hilditch	Expert evidence accepted and consistent with Waldram methodology
1931	Sheffield Masonic Hall Company, Limited v. Sheffield Corporation	Judge did not like the evidence provided by Waldram
1935	Fishenden v Higgs and Hill Limited	Sky contour diagrams used. Generally followed Waldram
1954	Cory v The City of London Real Property Co	Walsh gave evidence and judge commented upon inconsistency of advice to the courts
1967	Ough v King	Court supported principle of 50/50 rule although accepted that this might change

		over time
1986	Carr-Saunders v. Dick McNeil Associates	Possible future use (sub division) considered when assessing damage but still consistent with Waldram
1994	Deakins v. Hookings	Followed Ough v King and consistent with Waldram methodology
2005	Midtown Ltd v. City of London Real Property Co Ltd	Argument that artificial light normally used was rejected
2006	Regan v Paul Properties DPF No1 Ltd and Others	Confirmed 50/50 rule as a useful guide when dealing with residential properties.

For the purposes of this paper, the Rights to Light Act 1959 has been ignored as the main effective part of this is the notional light obstruction notice.

The more recent case of, *Regan v Paul Properties*, heard on appeal late in 2006 was expected to produce a definitive assessment of what is sufficient, the well lit area remaining being estimated at 42% but in the event, the final settlement occurred outside of court and nothing further has been published but the offending building has been reduced by one bedroom.

We do however have the benefit of the summing up of Stephen Smith QC Sitting as a Deputy Judge of the Chancery Division in the lower Court in which, he recited the legal history of the use of calculations to demonstrate loss.

Until the early 1920's, the most sophisticated method of assessing the adequacy or otherwise of any daylight entering a window was to a method commonly used to assess the adequacy of the light entering a window was to measure the angle between the window sill and the top of the proposed building. This was sometimes referred as the 'cones of light' approach. If the angle was 45^{o} or less, then it would be assumed that that there was sufficient light entering the window and if more, then there would not be enough.

During the 1920's, Percy Waldram, a well-known and self-proclaimed expert, devised a more sophisticated method of assessment, which required a knowledge of complex trigonometry and was used in this form until the late 1970's and even later by many practising surveyors. Few now continue to use the traditional methods as computers most often perform the calculation process and those who know how to do it in the traditional way are few and far between. This paper does not explore the actual methods by which computers produce their results as are subject to copyright and there are no publicly available versions. Suffice to say that they do not employ the Waldram diagram except as a visual output. They do however still produce contour plans as will be explained later in this paper.

The Waldram method measures the value of light from the sky (not reflected light and not direct sunlight) and thus ignores the variations in the amount of light from time to time caused by differences in the cloud cover or between the seasons. (Bickford-Smith and Francis 2000)

A standard was set and the figure of 500 foot candles illumination was adopted by the National Physical Laboratory in 1928 as being the average condition of sky brightness found in towns in Great Britain over the greater part of winter days, over long periods in late autumn and early spring, over substantial but less lengthy periods in early autumn and late spring and on wet days in summer. It was felt that over these periods and, therefore, over a great part of the year, reasonable people would normally expect to have adequate light for ordinary purposes.

A little earlier than this, in "The Illuminating Engineer"(1923) Mr. Waldram had opined (supposedly following extensive fieldwork undertaken by himself and his father):

[… for ordinary purposes, comparable with clerical work, the natural illumination at which average reasonable persons would consistently grumble was that which represented 1/250 (0.4%) of the outside illumination which would fall on a window sill from an unobstructed quarter sphere of sky, of the same brightness as that of a patch of sky which illuminated the position under consideration. This grumble point is, of course, the same as 1/500 or 0.2% of the light which would fall from an unobstructed hemisphere of uniform sky onto a flat roof.]

Not long thereafter, the Commission Internationale de L'Eclairage, which met at Cambridge, resolved a number of issues, including that less than 0.2% daylight (aka 1 foot candle, '1 Lumen per square foot' or approximately 10 Lux) should be regarded as inadequate for work involving visual discrimination, the assessment being made at tabletop height (which was to be taken to be 85 cm (2ft 9 in)).

Waldram's methods of measuring light devised around this time translates the three dimensional reality of light flowing through a window into a room at tabletop height, into a two dimensional diagram. By comparing the diagrams of the extent of adequate light (i.e. 0.2%) available in a room, which are produced to represent the position before and after a proposed development, the effect of the development on the available light can be plotted over the floor area of a room on what is known as a "sky contour diagram". The area between the 'before' and 'after' contours is the area in which adequate light has been (or will be) lost because of the development.

In this way, an easement of light confers on the dominant tenement a right to a minimum level of light, but it does not protect all the light which may have been previously available. Thus it is entirely possible for a developer to construct a development, which has the effect of reducing the amount of light, which has been received by neighbouring buildings for very many years, without committing the tort of nuisance.

To this day the courts are still being advised by rights to light practitioners that the value of the light from the unobstructed sky should be assessed as 500 foot-candles of illuminance, that this value is modified in accordance with the formula provided by Waldram and others and that 0.2% of the skydome as measured at a height of 850 mm above floor level will provide sufficient light if half the room or more is lit to the same level.

