ANGLIA RUSKIN UNIVERSITY

THE VALIDITY OF DAYLIGHT CALCULATIONS IN RIGHTS TO LIGHT CASES

(Challenging the validity of the methodology used by expert surveyors for determining whether a loss of light is actionable in law)

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ANGLIA RUSKIN UNIVERSITY

ABSTRACT

FACULTY OF SCIENCE AND TECHNOLOGY

PROFESSIONAL DOCTORATE

THE VALIDITY OF DAYLIGHT CALCULATIONS IN RIGHTS TO LIGHT CASES

By PETER STANLEY DEFOE

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There is a need to re-evaluate the basis of assessment of the sufficiency of daylight, in Rights to Light cases, where the loss of daylight after obstruction might lead to injunction and/ or damages. The aim of this research was to discover whether it is possible to justify an alternative level of sufficiency. It has however been established that any substitute methodology would need to be able to produce results which are capable of being used in both negotiation of compensation and advice to the court

By testing the validity of the original research, comparing this with alternative methods of measurement and a mathematical analysis of available illuminance using site and model measurements for triangulation, a new standard has been developed which more accurately represents the value of daylight in a room and leads to a better assessment model. Further research and experimentation would test and confirm the levels of illuminance required for sufficiency.

It is proposed, therefore, that the daylight calculation should be undertaken, in future, using a CIE overcast sky model, accounting for Lambert's formula and that the readings should be taken at work surface level (approximately 762 mm in most cases) rather than the current level of 850 mm. 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.

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Introduction

An entitlement to 'sufficient light' for the comfortable use and occupation of a dwelling house, or for the beneficial use and occupation of business premises, 'according the ordinary notions of mankind'

Lord Lindley, *Colls v Home & Colonial Stores* [1904] AC 179, HL

0.1 Purpose of the Research

The research discussed in this thesis demonstrates that the Waldram Method of assessment of daylight should be reconsidered and that a more relevant and more accurate method should be used. This will be accomplished by examining how much daylight is considered to be necessary, how much light is available and how this can be measured in a consistent and uniform manner. All of the existing alternatives will be considered, in addition to considering a potential new methodology.

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 is 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.

0.2 Significance of this Thesis

The method of calculation of daylight sufficiency, which has been accepted by the Courts, is based upon research undertaken by a small group of people in the early 20th Century. Of the individuals involved, the name most closely associated with the method used in 'Rights to Light' cases is that of Percy Waldram.

Waldram gave evidence to the Courts on a number of cases over a period of years where it was apparent that the Judges appreciated the manner in which the evidence was presented and their decisions were based upon the results, which were provided using the Waldram Diagram. In subsequent years, others have used this same methodology in evidence and the Courts have continued to accept the basis of assessment whilst failing to establish anything more than an indication of what they truly believed to be sufficient for the ordinary needs of man.

Since the original research and the publications, which have appeared over subsequent years, there have been many advances in measuring techniques, which have been applied to the measurement of daylight for planning and other purposes, but there has been no detailed critical assessment of the validity of the original research.

Waldram determined that the light from 0.2% of the sky dome, adjusted according to his formula, would provide 1 foot-candle of light at the working plane. (Definitions of foot-candle and other terms appear at appendix one). The Courts have since interpreted that if this amount of light was available over 50% of the area of a room then the room generally may be adequately lit. In more recent times this has been brought into doubt (Pitts 2000, Chynoweth 2004 and 2005, Defoe 2007) and whilst the measurement process has not been challenged, the well lit area may have to be larger. This basis has continued to be accepted by 'Rights to Light' Surveyors when advising their clients whether a proposed development is likely to cause an actionable loss to an adjoining property.

The situation now is that some practitioners are questioning whether the established amount of light is in fact sufficient and argue that modern technology would allow us to use more sophisticated methods of assessment, if they can be justified to the satisfaction of the Courts. This is evidenced by the record of the Focus Group Discussions at appendix two of this thesis. What is also clear from these discussions is that a more complex methodology would not find favour amongst practitioners.

It is possible that the accuracy of the Waldram method of measurement of sky component may not be critical in either manual or computerised calculation but the transfer of this information to form contours is more prone to error and an error as small as 10% may, in Law, be the difference between a non-actionable loss and an actionable loss. That is to say that a loss of 50% ± 10% could be as low as 45% or as high as 55% and, bearing in mind that the daylit appearance within a room is dependent upon the internal finishes of the room, the measurement may not in fact represent a true value of the daylight in any event.

With changes to legislation affecting the amount of daylight which may be received by windows, through residential buildings being placed more closely together to meet the requirements of the Planning Guidance Document PPG3, for example, and through the requirements of the latest Part L of the Building Regulations to reduce energy losses, the levels of light within new dwellings may be decreasing without the added pressure of new external obstructions being introduced. There is also the widely accepted premise that health can be affected by reductions in the quantity of daylight received and this can be observed during autumn and winter when more people are said to be affected by seasonal emotional disorder.

The need to establish a new standard and method of calculation of daylight values in 'Rights to Light' cases is therefore 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 the original research.

0.3 Why it is Appropriate to Undertake this Research

'Rights to Light' work is a curious combination of the legal, business and scientific areas. The practitioner should, ideally, have gained experience in undertaking surveys of properties including level surveys, knowledge of legal precedent and negotiating skills. Whilst these are not absolute pre-requisites, and there are some well regarded practitioners who have reached their current position through other routes, it is recognised that the qualification of Chartered Building Surveyor does usually arise through gaining experience in these core areas.

In the context of a Professional Doctorate, it is also important that there is a strong overlap between the subject matter of the doctorate and the professional work being undertaken as this has considerable bearing on the ability to undertake the necessary research and to produce the resulting analysis within the timescales available.

The author qualified as a Chartered Building Surveyor in 1978 and has since gained qualifications in Arbitration and Business Management Systems. The author's father was both a Chartered Building Surveyor and a practitioner in the 'Rights to Light' field and has the unique benefit of access to modern measuring technologies, a test subject room at the BRE site at Garston and the results of independent analysis undertaken by Paul Littlefair, an acknowledged expert on lighting at the BRE. The author also wrote the specification for the software now used by his practice for calculating daylight and sunlight for planning purposes and for 'Rights to Light' calculations.

Amongst the benefits of undertaking this research within the structure of the professional doctorate are that experienced researchers will review both the process and outcome. Ultimately, publication of the thesis to the peer group should result in positive change and be of benefit to professional practice.

In addition, the law of easements under which this falls, is currently under review by the Government and this research may provide a valuable input to their deliberations.

0.4 Explanation of Terms Used

Throughout this thesis there are various terms used which are peculiar to 'Rights to Light' and Daylight calculations and these will be explained at the appropriate time but it is worth identifying some of the fundamental terms including those, which appear in the title of this thesis.

Percy Waldram is forever linked to the methodology used for daylight calculations in 'Rights to Light' cases but he was by no means the only person who was involved with the research or in the methodologies used. His son John was certainly involved as were Messrs Taylor and Walsh. However the diagram which is used in the traditional calculation process is called the Waldram Diagram which is a rectangular representation of the illumination from half the sky dome which has been adjusted for the relative value of luminance produced by the sky at various angles of elevation and has useful droop lines marked on to represent relative perspective.

Daylight calculations are not merely undertaken for 'Rights to Light' purposes. In fact there is an increasing use for planning purposes to demonstrate sufficiency of daylight in and around planned new developments. However the methodology used for planning purposes differs quite significantly from the method used in 'Rights to Light' cases and highlights the need for an analysis to explain why the methods which satisfy planning requirements are not considered to be appropriate in 'Rights to Light' cases.

A Right to Light is a negative easement, recognised in Law, which might arise through long user or by a grant made between the servient and dominant owners. The concept is uniquely British and specifically English. Whilst it is recognised in certain British dependencies such as Gibraltar and formerly Hong Kong, it is not, for example, recognised in Scotland. Many other countries do acknowledge the need for sufficient daylight and in most other cases the countries use very similar methods of assessment to those used in England, for planning purposes.

The other concept identified is that of a room being 'well lit'. It will be seen later in this thesis that in fact the term is used as shorthand for the area of the room which receives more than the threshold level of light from the sky.

Further photometric definitions appear in appendix 1.

0.5 Synopsis of Theory and Approach Taken

There is a growing consensus within the specialism of 'Rights to Light' surveyors that there is a need to re-evaluate the basis of assessment of sufficiency of light in a room, for the purpose of providing evidence to the courts. (Defoe 2007)

The hypothesis for this research is that the methods used currently do not provide an accurate measurement of sufficiency.

By examining current practice, which is still firmly based on the original research of the early twentieth century, and by focussing on and testing the validity of the original research and comparing this with alternative methods of measurement for purposes, such as Planning, it is anticipated that a new standard might be developed which more accurately represents the value of daylight in a room and thus leads to a better test for sufficiency.

Whilst it is not proposed to explore, in this thesis, the law of easements which relate to the right to light it is appropriate to identify the relevant case law which sets the legal background and framework together with the theoretical approach taken to providing advice to clients in respect of 'Rights to Light'. Chapters 1 and 2 of this thesis identify the relevant cases and explore the mathematics involved in calculating available light using methodologies, which have been accepted by the Courts.

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 by many practitioners.

The concern amongst these practitioners is that the method of calculation of daylight in 'Rights to Light' cases is no longer valid (Chynoweth 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.

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*) 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 illuminance provided by the skydome is 500 foot-candles and that therefore 1 foot-candle (approximately 10 Lux) of illuminance is provided by 0.2% of the skydome and that, provided 10 Lux of illuminance from the sky is available to over half the area of the room, the room should be adequately 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 and in particular the following assumptions:

- that total Illuminance provide by an unobstructed skydome on the horizontal plane is 500 foot-candles (Approximately 5,000 Lux)
- a Uniform Sky can be assumed for the purposes of these calculations
- Lambert's Formula can be used to define the adjustment factor for low angle light and that this results in a symmetrical adjustment at the top and bottom of the chart
- the Waldram Diagram, which was originally 180 degrees in width by 90 degrees in height 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 foot-candle of illuminance 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 not be possible to justify the assumption under any circumstances.

Potential existing alternatives include the use of the 'no sky' line, the Vertical Sky Component or Average Daylight Factors as described by Littlefair 1991.

By using an actual room on the BRE site at Garston near Watford and comparing actual readings with theoretical and modelled readings it should be possible to determine whether the Waldram method is in fact a valid method of assessment. If, as is believed, there is a significant difference between actual and theoretical results, then the research methods used should indicate a more accurate methodology.

0.6 Research Objectives

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.

0.7 Research Plan

A considerable volume of research has been undertaken since the 1960's but more specifically in the last two decades, into daylighting generally but relatively little into the application in respect of 'Rights to Light' cases. This research project is designed to establish whether the present methods of calculation are valid and reliable and whether the level of lighting, which is needed, will be different from that which has previously been accepted.

The first objective will be to try to determine, by research, what amount of light is sufficient for ordinary needs without requiring artificial light. This may be achieved through questioning of experts in the fields of ophthalmology and psychology or even by replication of the original jury approach. Then it is essential to review the research and methods of calculation used by Waldram and others with particular emphasis on the scientific approach of using average sky values and the effects of variables such as internal and external reflectance. The intention is to compare the Waldram method with other forms of measurement, including those methods contained in guidance issued by the Building Research Establishment (BRE), CIBSE and others, and to assess whether any of the available methods provides a sufficiently accurate method of measurement or whether an alternative, simpler approach might be adopted such as measuring the 'no sky' line, which is the notional location within a room where the sky is no longer visible from the working plane.

Waldram recognised that the human eye is remarkably adaptable and that what the eye can tolerate for a short period of time may not be acceptable over the longer period. Once the required level or levels have been established, the various existing methodologies can be compared to assess whether the results are significantly different and, by using current technologies and databases, how this amount of light may be received from the sky dome and thus how measurement may be undertaken. By using an artificial skydome it might, for example, be possible to directly compare the effect of uniform and non uniform skies which can have a direct bearing on the amount of perceived light within a room and this may be relevant to the final calculation.

The research commences with a detailed analysis of the historical research publications and seeks to replicate early experiments to ascertain whether similar results can be obtained using both the original and modern techniques.

Another part of the research will involve experimental research design and a routine has been established for the measurement of available light, outside a subject room, at pre-defined intervals over the course of a year and the pre-defined variables. Measurements taken, at the same time, from within the room and at various grid points within the room can then be used to determine how much of the available light passes through the window to the room at any point within that room. In addition a daylight factor meter can be used which eliminates the effect of the variability of external lighting by taking readings simultaneously both internally and externally.

These measurements can then be compared to the predicted levels, which result, from current methodologies and from the use of the artificial sky dome.

The approach outlined above will involve monitoring and modelling the daylight performance of a standard room as well as detailed historical comparisons. It will be possible to extend this by using experimental techniques to test what happens when variables are changed such as physical obstructions and sizes of windows, colours of walls etc. The first stage will be to establish how the presently accepted level of sufficiency of light was established, by reference to the original research. This will involve the accumulation of relevant archived research papers and studies undertaken around the beginning of the last century and analysing them to determine whether any of the results are still reliable and can be used and/ or replicated for the present study. From this will develop two main lines of enquiry. Firstly, by comparing subsequent research, on daylighting generally, with the original research to see whether and how much the assessment of daylight has changed in the intervening years and, secondly to determine whether the original research can be replicated.

It may be appropriate to undertake some limited research into the areas of ophthalmology and psychology to ascertain whether any discussions have taken place on the levels of light which are considered to be necessary for ordinary purposes and more importantly whether a set level of daylight is considered to be desirable. The next phase of the research will use the results of the initial research to try to establish the amount of daylighting, which is in fact adequate, and then to determine how this is best measured in the context of 'Rights to Light' cases.

0.8 Assessment Of The Source And Quality Of The Research Material

Very little of the original research and few, if any, of the published papers are available electronically and it was necessary therefore to locate original documents from a number of sources. These sources included the Royal Institution of Chartered Surveyors (RICS) library and the libraries at Anglia Ruskin and Salford Universities. The thesis entitled 'Daylighting Design and Energy Conservation' by P J Littlefair, proved particularly useful on a number of levels.

There was disappointment however in being unable to locate any of the original research notes from the first quarter of the twentieth century and, by reference to published papers; it is unclear whether these were ever made available to others for review.

Of particular interest was the paper published by the RIBA following Percy Waldram's lecture entitled 'The Natural and Artificial Lighting of Buildings' in 1925 which also included commentary from other professionals of the time, which cast doubt on some of his assertions.

Most notable, however, is the frequency with which the same assertions were made in other publications and it was discovered that the same text was being repeated on each occasion, suggesting that there was no further research or validation beyond that point.

0.9 Difficulties Encountered

It had been intended to try to replicate one of the original experiments which involved the use a of a jury of people who each assessed the amount of daylight within a set of rooms and indicated where they believed there to be sufficient light.

Apart from the initials of the individuals involved, which enable an educated guess to be made as to the identities of some of the participants, there is no other information, which might be of use.

Knowledge of Age, Gender, State of Health and the like would all be useful in understanding how an opinion as to sufficiency of daylight might be formulated but this information is totally absent. In addition, there is no information regarding the appearance of the rooms, which were assessed although it is widely known that these rooms included offices at what is now the Ministry of Defence in Whitehall and the RICS at Great George Street, Parliament Square.

Some of the rooms at the RICS were, until recently, finished in dark material and wood panelling which would undoubtedly have affected the results.

To be effective, it would be necessary to identify a group of people who represented a cross section of society and who could be trusted to record their observations accurately. The group would have to be sufficiently large to give any degree of confidence and this in itself creates a problem in that, to be consistent, they would all need to carry out their assessment within a very short time frame. With changes in sky conditions, no two days will be the same and often even on overcast days, changes in lighting conditions occur continuously. Further, since the best time to undertake the assessment would be an overcast day, how easy is it to arrange for a large group of people to be available at the right time on the right day?

An alternative approach was required where the conditions were much more controlled and this is described further in chapter 5. It is recognised, however, that the benefits of replicating the 'jury' approach are not considered to be sufficient, in isolation, given the perception that the results will have low validity.

0.10. Ethical Considerations

The use of material or information relating to an identifiable case and/ or client might involve the use of privileged and/ or confidential information. For this reason, amongst others, it was decided to use a room within a building on the Innovations Park at the BRE for the test process. Both the BRE and the constructor of the show house (Kingspan TEK) gave their permission for this use.

The 'jury' approach, described in chapter 5, was carefully controlled to ensure that the participants were not put in potential danger and all confirmed their willingness to participate, which was made voluntary, by completing and signing the data sheet.

0.11 Structure of Chapters

The various issues considered within this thesis are laid out in figure 1 below which forms the basis of the inter-relationship of the main chapters of this thesis.

Part A describes the historical background and development of methodologies by way of a literature review.

Part B examines the current methodologies and available alternatives.

Part C defines the hypothesis, the research methodologies which were uses and the results obtained, concluding with an analysis of the results.

Part D provides the summaries and the conclusions reached, whilst identifying the limitations on the research and making recommendations for the future and for continuing research.

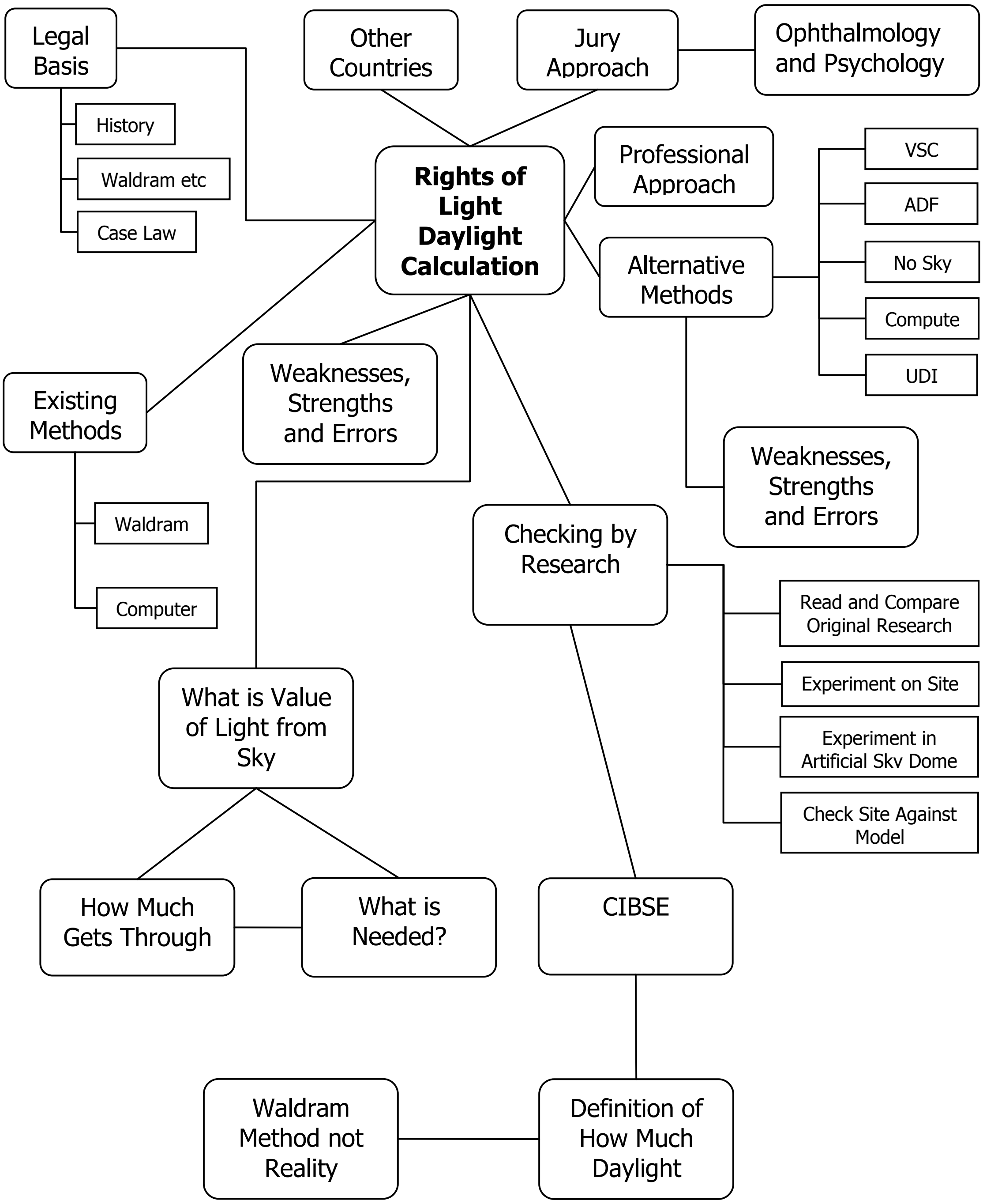


Figure 0.01 Mind map of research project

The initial conceptual framework for the research project is illustrated in Figure 0.2 below. The main areas which fall outside of this framework are firstly the possibility of taking a case through the courts to test the acceptance of any alternative methodology and secondly any application to Planning guidance. Few cases actually reach the courts and even fewer explore new interpretations or theories. This will only occur once a new theory has achieved currency with practitioners generally.