When referring to the 50/50 rule, the Courts have made the assumption that 50% of the room would be 'well lit' and the remainder would not. Whether this implies, as suggested in *Cory v The City of London Real Property Co (1954)*, that the overall appearance would be of an adequately daylit room or, as implied in *Ough v King (1967)*, that the remainder of the room might have a lesser use, is not clear.

This is important because on the one hand the so called 'grumble line' between well lit and not well lit areas would represent the overall illuminance of the whole room, not necessarily the average value, and, on the other, that the grumble line would represent the lowest value of illuminance of half the room thus ignoring the remainder of the room and assuming that only half the room needs to be useable. This latter interpretation is supported in the Judge's summary in *Regan v Paul Properties (2006),* which makes clear that the 0.2% value represented the minimum level required for clerical work.

3. The Calculation Process

3.1 Assu mptions

The calculations used to determine sufficiency are, as mentioned above, based upon a set of assumptions promulgated by Percy Waldram and others in the early part of the 20th Century. There are 6 main assumptions that have been challenged and which, if wrong, would have the potential to invalidate much of the advice given over recent years including that given in some high profile court cases.

1. The use of a Uniform Sky model
2. Ignoring the affect of Windows and Frames
3. Ignoring Internal Reflection

4. Taking measurements at 850 mm above floor level
5. Assuming that 500 Foot Candles (approximately 5000 Lux) of illuminance is available over the majority of the working day from unobstructed sky
6. Assuming that 1 Foot Candle (approximately 10 Lux) of illuminance is sufficient for ordinary needs.

3.2 *Use of the Waldram Diagram*

The physical manifestation of these assumptions is embodied in what is known as the Waldram Diagram. There are in fact several so called Waldram Diagrams including one that is used for assessing the vertical sky component for planning purposes but only one is actually used in Rights to Light cases.

4. Assessment Of Merits Of Assumptions

4.1 The use of a Uniform Sky model

A Uniform Sky is a theoretical but non-existent anomaly. There is no such thing as a uniform sky and never will be. Even when a sky is uniformly overcast as most people assume occurs frequently in the UK, the light from above tends to be stronger than the light from lower levels. When compared with the CIE model of overcast sky or the more recently proposed Useful Daylight Illuminance (UDI) sky, the traditional Waldram diagram misrepresents the value of light at higher levels. The Standard CIE overcast sky presents a theoretical model that values light from above at 3 times that from the horizon. $L=L_z\ 1+2(\sin\alpha)/3$.

The Waldram diagram also ignores the affect of the sunpath but it has to be remembered that the exercise is, for the most part, a comparative one. That is to say it compares the amount of light as existing with that, which would be available after an obstruction is erected. It does have the advantage of eliminating all variables and thus making the calculation process somewhat easier, it is also assumed to be a ‘worst case’ evaluation as for the majority of the working year a higher level of daylight is available (Littlefair 1991).

Table 2 shows the comparison of the CIE predicted overcast sky against the assumption by Waldram of a Uniform sky model and the results produced by measurement during a single experiment at BRE Garston.

It can be seen that the experimental results, albeit a single set, are closer to the CIE model than the Uniform Sky Model assumption by Waldram.

Table 2: Comparison Uniform Sky With CIE Standard Overcast Sky

Altitude in Degrees	Test Average (Cd)	Predicted based on CIE (Cd)	Uniform Sky Model (Cd)
90	5.85	2.0	1.34
80	3.75	1.98	1.34
70	2.63	1.92	1.34
60	2.2	1.82	1.34
50	1.95	1.69	1.34
40	2.03	1.52	1.34
30	2.01	1.33	1.34
20	1.83	1.12	1.34
10	1.1	0.9	1.34
0	0.55	0.67	1.34

4.2 Ignoring the affect of Windows and Frames

Window glazing resists the passage of light. Common double-glazing can reduce the amount of light passing through the opening by 40%. Different glazing and dirt on glazing will also change the results as will the size of window frames which can vary from thin metal to large PVCu cross sections where a common reduction in the area of an opening is around 15 to 20%.

By ignoring the losses that occur through transmission through glazing and the fact that the window frames will reduce the area through which light can pass the actual amount of light passing through the opening appears to be over valued. Here too it might be argued that as the process is one of comparison with these factors as constants, that there is no purpose served in being more accurate. It also assists in making the calculation process that much simpler as it would be difficult to formulate a fair calculation of daylight availability that depended upon the type of glazing and the size of frame. It is a principle of law that the dominant owner cannot place an unfair burden on the servient owner and thus, if the dominant owner wished to have opaque un-cleaned double glazing in a large frame which restricted the amount of light passing into the room quite significantly, this should not be considered a reason for the proposed development to be significantly less than the situation where the dominant owner had clean windows and small window frames allowing a reasonable level of light to enter the room.

4.3 Ignoring Internal Reflection

It is acknowledged in most daylight calculations that internal reflectances adds to the overall ambience of a room and that whilst no direct daylight may reach the back of the room, the room itself may be still sufficiently daylit

However, internal reflection is also ignored, possibly for mathematical simplicity, although it should be noted that legal doctrine prescribes that the complainant may not make the situation worse than it would otherwise be and a dark room such as one where the walls are clad in timber will reflect less light than one where the walls are painted magnolia. Mathematically, in the process used for determining the Average Daylight Factor of a room for Planning purposes, it is noted that in some circumstances the benefit of internal reflectance when measured has an equal and opposite affect to the losses from glazing and the frame of a window.