The proof of actual need also posed some difficulties as, despite considerable research it has not been possible to locate any authority that defines how much daylight a person actually needs, although there is ample information on how much task lighting is needed where artificial lighting is being considered. This is discussed further in this thesis as is the jury approach, which provides an indication but not actual proof of minimum levels of daylighting.

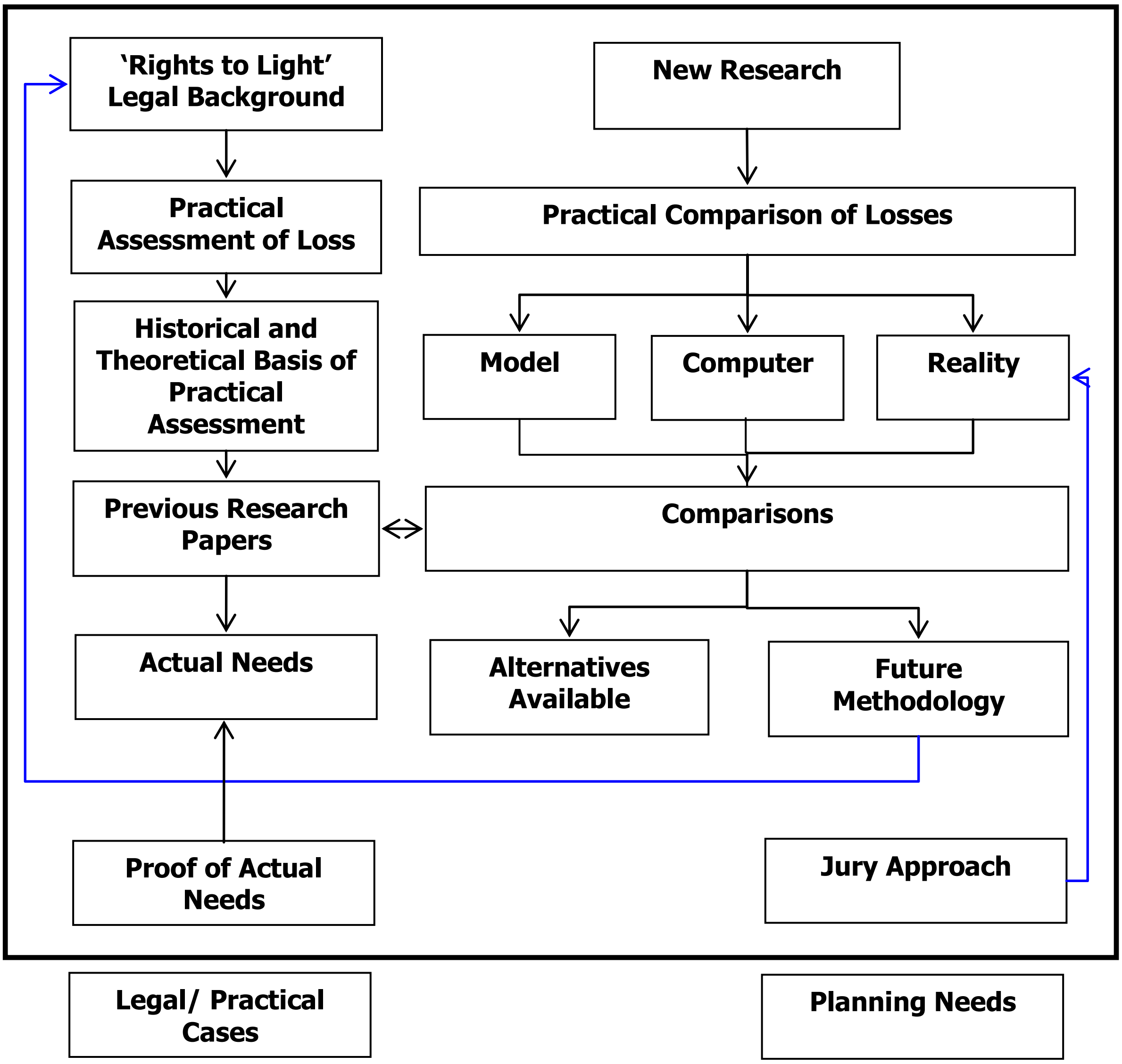


Figure 0.02 Conceptual Framework

0.12 Anticipated Outcomes

It must be acknowledged that there is a possibility that the results of this research could match the existing standards and/ or measurements in all respect. This would justify the position taken by many experts but it is highly unlikely to be the case. There is equally a possibility that there may be a slight difference between the standards and/ or the measurements and the results obtained, which is too negligible to concern practitioners but whilst this is possible, it is still not very likely. Finally, there may be a great difference between the standards and/ or the measurements and the results obtained. This was expected to be the most likely outcome not least because the number of variables involved in the traditional methodology must lead to statistical error. It is possible that this research could lead to a resetting of the computer software for absolute results even if the comparative calculations match the physical results. That is to say the starting and ending values may differ but the loss could be identical.

Part A
The Historical Background and Development of Methodologies (Literature Review)

Chapter One

The Legal Background

'It is scarcely possible to anticipate the complication belonging to an interest in Ancient Lights.'

Humphry W. Woolrych, 'the Laws of Lights', 2nd edition (1864)

1.1 Introduction

This chapter explores the legal position in respect of 'Rights to Light'.

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 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 elsewhere in this thesis but for the purposes of this introduction, 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 recently issued their consultation paper No 186, which looks at Easements, Covenants and Profits à Prendre. This consultation process may, in itself, 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.

Date	**Event**
1189	Time Immemorial
1832	The Prescription Act
1866	Dent v. Auction Mart Co
1904	Colls v Home & Colonial Stores
1921	Charles Semon and Company, Limited v. Bradford Corporation
1927	Horton's Estate Ltd v James Beattie Ltd
1930	Price v. Hilditch
1931	Sheffield Masonic Hall Company, Limited v. Sheffield Corporation
1954	Cory v The City of London Real Property Co
1967	Ough v King
1986	Carr-Saunders v. Dick McNeil Associates
1994	Deakins v. Hookings
2005	Midtown Ltd v. City of London Real Property Co Ltd
2006	Regan v Paul Properties DPF No1 Ltd and Others

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

In undertaking research of historical records it is important to recognise that opinions are often recorded as facts and that there is the possibility that, over the years, these opinions have become enshrined in the interpretation being applied by practitioners. It is important therefore to closely examine the relevant legal background to attempt to determine what is fact and what is merely opinion accepted as fact.

1.2 Time Immemorial

It is difficult to establish at what point daylight calculations were first undertaken but there is certainly evidence that people took the right to daylight seriously in the middle ages and that they relied upon the notion of 'time immemorial' when settling their right to the passage of light over another's land. The first year of the reign of King Richard I in 1189 was established by the Statute of Westminster in 1275 as being beyond the length of the oldest man's memory at the time and was thus deemed 'time immemorial' and anyone who could demonstrate that their use has been enjoyed since time immemorial would enjoy that use as of right and would have that right protected by the Courts. This remains, in theory, one of the methods by which a Right to Light can be proven although it is unlikely that any new cases will arise.

1.3 The Prescription Act 1832

More recently, but still over 170 years ago, the government of the time passed the Prescription Act 1832 which, in Section 3, states *"When the access and use of light to and for any dwelling house, workshop, or other building shall have been actually enjoyed therewith for the full period of twenty years without interruption, the right thereto shall be deemed absolute and indefeasible, any local usage or custom to the contrary notwithstanding, unless it shall appear that the same was enjoyed by some consent or agreement expressly made or given for that purpose by deed or writing".*

At this point there is no indication that the amount of light was to be considered. The word 'absolute' is linked to the 'right' rather than to the quantum although it is tempting to consider the implications if it could be proven that no reduction was to be permitted once a right had been acquired.

1.4 The Legal Cases and Their Implications

1.4.1 <u>Dent v. Auction Mart Co. (1866) L. R. 2 Eq. 238</u>

This case was, in fact, only the headline case in a group of three, where the plaintiffs were seeking an injunction against the obstruction of light to their premises, which was heard by Sir W. Page Wood, V.C.

The Plaintiffs in this, the first of these suits, Messrs. Dent, Palmer, & Co., China and East India merchants, were lessees for twenty-one years from the 24th of June, 1855, of a house, No. 11, King's Arms Yard, in the City of London, where they carried on business. The Plaintiffs in the second suit, Messrs. Pilgrim & Phillips, were in business as attorneys and solicitors, at a house situate in Church Court, Lothbury, under a lease for twenty-one years from the 25th of December, 1859.

From the evidence it appeared that the result of the proposed development would be, as one of the witnesses deposed, *'to place the staircase windows of Messrs. Dent's house in a dismal stagnant well of small size and great depth; to add a row of ordinary two story houses on the top of a row of ordinary four-story houses, and nearer by seven feet to the two houses; and to reduce the superficial area of space of which the two houses formerly had full enjoyment (except where the twenty-one foot building stood) from about 454 superficial feet to about 205 feet'.*

The Defendants admitted that their building would interfere to some extent with the Plaintiffs' light and air, but only to a limited degree, and not to such an extent as to make the houses less comfortable or convenient.

In reply, the Plaintiffs' witnesses asserted that side light was quite as valuable as front light and more so in the mornings and evenings, when light was beginning or failing but the Defendant's solicitors argued that the models were inaccurate, and, in any case, the Court could not decide upon mere inspection of models.

In summing up his decision, the Judge stated that, in order to give a right of action, and sustain the issue, there must be a substantial privation of light sufficient to render the occupation of the house uncomfortable, and to prevent the Plaintiff from carrying on his accustomed business. He thought it probable that Messrs. Pilgrim, for example, by carrying on their business by gaslight all day, would not lose a single client; but they would carry it on much less beneficially to themselves, whether in discharging their duty to their clients on the one hand, or in preserving their health and their facility of transacting business on the other. He also observed that it was no answer to a Plaintiff complaining that his light had been obstructed to show that other persons had been able to carry on trade successfully with less light than would remain to the complaining party after the obstruction had been set up.

Within his decision he observed that the Defendants had argued that the Plaintiffs might have made their windows larger and he stated that '*it was not for the Defendants to tell the Plaintiffs how they were to construct their house, and to say, 'You can avoid this injury by doing something for which you would have no protection'. If the Plaintiffs constructed their new window, it could be immediately obstructed as being a new window. They have a right already acquired by their old existing window; that right they wish to have preserved intact; and I think they are clearly entitled to retain the light as they acquired it, without being compelled to make any alteration in their house to enable other people to deal with their property'.*

It is interesting in this respect that it is in fact accepted by practitioners that as long as new windows occupy substantially the same location as the original windows, that the right would be continuous but clearly this had not been decided at the time.