It is possible therefore that a reasonable interpretation of the historical methodology is that these two variables over which the other party has no control (The window and the internal surfaces) are deemed to cancel each other and can therefore be ignored.

In an experiment that formed part of this research, a model under an artificial sky dome was tested with and without glazing and with the internal surfaces reflective and non-reflective. Under these conditions the central reading of daylight factor was 1.75% with glazing and internal reflectance and 1.5% without glazing and with non-reflective finishes. A small change to the window material or a slightly less reflective internal finish would bring these two results even closer together.

4.4 Taking measurements at 850 mm above floor level

The rationale for taking measurements at 850 mm above floor level has never been fully explained although it is often referred to as the work surface height. However most work surfaces are at around 700 to 750 mm in height.

Underlying this assumption is the fact that light striking a surface a shallow angle provides less illuminance than that from a steeper angle. This is referred to as Lamberts cosine rule, which is used to adjust value of light at lower levels according to Waldram. By taking a higher working plane for the calculations there will be a small change to the results obtained generally although this often depends upon the height of the window cill being considered as a surface close to the window and below the cill level would show an are as being unlit.

Waldram and others asserted that this adjustment was incorporated into the Waldram Diagram model but this has not been possible to justify this mathematically. In addition, to be valid, the reading must be taken at work surface height not some arbitrary height above floor level.

4.5 Assuming that 500 Foot Candles (approximately 5000 Lux) of illuminance is available over the majority of the working day from unobstructed sky

Many people have now measured the light from the sky, including the BRE (Littlefair 1993) and particularly across the south of England, and have shown that the value of the illuminance measured varies considerably across time but that, statistically, the illuminance provided exceeds 5000 Lux for more than 80% of the working year (Hunt 1979). Bearing in mind how gloomy it can get on winters evenings and the fact that at these times it is normal to use artificial lighting, it seems that this value provides a reasonable constant to be used in the calculations.

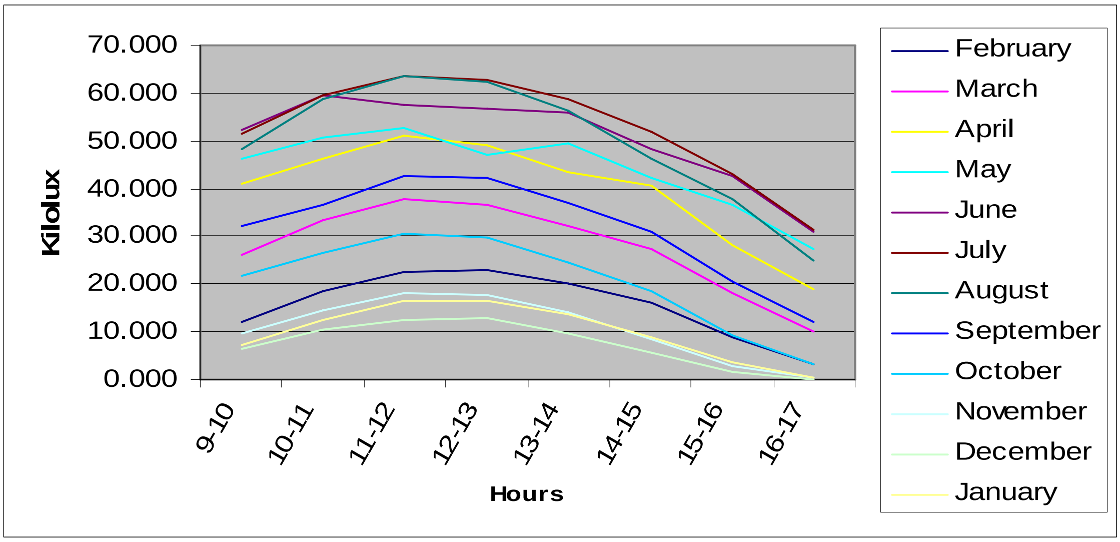

Figure 1: 5000 Lux Sky

4.6 Assuming that 1 Foot Candle (approximately 10 Lux) of illuminance is sufficient for ordinary needs.

There is no sound basis for this assumption and this is where there is the largest scope for challenge to Waldram in particular. Waldram carried out a very limited study in the first quarter of the Twentieth Century, using rooms in various offices in London where participants were asked to indicate where in the room they felt that they had sufficient daylight to work by. These responses were then charted and compared with a diagram where the predicted levels of daylight had been drawn (notwithstanding that these levels will have varied during the experiment itself). The results were then ‘interpreted’ by Waldram who had publicly acknowledged that he could work in lower light levels than his peers and resulted in his statement that an illuminance of 1 foot-candle was sufficient for ordinary needs.

It appears from available evidence that contours were plotted on each plan showing the 'daylight factor levels that correspond with the points at which the observers felt that the amount of light changed from being just sufficient to insufficient (what later became called the 'grumble line'). The results were then compared with the 'no sky line' contour for the rooms and in one classic case it shows the no sky line as being between the 0.1% and 0.25% daylight factor contours and nearer the window that at least five members of observers indicated that they had sufficient light to work by. Evidently this was achieved through internal reflectance.

The interpretation of these results is subject to serious questions but if Waldram's assertion that 0.2% of the sky dome would provide 1 foot candle of illuminance (approximately 10 Lux) is accepted then this must be compared with a controlled test undertaken by the authors, in 2007, with twice as many participants, that showed the minimum level of sufficiency for over 80% of the participants was around 25 Lux.