Finally, the Judge turned to the question of the suggestion of glazed tiles – '*often made and never listened to by the Court …. that a person who wishes to preserve his light has no power to compel his neighbour to preserve the tiles, or a mirror which might be better, or to keep them clean ……, and, therefore, it is quite preposterous to say, 'Let us damage you, provided we apply such and such a remedy.' …. The question comes simply back to this: Is there substantially an interference with comfort? Is there a substantial diminution of light for carrying on work?'*

Referring to the 'important evidence on the part of scientific witnesses', which he stated *'could not be disregarded'*, he confirmed that. the result of the scientific evidence was that light which formerly fell upon the floor of the Plaintiff's room to the extent of five feet three inches, would now come in only to the extent of one foot; and in another direction light which formerly fell eight feet into the room would now reach it to the extent only of four feet six inches. At this point the judge was referring to what is now referred to as the 'no sky' line although it is not clear whether it was actually being applied to floor level or to worktop level.

One particularly interesting *obiter* comment was the following: *'I confess it did strike me as a singular thing that a man should be compelled to wear out his eyes daily by gaslight for one hour a day - and every one knows what the effect of artificial light is upon the human eye - without its being supposed to be any diminution of his comfort.'*

Clearly there is a difference between the gas light of the day and modern electric lighting but the Judge recognised the benefit of natural daylight.

1.4.2 Colls v Home & Colonial Stores 1904 A.C.203

For many practitioners, the starting-point in considering whether an interference with light constitutes a nuisance is the decision of the House of Lords in *Colls v. Home and Colonial Stores Ltd [1904] AC 179 when* . Lord Lindley clarified, that '*….generally speaking an owner of ancient lights is entitled to sufficient light according to the ordinary notions of mankind for the comfortable use and enjoyment of his house as a dwelling house, if it is a dwelling house, or for the beneficial use and occupation of the house if it is a warehouse, as shop or other place of business. The expressions 'the ordinary notions of mankind', 'the comfortable use and enjoyment', and 'the beneficial use and occupation' introduce elements of uncertainty; but similar uncertainty has always existed and exists still in all cases of nuisance, although the right to light has been regarded as a peculiar kind of easement.*

It was also stated that it was not how much light was taken that was the criterion but whether what was left was sufficient. How the dominant owner chooses to lay out his building is his own affair.

By this judgement it was inferred that a development, which reduced the amount of available light to a room but still left sufficient according the judgement of the court, would not be considered to have caused an actionable loss. The difficulty, which it created, was that the decision on whether sufficient light remains was left with the court and so it remains to this day.

1.4.3 Charles Semon and Company, Limited v. Bradford Corporation. [1921. c. 4353.1

The Judge in this case, Eve J., concluded from the evidence that there was a consensus of expert opinion that if the worst lighted desk received 1 per cent of the sill light that the room would be adequately lit for the purposes of an ordinary public elementary schoolroom and quoted Mr. Waldram who had stated that *'A public elementary school constructed according to the rules of the Board of Education, that is a room wherein there is 1 per cent of sill light at the worst lighted desk, is the best side lighted room I have ever come across. For adult clerical work a much lower percentage is required'*. He also referred to Mr. Waldram's investigations, made some years previously, '*which had been accepted by textbook writers and confirmed by an average of 0.5 ascertained by the careful measurements of existing conditions at a large number of factories dealt with at pp. 40 and 41 of the First Report of the Departmental Committee, appointed by the Home Office (Waldram 1923), to enquire as to the conditions for the adequate and suitable lighting of factories and workshops, which led him to the conclusion that the point where ordinary people would begin to grumble at the quantum'*.

This judgement effectively reaffirmed the position that the court was also looking at the light that was left and whether that light so left was adequate in all the circumstances according to the objective standards of a reasonable man. The references are interesting in that the sill ratio is not longer used but rather the sky factor (both of which will be explained later in this thesis) and in fact it was proposed, by derivation, that the minimum sky factor should be 0.2% 'at the worst lighted point in the room'. The significance of this will become apparent later.

1.4.4 Horton's Estate Ltd v James Beattie Ltd 1927

In 1927, Russell J., the judge in *Horton's Estate Ltd v James Beattie Ltd,* stated that *"The human eye requires as much light for comfortable reading or sewing in Darlington Street, Wolverhampton as in Mayfair."*

This judgement established that no different measure should be applied for class of dwelling or for the task being performed and is something, which is being challenged, in more modern cases.

1.4.5 Price v. Hilditch [1930] 1 Ch 500

This is the first case where it is known that a plan, which may have been a sky contour diagram, was used. In that case the erection of a high boundary wall was established to be a nuisance. The case does appear to have been a somewhat extreme one, as Maugham J recorded at p. 505:

"A ground plan put in by one of the expert witnesses for the plaintiff shows the amount of floor space to which the light of the sky has access, calculated from the point of view of a table 2 feet 8 inches high, and the fact now is that there is hardly any part of the floor in the scullery from which the sky can be seen, whereas, before the erection of the wall, the sky could be seen from practically the whole of that small room."

The Judge in this case did not indicate whether there was a level of loss that might have been acceptable.

1.4.6 Sheffield Masonic Hall Company, Limited v. Sheffield Corporation. [1931. S. 2782.]

This case was complicated by the issue of whether a room with dual aspect could be deprived of light on one side to the extent that only by reliance on the light available from the other side would there be sufficient light to the room. However this ignores some of the more telling points, made by the judge, Maugham J., in his summing up when he made reference to previous case law and stated that the question to be solved by the Court was not really a question which could always be fairly decided by the amount of direct sky which would reach a hypothetical table two feet nine inches high in a particular room. Instead, he preferred to think that it was safer to rely upon the view expressed in *Colls v. Home & Colonial Stores, Ltd*. and to consider whether, as a matter of common sense, there would be such a deprivation of light as to render the occupation of the house uncomfortable in accordance with the ordinary ideas of mankind.

Of particular interest was that he stated that the hypothetical table two feet nine inches high is a test which might not always be satisfactory as it gave too much importance to the height of the window above the floor and he cited the example of a case which he had previously heard of a cottage with very low windows, in which he thought that the test was wholly unsound. The particular case was not identified but he remarked that he thought Mr. Waldram was quite right in taking into account reflected light coming from floor, walls and ceiling, and added that it was his opinion that such reflected light as that might often be of great importance.

This is remarkable in that most experts accept that reflected light is ignored in calculations and the only available interpretation is that Mr Waldram must have stated in evidence that the direct sky value was enhanced by internal reflectance.

The Judge went on to disagree that the injury done might, in all cases, be tested fairly by considering only the amount of visible sky light to be perceived by an eye situate two feet nine inches high and he found, among other things, that *'that would attribute the same result to a building ten feet away, cutting off, say, 50 per cent. of the light, as would be attributed to a building sixty feet away cutting off a similar number of degrees of light, and yet it is obvious to anybody who has ever considered the matter for five minutes that the effect as regards the occupation of a house and its comfort would be very much greater in the former case than in the latter'.* It was his opinion that it would be quite wrong to disregard reflected or diffused light coming to a room from outside as well as the effect of such light inside a room.

Referring to the doctrine established in *Dent v. Auction Mart Co*. that reflected light offered or promised by the owner of the defendants' premises ought, for the reasons given by the learned judge in that case, to be disregarded, he stated that this was nothing akin to the suggested proposition that, in considering whether there has been such a deprivation of light as to render the occupation of the house uncomfortable according to ordinary ideas, reflected or diffused light coming into the premises under the conditions that subsist is to be rejected. He voiced the view that in, his belief, there would be many rooms in ordinary buildings where the table test would give a wholly false view of the condition of things in the room and he added he had had cases before him, which supported that view. Unfortunately he did not cite the cases in his judgement. He did however go on to explain his understanding of the evidence supplied by Mr Waldram:

'The degree of illumination at any given point in a room may be expressed as a percentage of the illumination of a horizontal surface placed on a flat roof, all external buildings or other obstructions being supposed removed, and all visible sky assumed to be of uniform brightness. This method was explained by Mr. Waldram and the ratio is termed the "daylight factor." If, for the horizontal surface on the roof a vertical surface placed at the window-sill is taken, then the ratio is called "sill ratio." Obviously, the ratio when given as "sill ratio" is always double the "daylight ratio." The judge described his preferred method, as a series of contour lines which were drawn showing all the important variations in the percentage, *'But the charts so carefully prepared and so clearly explained by Mr. Waldram only indicate the area of the rooms in question which receive light that comes up to a standard fixed by reference to what he calls the "grumble point," which appears to be the minimum tolerable.'* He complained that the importance of this standard for *'ancient lights'* was not very clear to

him. In interpreting Waldram's evidence he summarised that where 50 per cent of the floor area measured at table-height (2 ft. 9 in.) 840 mm enjoyed a small percentage of light, then, the room is a well lit room and the Court ought to consider that the occupants have no just cause of complaint. Clearly he did not agree with this position. He also complained that Waldram had not *'made a chart in reference to that percentage showing the effect of the increased elevation of the new theatre'.*

In summary he described the net result of Waldram's charts as simply showing that, when estimated in reference to the 'grumble point' fixed by experts, the rooms on the third and second floors were well lit and that, according to Waldram's reasoning, the top room might even be deprived of a great deal of its present light and still the 'grumble point' would not be reached.

He then went on to state that *'Mr. Waldram's charts seemed at first to make liars of all the plaintiffs' witnesses…. because the charts took no account of …….those who used the colour-printing machines in the top room. At the height of the machines, which is 4 feet 6 inches the direct light coming over the old theatre reached a point about 8 ft. 6 in. from the windows and so came well on to the machines, and gave good light precisely where it was needed. The direct light coming over the new theatre only penetrates 2 ft. 9 in. and so only just reaches the end of the machines. Hence the operatives have now to put up with merely reflected light at the vital point where direct light was previously enjoyed. Considering that fact I have no hesitation in accepting in substance the evidence of Mr. Hamilton and Mrs. Redmond, and saying that Mr. Waldram's charts, carefully prepared and interesting as they were, leave me cold.'*

It is worth noting here that until the 1930s, the only way of judging what was sufficient was for the Judge(s) to go to the property concerned, sit down and try to read 'The Times'. They had to make allowances as best they could for summer and winter, for sunny days and heavy rain, to come to some sort of view as to whether it was enough.