Figure 2: Room with 10 Lux illuminance

Figure 2 shows how a room would look if it were illuminated to the levels accepted as sufficient for ordinary purposes. In the experiment, undertaken at Anglia Ruskin University, less than 15 % of participants were able read properly at this level of illumination.

5. The Waldram Diagram

The traditional Waldram Diagram, illustrated in Figures 3, 4 and 5, commences with a series of horizontal lines representing altitude. The adjustment of spacing between these lines is, according to Waldram, based upon the value of light and the area of sky at each angle. On this is plotted a series of droop lines that represent the geometrical location of points in the hemisphere parallel to the plane of the window. Over this there is another set of droop lines representing geometrical points perpendicular to the plane of the window and over all this is the grid dividing the whole chart into 500 equal squares (each square representing 0.1% of the sky dome). A window, shown outlined in red, is plotted onto the chart illustrating how the droop lines modify the window head as it projects onto the sky dome, and within this window projection an external obstruction is plotted. The area of window unobstructed is calculated using the square grid. The light from two squares (representing 0.2% of the sky dome or 1 Foot Candle where the whole sky provides 500 Foot Candle Illuminance) was deemed sufficient by Waldram.

Traditionally a series of charts was produced for a number of grid points within a room and the values plotted on the grid. The practitioner would then interpret the results and draw a contour line representing the pints where 0.2% of the sky dome should be visible based upon this data as in the example at Figure 6. It was then often the case that a further series of checking charts would be produced along the contour line to verify the result where accuracy was important (usually where the loss was deemed to be significant) as shown in Figure 7.

Even for simple situations the charts took several minutes to prepare each and series of charts would run to hours of work with no absolute guarantee of the accuracy of the result. Common errors included:

- Using the wrong Waldram Diagram
- Incorrect assessment of angles
- Incorrect datum levels
- Wrong Grid spacing
- Calculation of Contour Area
- Omitting Distant obstructions

In fact the outcome of any analysis might be subject to an accumulation of errors if the practitioner failed to check his work at each stage.

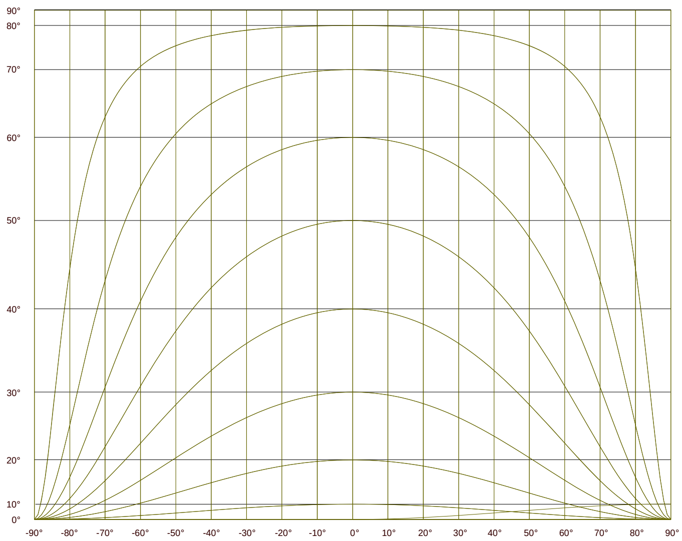

Figure 3: The Basic Waldram Diagram

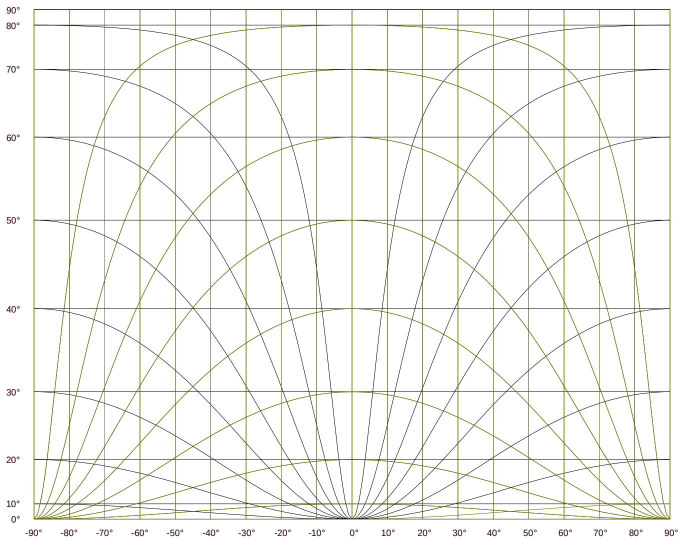

Figure 4: The Basic Waldram Diagram with lines added for obstructions at right angles

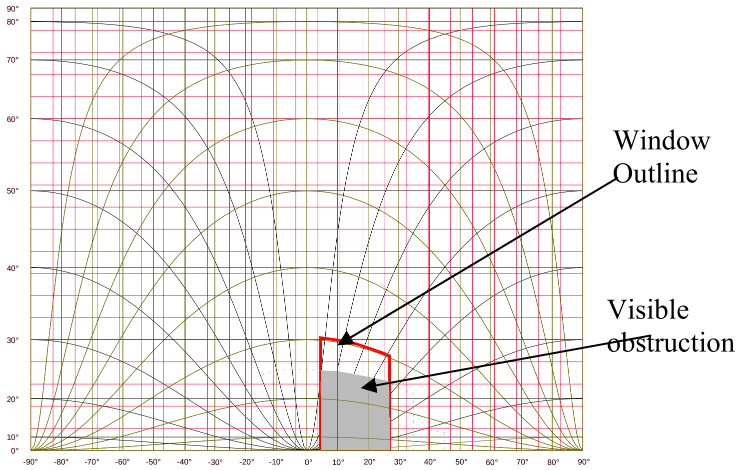

Figure 5: The full Waldram Diagram with Grid added and example of window with obstruction

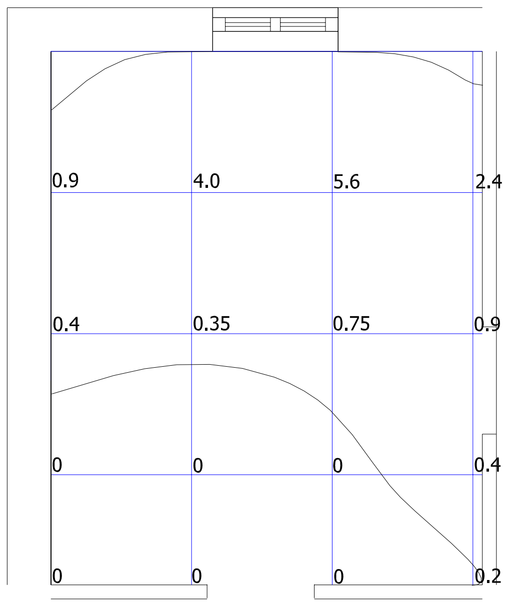

Figure 6: Grid and Typical Contour Drawing

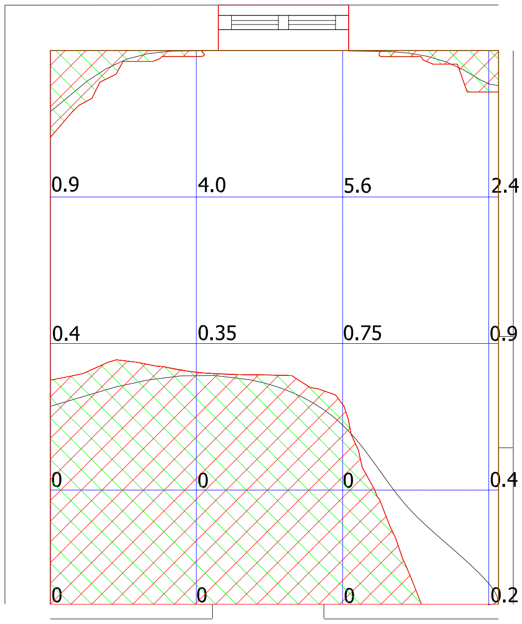

Figure 7: Corrected contour

6. The Development Of A New Diagram In Place Of The Waldram Diagram Used For Rights To Light Cases (The CIEL Diagram)

This investigation has established that the uniform sky model does not provide a satisfactory basis for establishing the amount of light available from various parts of the sky and that the non uniform CIE model is closer to reality. To create a diagram that is the equivalent of the traditional Waldram Diagram it is necessary to modify the value of light from the various altitudes in accordance with Lamberts Formula, which considers the illuminance on a horizontal plane from light at different angles.

To derive a formula that recognises a non-uniform sky and can be used in the calculation of illuminance at any point on the horizontal plane it is necessary to modify the formula used by Waldram and to achieve this it was necessary to seek assistance from the computer software providers who had created the 'Rights to Light' programme used in one of the experiments that formed part of this research. In the first instance, a series of questions were posed regarding the potential modifications that could be applied to the original formula and by discussion it was decided that it should be assumed that the non uniform sky should be represented by the CIE sky and then the mathematical analysis would produce the following (Manescalchi 2007):

6.1 Assu mptions

Horizontal Angle = β

Vertical Angle = α

The Differential Surface Area Element (DSAE) for a unit sphere is given by:

$\cos(\alpha)\, d\alpha\, d\beta$

The CIE Standard Sky transformation can be represented by $(1+2\sin(\alpha))$. The constants 0.33Lz have been dropped for mathematical simplicity.

6.2 *Skydome Modified by CIE values*

If the DSAE is adjusted by the CIE transformation the resulting formula would be:

$\cos(\alpha)\,(1+2\sin(\alpha))\, d\alpha\, d\beta$.

6.3 *Adjusted Sky Values*

If the Waldram Diagram is to represent the luminance of the sky dome onto the x/y plane then the Differential Surface Area Element of the Waldram Diagram must be:

$\cos(\alpha)\,(1+2\sin(\alpha))\, d\alpha\, d\beta$

The horizontal scale is proportional to $\int_0 d\beta = \beta$

i.e., the horizontal scale is uniform. It is just the horizontal angle.

$\cos(\alpha)\,(1+2\cos(\alpha))\, d\alpha$ denotes the rate of change of the area along the vertical axis.