1.4.7 Fishenden v. Higgs and Hill Limited 153 (1935) L.T 128

Sky contour diagrams were undoubtedly used in *Fishenden v. Higgs and Hill Limited 153 (1935) L.T 128* and printed in *Easements of Light (A synopsis of modern practice and a brief explanation of simplified methods of measuring daylight and assessing compensation)*, by John Swarbrick (1938). Mr. Swarbrick had been an expert witness for the plaintiff in the Fishenden case.

Crossman J referred (at p.131) to the *'so-called grumble line'* and the *'generally accepted view': 'that something like 50 per cent of an ordinary shaped room ought to be adequately lighted within this so-called grumble line.'*

The Defendants in that case, whilst accepting that the proposed development would bring the plaintiff 'materially beyond the grumble line', argued 'with great force' that no actionable nuisance was caused because the plaintiff would not be worse off than many other persons in London. That argument was rejected by Crossman J.

In the Court of Appeal, the appeal against the finding of nuisance was dismissed, the Court ruling that there was sufficient material before the learned judge to justify his conclusion that a nuisance would be committed. In their judgments, Lord Hanworth MR and Romer LJ said nothing disapproving of daylight plans, grumble lines or the 50-50 rule. Maugham LJ, whilst finding the daylight plans *'exceedingly useful'* said that *'no hard and fast mathematical standards can be applied'* (p.143) and continued at p. 144:

A passage in the evidence which appears to have impressed Romer LJ was where the plaintiff said that *'he now – that is to say, in the last few weeks – has to use artificial light to eat his lunch, though formerly he could do so by daylight'* and he stated *that 'In whatever neighbourhood a dwelling-house is situated, a man is entitled to have his ancient lights protected to this extent, that he may be able to go on having his lunch without the use of electric light in places where obviously he had so lunched.'*

1.4.8 Cory v The City of London Real Property Co 1954

In this case the use of the Waldram diagram was discussed and evidence was also presented by Dr Walsh, which demonstrates an interesting conflict of interpretation.

According to the evidence, the subject rooms could all be considered to be *'poorly lit'* and would suffer a reduction in lighting as a result of the development.

The judge, Upjohn J., referred, in his decision, to models, which were used in evidence and appeared to rely upon these in his understanding of the issues. He referred to the decision in *Colls* and quoted the view of Lord Davey at page 204 regarding the availability of sufficient quantity of light for ordinary purposes. He also referred to *Back v Stacey (1826) 2 C. & P. 465; 31 R. R. 679*, when Chief Justice Best summed up that *'In order to give a right of action and sustain the issue there must be a substantial privation of light, sufficient to render the occupation of the house uncomfortable'.*

Turning to the evidence he expressed the view that the evidence of theoretical calculations had proved very helpful and he thanked the experts whilst going on to explain the difficulties involved where exact measurements were not available but he stated that it was agreed that the differences were such as not to make any practical difference to the calculations of lighting experts. He then summarised his understanding of the *'grumble line'*, pointing out that it is not a physical line nor is it a fixed line as the point at which the user might grumble might vary from one moment to the next but that it did represent an average.

One of the experts, Mr Burnett, gave evidence based upon the *'no sky' line'* which differed from the approach taken by Mr Crompton, another of the experts, and this lead to some confusion until Mr Burnett revised his results.

This however highlighted, for the judge, the potential for errors and he went on to describe the *'very large numbers of imponderables which one comes across when making these calculations'*. He explained that the plaintiff's expert had used the original Waldram Diagram whereas the defendant's expert had used a revised Waldram diagram, which was devised by Mr Waldram in 1936 to take some account of the loss through reflection of light coming through the glass. Both sides apparently agreed that this would make a difference of only two or three inches.

Mr Burnett apparently took the brickwork as being the appropriate point from which to measure the light coming through the window whereas Mr Crompton took it from the bottom of the wooden frame of the window which they agreed would make a further difference. Then, going into detail they found that the building plan prepared by Dr Walsh, who was the defendant's second expert, differed from Mr Burnett's.

Up to this point it was acknowledge that if the room was 50% adequately lit and 50% inadequately lit, it would, on average, be a satisfactory room. Dr Walsh apparently agreed that this would be a rough and ready guide but he preferred *'the more modern methods'*, (Though what these were, is not recorded). The judge expressed the view that it might well be the case that the standards might increase with the passing of the years but confirmed that he was prepared to accept this standard for the case and went on to compare the relative results of the calculations.

Of the defendant's experts, the judge preferred the evidence of Dr Walsh referring to him as a *'gentleman of the highest distinction and very great experience'*. Dr Walsh was at this time an illumination engineer and he had proposed certain practical tests, which appealed to the judge as being helpful whilst not necessarily applicable in every set of circumstances.

The suggestion was that the loss of light should be assessed by taking a hypothetical set of observers, who were the persons who would occupy the subject rooms in question, and take them hypothetically from the room under the old condition to the room under the new condition instantly and to ask them to express their opinions on the matter. If the answers were, from some that there was no difference, some saying a little brighter and some saying a little darker then there could be no nuisance. If however there were unanimity then there was an appreciable loss.

Before deciding the result of the case, the judge dealt with the issue of Dr Walsh having given evidence in another case seven weeks previously (the case is unnamed in the decision) where Dr Walsh gave evidence that where the *'grumble line'* moved forward by 1 foot, between 4 feet 8 inches and 3 feet 8 inches that this would be serious but in this case, in one instance, a loss of 1 foot between 6 feet 6 inches and 5 feet 6 inches was not appreciable but borderline. In *'being fair'* to Dr Walsh the judge pointed out that the nearer the *'grumble line'* was to the window the more serious any movement would be but he stated that it did seem startling that one could be appreciable and the other less serious.

1.4.9 Ough v King [1967] 1 WLR 1547 at pp 552-3

In *Ough v. King,* the defendant relied on Waldram diagrams to demonstrate that the extensions he had constructed did not reduce the amount of adequate light, remaining available, below the 50% threshold. The relevant room had a floor area of 156.50ft^2; before the construction 100.25ft^2 had been adequately lit; after the construction 80.25ft^2 remained adequately lit. In other words, the adequately lit area had declined from 64.05% to 51.27%.

The county court judge nonetheless found that an actionable infringement had occurred. The Court of Appeal dismissed the defendant's appeal. Lord Denning MR said this (at p.1553):

'... I think the judge was entitled to have regard to the higher standards expected for comfort as the years go by. ... In these days I would not myself be prepared to regard the 50:50 rule of Mr. Waldram as a universal rule. In some cases a higher standard may reasonably be required.'

Danckwerts LJ also referred to the *'more demanding standards at the present time in the modern situation',* and Diplock LJ referred to the 50:50 rule as *'a convenient rule of thumb'* in the 1920s *'and perhaps later'*.

Lord Denning MR, who enjoyed a certain reputation, at the time, for giving decisions which stood apart from the general consensus, found that the 50/50 'rule' was not a rule at all (which everybody understood at the time but continued nevertheless to make use of it) and ruled that in modern conditions people wanted a better standard of natural light than they had previously found to be adequate so that 50% well lit might not be enough and a higher figure might be appropriate. Importantly, he found that the assessment should be made by Judges and not by experts using calculation methods. He was perfectly happy to stick to the Waldram method of drawing the contours but he wanted to have the freedom to rule that in this case 50% was adequate but in that case, 53% or some other figure would be inadequate.

It is important to read some of the detail in *Ough v King* because it is quite apparent that what the Court of Appeal had in mind (following something the judge below had said) was that the notions of mankind as to what was adequate had changed and continued to change, i.e. people in modern conditions were no longer prepared to put up with the dingy lighting standards of their ancestors and that regard should be had to the following criteria:

- In a room that is already poorly lit every bit of light is precious.

- Except in an extreme case it would be difficult to say that once a living room as opposed to a store fell below 50/50 that the light left was adequate.
- In considering whether a room where more than 50 per cent remained well-lit regard should be had to the use to be made of the remainder and how bad, vis a vis that use, the remaining light was.
- The test is not merely a statistical one;

1.4.10 Carr-Saunders v. Dick McNeil Associates [1986] 2 All ER

In *Carr-Saunders v. Dick McNeil Associates [1986] 2 All ER 888*, Millett J. was shown daylight contour plans by both parties' expert witnesses, and he referred (at p.891e) to:

'the conventional fifty-fifty rule by which a room may be regarded as adequately lit for all ordinary purposes if 50% or more of its area receives not less than one lumen of light at table level.'

At p.893b, however, he said this when dismissing an argument that recently erected internal walls should be disregarded when determining whether there had been an actionable infringement:

'I reject this approach. It applies the fifty-fifty rule rigidly as if it were a rule of law and not (as it is) as merely a useful guide to be adopted or discarded according to the circumstances. The fifty-fifty rule is not, in my judgment, to be applied without any regard to the shape and size of the room or the disposition of the light within the room to which it is applied.'

1.4.11 Deakins v. Hookings [1994] 1 EGLR 190

The decision in *Deakins v Hookings*, in the county court, followed *Ough v King* and Judge Cooke stated (at p.192) that he thought that the Court of Appeal decision *'really means not so much that one disregards the 50/50 rule, but that it is a bare minimum.'* He then said:

'It seems to me that having regard to the authorities I ought to approach the problem on these bases: He then went on to paraphrase Denning in *Ough v King* and concluded that, in this case, the 'well-lit' area in the living room represented 51% of the floor area prior to the development; after the development the well-lit area had reduced to 41%.

Judge Cooke found that there had been an actionable interference with the plaintiff's right to light.

1.4.12 Midtown Ltd v. City of London Real Property Co Ltd [2005] EWHC 33, [2005] 14 EG 130

In the recent commercial premises case of *Midtown Ltd v. City of London Real Property Co Ltd [2005] EWHC 33, [2005] 14 EG 130*, counsel for the defendant submitted that the time had come *'to dispense with rigid and unhelpful rules that had been devised in the past, such as* *the 50:50 rule'* (paragraph 59). *Midtown* was a case where the sky contour diagrams projected that the reductions in available light as a result of the development would be very large. In general, the percentages would be reduced to single figures from figures prior to development, which were in excess of 50% (paragraph 52). The principal argument of counsel for the defendant was that since the offices of the claimant (a firm of solicitors) had always been, and would continue to be, lit by artificial light during all working hours, the projected interferences would not be actionable. Peter Smith J. rejected the defendants' arguments and concluded that a nuisance had indeed been established.

1.4.13 Regan v Paul Properties DPF No1 Ltd and Others [2006] EWCA Cc 1319

The more recent case, *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, at the time of writing, 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. It is difficult to improve upon this summation and for this reason large parts are referred to in this chapter.

'Until the 1920s, a method commonly used to assess the adequacy of the light entering a window was not sophisticated; it involved measuring the angle between the window sill and the top of the proposed or infringing building. This is sometimes known as the 'cones of light' approach. If the angle was 45^o or less, then prima facie there was no infringement; if more, then prima facie there was an infringement.

In the 1920s, Percy Waldram, an accomplished expert, devised a more sophisticated method of assessment. In those days the method required a lot of painstaking trigonometry; these days there are computer programs, which relieve most of the pain.

The Waldram method measures light from the sky (not reflected light and not direct sunlight). The method is designed to eliminate variations in the amount of light from time to time (caused, e.g. by differences in the cloud cover or between the seasons). The point is put thus in the work co-authored by Mr. Bickford-Smith and Mr. Francis with Elizabeth de Burgh Sidley, Rights of Light, The Modern Law (2000), at paragraph. 12.10:

[Sky brightness varies unpredictably in temperate climates. It depends on the height of the sun above the horizon and on the various cloud formations. The amount of light in a room lit by daylight is proportional to sky brightness. The intensity of light coming from a window varies with time unpredictably and over a wide range of conditions. A standard had to be 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, in "The Illuminating Engineer" in 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 or 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)).

Mr. Waldram's methods of measuring light devised around this time translate 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 contours is the area in which adequate light has been (or will be) lost because of the development.

It is certainly not the law that any interference with the light entering a building will constitute a nuisance, even if, as here, the building undoubtedly has a right to ancient lights. 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.'

From these few cases it can be seen that the methods of measurement, which are still used, have not always been accepted by the courts as an absolute measure of sufficiency

(*Sheffield Masonic Hall Company Ltd v Sheffield Corporation* and *Cory v City of London Real Property Co*), nor have the experts always used their own espoused standards when giving evidence (*Cory v City of London Real Property Co*).

1.5 Conclusions

In essence, the courts are still being advised by rights to light practitioners that the value of light from the unobstructed sky should be 500 foot-candles, 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. These values have remained unchanged since the original cases in the 1920's and have not been independently verified since then, despite concerns raised in some cases and also by specialists as demonstrated in the focus group output at appendix 2.

It can also be seen that the courts, when referring to the 50/50 rule, 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*, that the overall appearance would be of an adequately daylit room or, as implied in *Ough v King*, 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*, which makes clear that the 0.2% value represented the minimum level required for clerical work.

In Chapter Two, the development of the method of calculation is explored using mathematical techniques in an historical framework.

Chapter Two
The Development of the Present Methodologies

'I may have a passion for looking at the sea, whereas to some people it is a hateful sight, but access to light from the sky is essential to every normal person's normal enjoyment of the use of rooms having apertures admitting light, and hence it is with access to sky visibility that the easement to light is essentially concerned.'

Anstey, B. 1963

2.1 Introduction

In this chapter the key events relating to the assessment of daylight in 'Rights to Light' calculations during the twentieth century are identified, discussed and analysed in chronological order but, as will be seen, there was a great tendency amongst the experts of the early twentieth century, to simply reiterate that which had been stated previously rather than to reinvestigate, or examine the validity of, the original bases of assessment.

2.2 1907 to 1919

There are a number of events, which have lead to the current methodologies for calculating the availability of daylight for 'Rights to Light' cases. Probably the first of these to be recorded was when Percy Waldram undertook measurements of existing daylight conditions in a variety of public and private buildings, using the 'Trotter' photometer, in 1907 (figure 2.04). The results of these measurements were published in 1909 when Waldram recommended that 1 foot-candle should be used as a 'rough working rule' to measure the adequacy of interior daylight and that interior daylight illumination should be expressed as a proportion of that which is simultaneously available from the dome of an unobstructed sky (Waldram 1909a). It should be noted that, at this point, Waldram was advocating that all parts of a room should have a minimum illumination of 1 foot-candle on the basis that the assumed sky luminance was estimated to be 1000 foot-candles and the 'grumble point' i.e. the point within a room where the occupant would start to complain that there was insufficient light for normal purposes, would be where 0.1% of the sky was visible. It will be seen later in this chapter that there is an inbuilt contradiction in this approach.

Very little direct documentary evidence of the 1907 measurements remains. Such information as is available consists mainly of sections incorporated by Waldram into subsequent publications and invariably the information is lacking in the detail, which might make it useable for comparison. For example, there is no information about the appearance of the rooms tested. Did they have wooden panelled walls? What colour were the finishes etc.

In his other publication that year entitled 'The Measurement of Illumination; Daylight and Artificial: With Special Reference to Ancient Light Disputes' (Waldram 1909b; p135) he was proposing that interior daylight illumination should be expressed not as an absolute value, but as a proportion of that simultaneously available from the dome of the unobstructed sky.

It was not until 1914 that the Illuminating and Engineering Society produced their report on daylight illumination in schools (Gaster 1914) and the Home Office followed this in 1915 with their report on lighting conditions in factories. (Home Office 1915) which, whilst adding to the body of knowledge of lighting levels and the measuring instruments available, did little to add to or define how the courts might be advised as to adequacy.

2.3 1920 to 1929

It is widely accepted, by practitioners, that after the decision in *Charles Semon & Co v Bradford* Corporation in 1922 when Waldram's use of the 0.2% sky factor as a measure of the grumble point received judicial approval, his publication in the Illuminating Engineer 1923 entitled 'Window Design and Measurement and Predetermination of Daylight' (Waldram 1923) was his first seminal paper. The second seminal paper was published in The Illuminating Engineer and presented to the RIBA in 1925 and entitled 'The Natural and Artificial Lighting of Buildings'. (Waldram 1925)

In this second paper, Waldram (1925:5) 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.

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 an oversimplification and it is understood that the direction of the sun can affect the amount of light available even for an overcast sky and this will be examined later in chapter four.

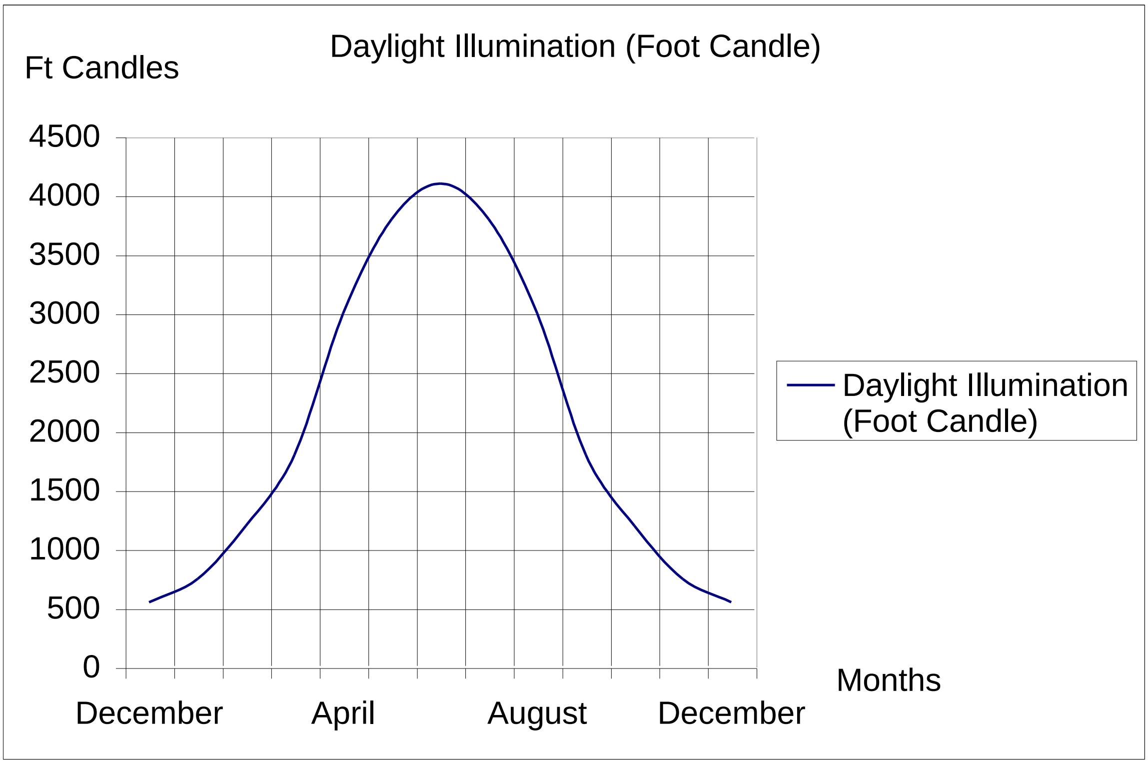


Figure 2.01 Seasonal Variations of Noon Daylight (1914) Home Office Report on Factory Lighting

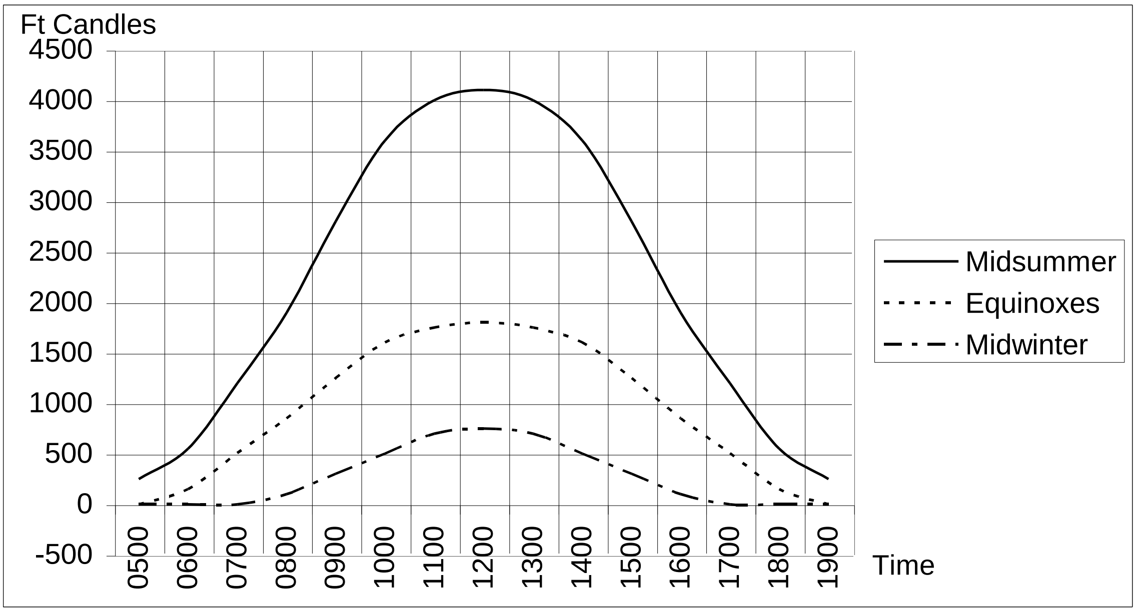


Figure 2.02 Diurnal Variations of Daylight, Midsummer, Equinoxes and Midwinter. (1914) Home Office Report on Factory Lighting

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 vales.