The vertical scale is proportional to

$$\int_0^{\alpha} \cos(\alpha)\,(1+2\sin(\alpha))\, d\alpha = \mathbf{(\sin(\alpha) - \tfrac{1}{2}\cos(2\alpha) + \tfrac{1}{2})}$$

6.4 *Lambert Cosine Law + CIE Overcast Sky*

The above formula would have to be modified by Lambert's formula in order to replicate the stated basis of the Waldram diagram

If the DSAE is projected onto the x/y plane (Lambert Cosine Law), this produces:

$\cos(\alpha)\sin(\alpha)\, d\alpha\, d\beta$

(Note that the angle from the vertical is: $(90-\alpha)$ and $\sin(\alpha) = \cos(90-\alpha)$)

If the CIE Standard Sky is added then this produces $(1+2\sin(\alpha))\cos(\alpha)\sin(\alpha)\, d\alpha\, d\beta$

If the Waldram Diagram is to represent the luminance of the skydome onto the x/y plane then the Differential Surface Area Element of the Waldram Diagram must be:

$(1+2\sin(\alpha))\cos(\alpha)\sin(\alpha)\, d\alpha\, d\beta$

As before, the horizontal scale is proportional to:

$\int_0^{\beta} d\beta = \beta$ i.e., the horizontal scale is uniform. It is just the horizontal angle.

(1+2Sin(α)) Cos(α) Sin(α) dα denotes the rate of change of the area along the vertical axis.

The vertical scale is proportional to:

$\int_0^{\alpha}(1+2\sin(\alpha))\cos(\alpha)\sin(\alpha)\,d\alpha$ = **$(-\frac{1}{2}\cos^2(\alpha)+\frac{1}{2}\sin(\alpha)-1/6\sin(3\alpha)+1/2)$**

From this a modified Waldram Diagram (or CIEL Diagram) might be constructed using Microsoft Excel where **ATAN(TAN(α*PI()/180)*COS(β*PI()/180))**, provides the equivalent angle '**α**' in the CIE Lambert formula above.

Figures 8 and 9 below show the comparison between the traditional Waldram Diagram droop lines and the amended version using the above formula.