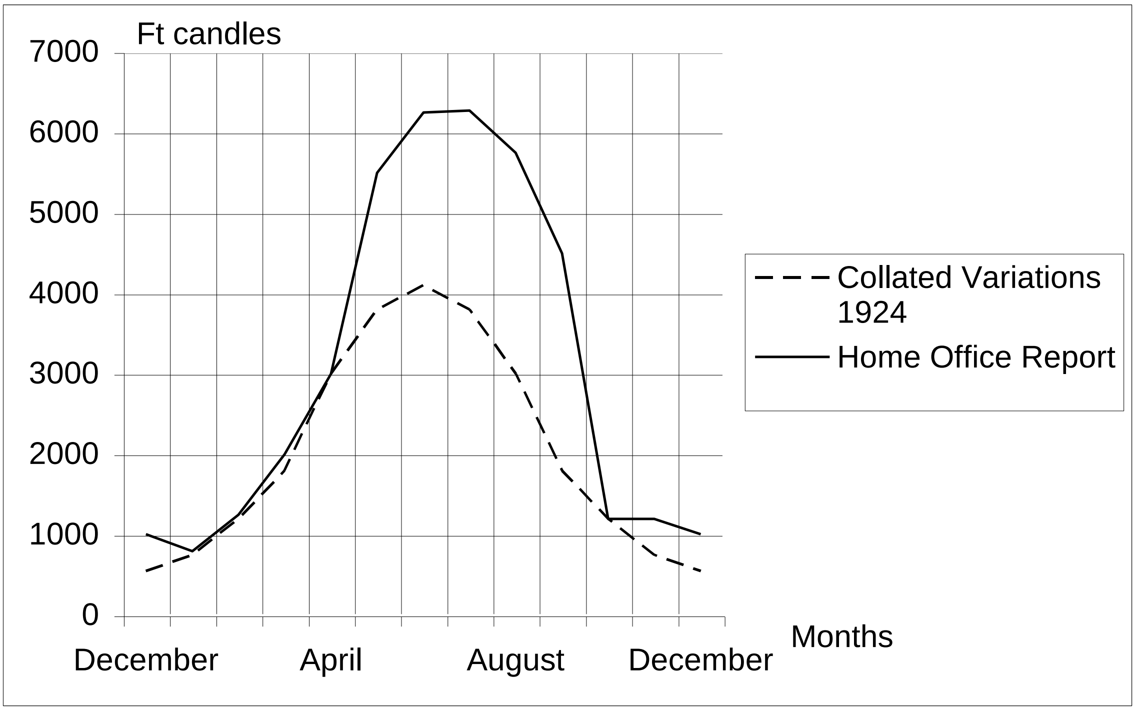


Figure 2.03 Seasonal Variations of Noon Daylight, Teddington 1924

At page 14 of the 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 adopted, for some years, 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. (Note that this differs from his original use of 1000 foot-candles).

When Waldram, (1925 p5) referred to the zenith sky being nearly always brighter than sky nearer to the horizon he may have been alluding to the theory behind the CIE sky which suggests that the value of light from the sky at the zenith is three times that at the horizon and which is expressed as $\mathbf{L\alpha=0.33Lz(1+2Sin(\alpha))}$. However, the adjustment, which he used, was supposed to have been based on Lambert's formula, which recognised that diffuse reflection redirects light equally in all directions and is common for dull surfaces. Lamberts formula is stated as $\mathbf{E = p\ E0cos(\theta)}$ **w**here **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.

It appears that Waldram used neither of these formulae to produce his diagram but he used the formula **1-cos2 θ** for the vertical adjustment of the chart and the rationale for this is discussed later in this chapter.

At the end of his presentation to the RIBA in 1925, there was the opportunity for questions and comments from the audience during which Mr J W T Walsh, of the National Physical Laboratory (NPL), voiced his concern that Mr Waldram had alluded to the comparative unimportance of diffused light in rooms and argued that in some cases over 50% of the natural illumination of a room comes from the internally reflected component.

He did not agree with Mr Waldram that people could manage with less daylight than artificial light and he pointed out that, where Mr 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 the figure. He asserted 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.

In the section of the paper entitled Principles of Measuring Daylight, Waldram commented that the difference between the amount of daylight externally and the amount of light internally can be different by several hundred times. He stated however that with a sky that is uniformly bright, the ratio between the external light and the internal will remain constant at all times.

In 1927, the Department of Scientific and Industrial Research published their technical paper number 17 entitled 'Penetration of daylight and sunlight into buildings'. The research committee contributing to the paper included both P J Waldram and J W Walsh and their chairman C C Paterson who, in his prefatory note, referred to *'the establishment of a ratio generally known as the daylight factor or sill ratio as a recognised criterion of interior lighting and the tendency towards the establishment of a given sill ratio as indicating the borderline between the sufficiently and insufficiently lighted portion of a room'.* (In fact the daylight factor and sill ratio are not the same – see appendix one) He also referred to the development of methods of measuring the sill ratio in cases of existing buildings and of calculating it in the case of a proposed building. The paper sought to set out the current state of knowledge at that time and described how *'the sill ratio would be affected by the amount of sky visible from the point in question, the transmission of the window glass, external reflected components and internal reflected components'.* The first diagram used in this paper is the rectangular diagram described by Waldram described as 'diagram for the calculation of sill ratio' but apart from the vertical adjustment referred to later in this chapter, there was no adjustment for the transmission value of the glass.

The paper went on to express the committee's opinion that the fixing of a 'minimum tolerable' value for the sill ratio was *'arbitrary and depended on the opinion of reasonable people as to what constitutes adequate lighting'.* They referred again to the 'extensive series of measurements of sill ratios that had been made in offices and in the footnote commented that these measurements were made in a number of clerical offices at points selected by a committee of four architects as having *'only just adequate lighting'.* It also reaffirmed the principle that the sill ratios should be *'expressed in terms of illumination which is derived in dull but not abnormally dull weather during the period from 9.00 a.m. to 3 p.m. GMT between February and October'.* Much of the remainder of the text is a reiteration of previous publications and provides no new evidence.

On the 5th March 1928, P J Waldram gave a paper to The Surveyors Institution (now the Royal Institution of Chartered Surveyors) at 12 Great George Street, entitled "The Estimation of Damage in Ancient Light Disputes" (Waldram 1928) where he described the circumstances whereby a neighbourly dispute about light could be resolved by the use of *'modern methods of ascertaining and of presenting the facts of any case'*. This paper was subsequently published by the International Illumination Congress; Commission Internationale de L'Eclairage in September 1928 entitled '*Daylight and Public Health'*.

In this paper, he described how, twenty years previously, '*any expert report was mere guesswork but that this was no longer the case as standards of good and adequate light had now been established'* and he referred to the critical investigations undertaken by the National Physical Laboratory at Teddington and to the Government Report (Technical Paper No.7, Illumination Research Committee, Department of Scientific and Industrial Research) which, he said, '*places them beyond dispute'.*

He also referred to material in the papers read before the Illuminating Engineering Society in May 1923 and the RIBA in 1925.

The principles espoused by Waldram were as follows:

1 That the material illumination of any interior position can never be other than a proportion, generally a surprisingly small proportion, of the light existing simultaneously out of doors, and can only be expressed as such. Natural illumination cannot be expressed as being of any fixed value, as is the case with an interior lit from artificial sources such as 1-foot-candle (the illumination obtained from 1 candle at a distance of 1 foot) or 2, 5 or 20 foot-candles. Whatever it may be at one moment, it will almost certainly be something quite different an hour or so later. Sometimes in windy changeable weather it will vary by several hundreds per cent from one minute to the next.

2 *That the light by which objects are rendered visible is not the light, which falls on them, but the light, which is reflected from them into the eyes of the observer. The useful light in an office is not the light which an observer notes when he walks into the room and looks out of the window; nor is it merely the light which falls on the table. It is the light, which can be reflected from books, papers, drawings etc into the eyes.*

3 *That the human eye is generally quite unconscious of huge percentage differences in daylight.*

4 *That with a given sky brightness the useful light at any interior position depends primarily upon how much sky can be seen from that position through the windows, and how high that sky is above the horizon. Light reflected from external objects and from walls and ceilings of interiors is very seldom sufficient per se to supply light reasonably adequate for ordinary purposes.*

5 *That any definition of adequacy in daylight illumination must of necessity cover the condition of moderately dull weather such as a wet day in summer, when the visible sky is fortunately uniform at all aspects. In so far therefore as adequacy can be defined as adequacy in moderately dull weather – and no other criterion would appear possible – we may neglect aspect and sun and pre-suppose a uniformly grey sky.*

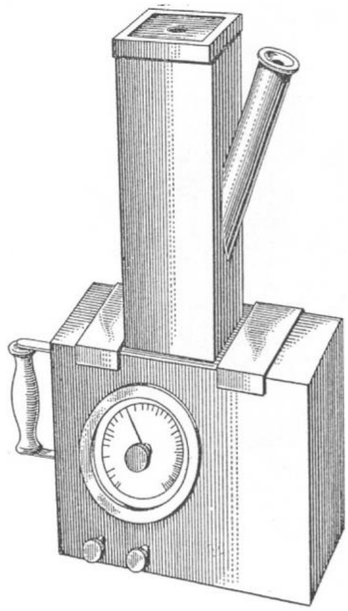
Thus, in those few short passages, Waldram jumped from the identification of the problem to a solution, which ruled out many of the factors, which are now taken into account when calculating daylight availability for planning purposes.

It may be a coincidence but, by this time, the National Physical Laboratory had, rather helpfully, established that the brightness of the sky on the moderately dull day in England, proposed by Waldram, would amount to 500 foot-candles (approximately 5,000 Lux) measured on a horizontal surface with no obstructions in any direction or 250 foot-candles (2,500 Lux) falling on the sill of an otherwise unobstructed window.

Waldram actually produced charts of his assessment of the amount of daylight in some of the rooms of the Surveyors Institution (Now the Royal Institution of Chartered Surveyors (RICS)). Those at the front still exist and could provide an opportunity to check his results. (Waldram 1928, figures 4 and 5).

At figure 2 of paper 512, Waldram (1928) referred to his first version of the now famous Waldram diagram, which represented the light from the sky in a rectangular diagram where the spacing between lines of altitude nearer to the horizon and the zenith are reduced for reasons explained elsewhere and he described the sill ratio as the ratio between the amount of light falling on a table to the amount of light falling on an unobstructed sill and stated that a sill ratio of 1 per cent would always represent 2½ foot-candles and that the "fairly well known 'grumble point' of 0.4 per cent sill ratio would always mean one foot- candle.