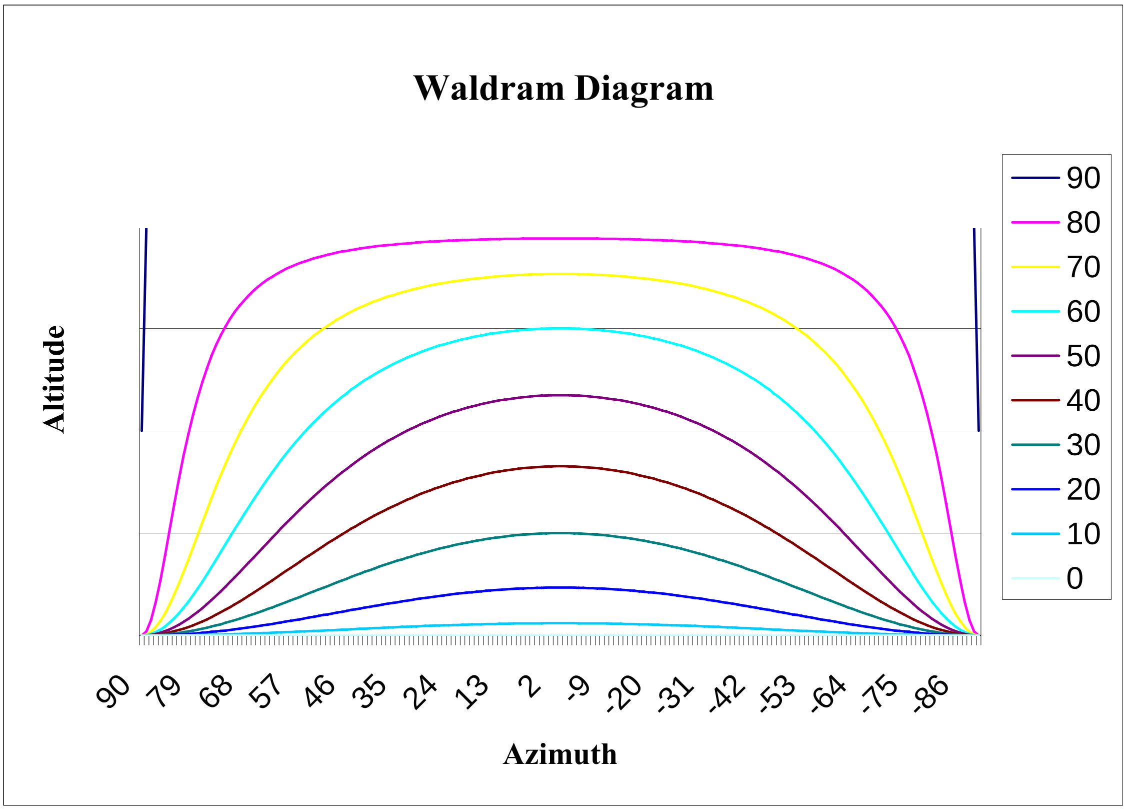

Figure 8: Waldram Diagram

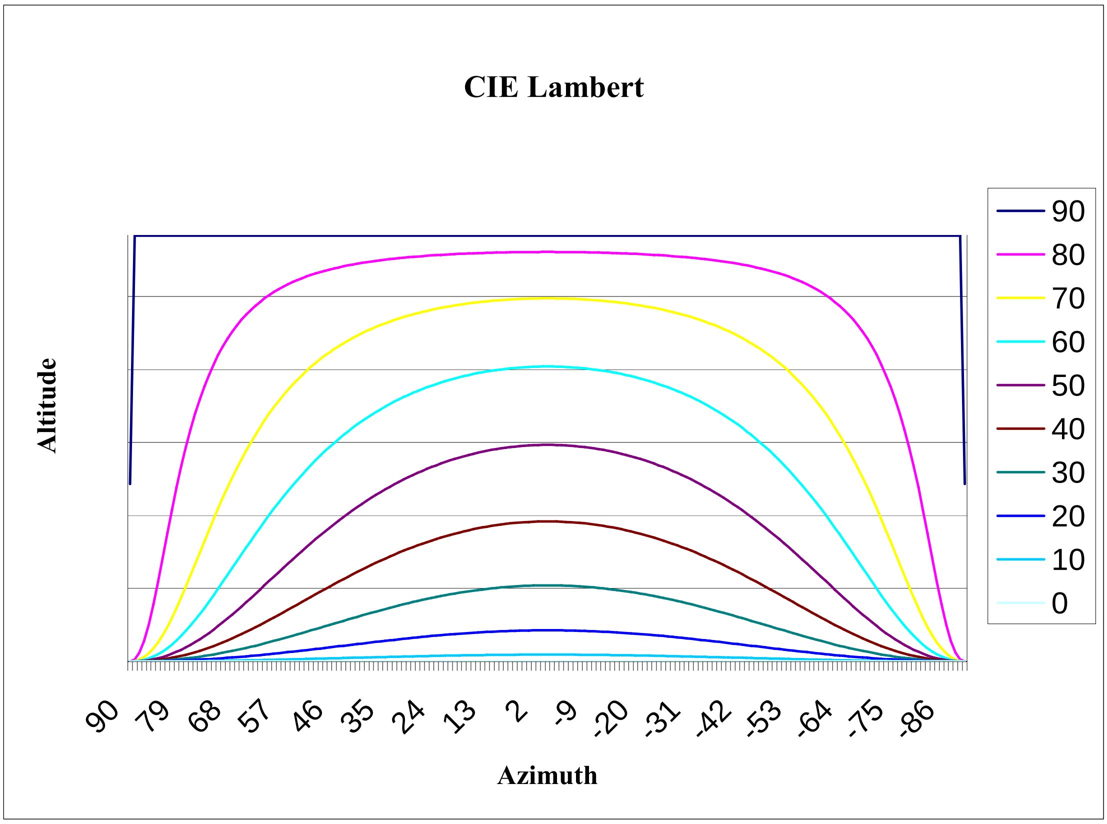

Figure 9: CIEL Diagram

A direct comparison of the two charts shows that spacing of the lines at lower altitudes is less and at higher altitudes greater, using the CIE Lambert Diagram. This means that light from higher altitudes has greater value than at lower altitudes. The significance of this is that in rights to light cases most of the light being received is from the sky above 45 degrees and thus the diagram will predict a greater amount of light entering a room than the Waldram diagram for the same point. Figures 13 and 14 below show how this relates to the results in the test room.

7. Testing of the New Diagram

A test room was provided by the BRE and readings were taken within the room. Figures 8 and 9 below show the outside of the building being tested and the obstruction opposite.

The room was also modelled electronically and physically so that actual results could be compared with those obtained through traditional means, electronically and in the artificial sky dome at Anglia Ruskin University.

Figure 10: Outside of the Building being tested

Figure 11: Obstruction Opposite Window

Figure 12 below shows the view from one point within the room, looking through the window towards the obstruction

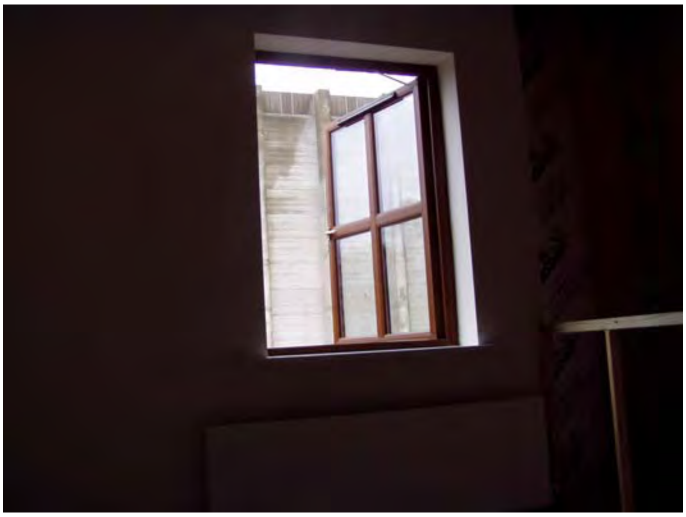

Figure 12: View from Within Room

This shows how the obstruction looked through the window and the same projection onto the Waldram Diagram is at Figure 5 above. The amount of sky visible is at the threshold deemed by Waldram to be just sufficient. Note that the Waldram diagram ignores the window frame.

Using the Waldram Diagram results for a series of points within the room produces a contour line as shown in Figures 6 and 7 above.

7.1 Comparison of Results from Two Methods

Both methods, the Waldram Diagram and the CIEL Diagram, were then used to produce a series of contours for different values of illuminance within the room.

Figure 13 shows the results from the Waldram methodology and Figure 14 the results from the CIEL methodology.

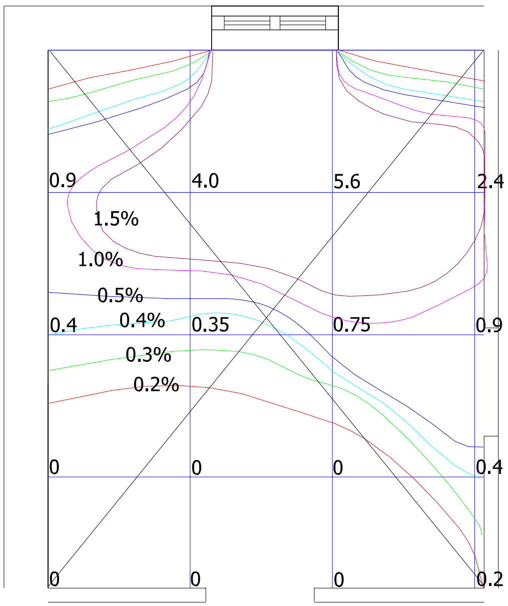

Figure 13: Contours Using Waldram

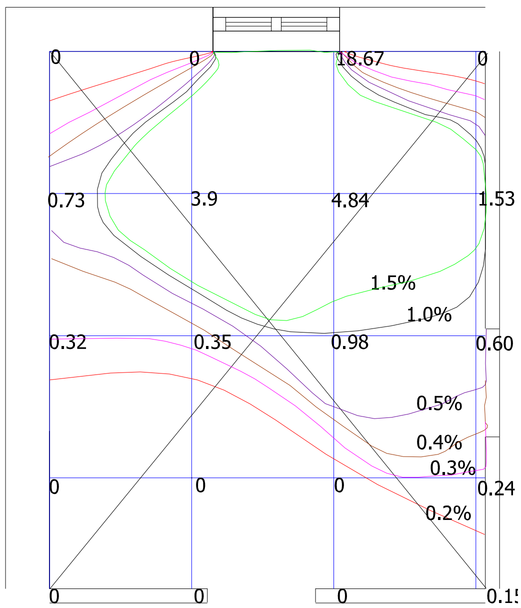

Figure 14: Contours using CIEL

7.2 Comparison with results achieved experimentally

Readings taken on site and in the artificial sky dome using a 'Megatron' meter that allows the user to determine the daylight factors at any point within the room by comparing the value of the light at that point with the unobstructed value of the light from the sky dome. Once it was clear that the model in the sky dome was producing results that were close enough to those achieved on site, the model in the sky dome was then altered so that the internal surfaces were non reflecting and the glazing was removed so that only the sky factor was being measured and the windows were not causing an obstruction..

The outcome of these results was that the value at the centre of the room, when only the sky factor was being measured, which is the closest approximation to the Waldram methodology, achieved a result of 1.5%. Daylight Factor. This figure is closest to the predicted result in figure 14 above. By comparison, the Waldram Diagram only predicts a value of 0.4%. These equate, in a 5000 Lux skydome, to 75 Lux and 20 Lux respectively.

8. Consideration of results of research

There were two main areas to this research, firstly to try to establish what illuminance is actually required for normal use if it were assumed that this was to be totally supplied through natural daylight remembering that this excludes specific task lighting requirements, with the aim to demonstrate that the accepted level of 1 foot candle is insufficient. The second was to derive a methodology for determining the actual amount of light that would be received in a room whilst still providing a graphic output from which rights to light practitioners could assess loss and thus advise both their clients and the courts.

It was relatively simple, in a controlled environment, to establish that the majority of participants required rather more than 1 foot candle of illuminance for ordinary use and the fact that over 80% required approximately 2.5 times that was not a great surprise and would not of itself cause surprise amongst practitioners.

The derivation of a new methodology for measurement was rather more difficult in that first the fundamentals of the present measuring system had to be tested and in doing so challenging the assumptions that had been made by Waldram and others for reasons of mathematical simplification more than anything else.

Of most significance was the fact that the traditional methodology, failed to predict the correct value of illuminance within the test room whereas the new CIEL diagram achieved a close approximation.

9. Conclusions

Whilst it has always been known that the Waldram Diagram does not provide a true representation of reality, this research has shown that there is sufficient doubt, that it provides even a close approximation of levels of illumination within a room lit solely by daylight, to warrant a re-examination of the basis of assessment. The proposed CIEL diagram achieves, at least in the property tested, a result that is demonstrably closer to reality whilst still providing a constant basis for assessment i.e. eliminating variables that will remain constant for both sets of calculations, existing and proposed.

When Waldram's assertion, that 1 foot-candle of illuminance is sufficient, is tested under controlled conditions it is apparent, even with a very limited study, that this is not adequate for any normal working conditions without artificial light and that the level required by the majority of people is more likely to be in the region of 25 Lux or approximately 2.5 foot-candles or 0.5% of the sky dome.

Thus, if the example room illustrated above were assessed using the CIEL Diagram and the requirement for the room to be lit over 50% of its floor area to 25 Lux; or more, then it would be on the cusp of being acceptable whereas using the Waldram Diagram and 0.2% of the sky dome the room would be considered more than adequately daylit. It is interesting to note also that even using the Waldram Diagram, if a value of 0.5% is sought, the room would be consider to be only just about sufficiently daylit.

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