Waldram stated that the theoretical possibility that interior daylight illumination could be expressed as a proportion of the light obtainable simultaneously externally was first suggested by a Mr Trotter who had been an adviser to the Board of Trade. At that point in time there were no instruments such as portable photometers and the only instrument available was the Trotter photometer (Figure 2.04), which measured the brightness of daylight against the brightness of a lamp seen through separate slots. This instrument would only register up to 12 foot-candles whereas it was stated that daylight could reach 10,000 foot-candles. To deal with this they fitted a tube of known length, which would reduce the amount of light getting through in proportion to its length. (Walsh 1922; p157).



Source: Trotter (1911)

Figure 2.04 The Trotter Photometer

Waldram reported that, from this development, progress was rapid and daylight ratios were measured in many buildings and results were published from time to time (although very few have been found by the author). He asserted that the system for measuring light was adopted by the Home Office for factory inspectors and by 1914 was adopted by the National Physical Laboratory. He went on to state that despite intensive scientific investigation both in England and other countries, and in hundreds of '*ancient lights cases*' the standards arrived at had not been altered from the levels established by *'the laborious process of noting the opinions of ordinary people and then measuring the light which they had judged as 1% cill ratio and above was good, 1% to 0.4% adequate and 0.4% and under inadequate'.*

At this point, one percent sill ratio was deemed to be the equivalent of 2.5 foot-candles (25 Lux) and 0.4% sill ratio would be equal to 1 foot-candle (10 Lux). He acknowledged however that these values appeared low according to text books on artificial lighting but argued that in view of comprehensive tests in Government offices he did not expect to find the original standards varied.

Later that same year, Waldram presented another paper, in September 1928, entitled 'Daylight and Public Health' to the Commission Internationale de L'Eclairage in which he summed up by stating that:

a) the positions from which no sky at all is visible at table height are inadequately lit for ordinary purposes, such as continued clerical work, and

b) it is undesirable that rooms should be constructed, or used for habitancy (sic), *or for clerical or other ordinary work over long periods, unless they have at least some sky visible from table height over some reasonable portion of their area.'*

He further advised the members of that forum that 'whitened obstructions, light walls and ceilings and other expedients for mitigating gloom were no longer beneficial once the surfaces became dirty and especially on dull days. Prior to this he had also stated that the human eye could not be trusted when dealing with light levels and gave an example where the light in an ordinary room lit by windows on one side only, fell away very quickly indeed as the distance from the window increased as the amount of visible sky decreased rapidly but the human eye was not necessarily aware of this. He concluded by stating, amongst other things, that the light must be direct from the sky, and not from artificial light or from reflected surfaces.

2.4 1930 – 1939

In 1931 the Department of Scientific and Industrial Research published a report on the daylight illumination required in offices (Taylor 1931), which described the research in various government offices and confirmed, in their view, the validity of the 0.2 sky factor, although it is important to note that the Commission Internationale de L'Eclairage (CIE), later that year, refused to recognise it as an appropriate standard.

In this report, the Chairman, Clifford C Paterson, referred to work by the Illumination Research Committee and concluded that the paper supported the previously adopted figures with particular reference to the work by PJ and JM Waldram in the Illuminating Engineer of 1923, where it was stated that over a wide range of illumination values, the adequacy or inadequacy of the lighting at a point was closely correlated with the daylight factor at that point. The paper went on to describe how they had established the levels of light necessary by engaging a 'jury' to visit several offices and establish where in the rooms they each thought that there was sufficient light. However, Waldram had previously stated that the human eye could not be trusted when dealing with light levels and the validity of this jury approach has to be questioned. The author then took these results and produced them in graphical and tabular form and gave the answer, which he said best suited the results and replicated the methodology suggested in the 1923 paper.

Prior to the visit by the jury, the daylight factor contour plans had been prepared for a number of clerical offices in the new government building in Whitehall. Each room was surveyed photometrically (It is assumed that this was accomplished using the Trotter device but no explanation is given on this) and plans were prepared to show the contour lines corresponding to the daylight factors of 0.5, 0.25 and 0.1 percent at a level of 2 feet 6 inches from the floor, which equates to 762 mm.

It is known that the jury consisted of seven members for the first part and six for the second part of the experiment. In addition, for the second part, the occupier of each room was asked to give an opinion and each observer was asked to plot onto the plan the line which in his (no mention of her) opinion divided the room between the adequately daylit and the inadequately daylit. It was noted that the contours between observers did not agree but were thought to be comparatively close.

The author noted that the first set of assessments were all carried out on the same day which was bright with a certain amount of sunshine and that only two observers (JMW and JWTW) made allowance for the effect of either direct sunlight or of reflection. From the initials provided it is possible to determine that the jury included both of the Waldrams, father and son, and J W T Walsh.

In the second part of the experiment the observations were made on different days with the weather conditions being dull on most occasions.

The tables (Tables 2.01 and 2.02), reproduced below, show the results as they were presented. What is clear from these is that there is a wide spread of perception as to adequacy in each room and that it cannot even be said that the occupiers always required more, or less, than the jury members. What can also be seen is that the average daylight factor required on a bright day, measured over all twenty rooms, is half that required on a dull day.

Unfortunately, without information regarding the external conditions it is impossible to determine the value represented by the average of 0.26% on the dull day. An external value of 7,500 Lux (which is consistent with an averagely dull day) would produce an illuminance of 19.5 Lux compared with only 13 Lux under a 5,000 Lux external value. This however is only an average and it may be argued that the same principles should apply as those used in assessing the availability of daylight where the value selected was that which was achieved on all but the dullest of days. In this instance perhaps it may have been valid to assess the daylight factor required by all but those with the poorest eyesight. By reviewing the readings for each room against the numbers of people requiring daylight factors in 0.1% increments, on the dull day, the highest requirement was by the occupier in room 4, 3rd floor, at 1% which represents the value which would satisfy 100% of the occupants. Table 2.03 shows an analysis of the percentage satisfaction at the various levels. From this is can be seen that 80% satisfaction is only reached at 0.3% to 0.4% daylight factor but even this is unreliable as the illuminance would have changed frequently during the process meaning that, even for a single observer, the points where there was sufficient illuminance would change if they carried out a reassessment within a matter of minutes.

The tables also make clear that at least some of the windows were obstructed externally and were benefiting from reflection off glazed tiles and mirrors, which means that external reflectance will have been a factor.

TABLE 2.01 Summary of Observations by Seven Observers on a Bright Day

Room Number	4 -- 2nd F.	4 -- 3rd F	4A -- G.F.	6 -- 1st F.	64 -- 1st F.	69a -- G.F.	69a -- 3rd F.	72 -- G.F.	72A -- S.G.F	73 -- 1st F.	73 -- 2nd F.	73A -- S.G.F.
	Per cent	Per cent	Per cent	Per cent	Per cent	Per cent	Per cent	Per cent	Per cent	Per cent	Per cent	Per cent
P.W.J	0.05	0.10	0.04	0.02	0.10	0.05	0.07	0.05	0.05	0.08	0.05	0.03
J.M	0.05	0.10	0.05	0.02	0.15	0.05	0.08	0.10	0.10	0.05	0.05	0.05
A.E.M	0.05	0.20	0.05	0.03	0.25	0.15	0.15	0.30	0.50	0.05	0.20	0.05
J.M.W	0.15	0.20	0.05	0.25	0.35	0.10	0.20	0.20	0.50	0.25	0.20	0.02
P.J.W	0.15	0.60	0.20	0.25	0.50	0.10	0.15	0.22	0.17	0.20	0.05	0.25
J.W.T.W	0.25	0.35	0.10	0.08	0.50	0.10	0.15	0.10	0.08	0.25	0.15	0.03
J.G.W	0.05	0.25	0.03	0.03	0.10	0.03	0.05	0.05	0.10	0.05	0.05	0.05
Mean for each room	0.10	0.25	0.07	0.10	0.28	0.08	0.12	0.15	0.21	0.13	0.11	0.07

Room Number	74 -- S.G.F.	74 -- 3rd F	74 -- G.F	130 -- 3rd F.	133 -- S.G.F	133 -- G.F	133 -- 1st F.	133 -- 2nd F.	Mean for 20 Rooms	Weather Conditions
	Per cent	Per cent	Per cent	Per cent	Per cent	Per cent	Per cent	Per cent	Per cent	
P.W.J	0.02	0.20	0.03	0.15	0.03	0.02	0.03	0.05	0.06	
J.M	0.03	0.15	0.02	0.15	0.07	0.03	0.02	0.07	0.07	
A.E.M	0.05	0.35	0.05	0.30	0.05	0.05	0.05	0.10	0.15	Generally Fair
J.M.W	0.03	0.35	0.07	0.45	0.25	0.20	0.10	0.10	0.20	
P.J.W	0.02	0.25	0.15	0.25	0.20	0.20	0.05	0.25	0.20	
J.W.T.W	0.03	0.35	0.25	0.25	0.10	0.05	0.05	0.08	0.16	
J.G.W	0.02	0.10	0.10	0.10	0.01	0.03	0.05	0.05	0.06	
Mean for each room	0.03	0.25	0.10	0.24	0.10	0.08	0.05	0.10	0.13	Generally Fair
Corrected	0.03	0.25	0.10	0.24	0.10	0.08	0.05	0.10	0.13	

(light shading)	Denotes sun shining on wall opposite	(dark shading)	Denotes sun shining into room

NOTE - The figures in the columns give the Daylight Factor Contours approximately in agreement with the line separating adequately from inadequately lighted portions of the corresponding rooms as determined by the several observers.

TABLE 2.02 Summary of Observations by Six Observers on a Dull Day and by Occupiers

Room Number	4 -- 2nd F.	4 -- 3rd F	4A -- G.F.	6 -- 1st F.	64 -- 1st F.	69a -- G.F.	69a -- 3rd F.	72 -- G.F.	72A -- S.G.F	73 -- 1st F.	73 -- 2nd F.	73A -- S.G.F.
	Per cent	Per cent	Per cent	Per cent	Per cent	Per cent	Per cent	Per cent	Per cent	Per cent	Per cent	Per cent
P.W.J	0.60	0.60	0.45	0.20	0.50	0.50	0.25	0.25	0.20	0.20	0.25	0.45
J.M	0.25	0.35	0.05	0.10	0.20	0.15	0.15	0.50	0.20	0.25	0.15	0.10
J.M.W	0.10	0.75	0.45	0.20	0.15	0.20	0.25	0.20	0.10	0.25	0.15	0.15
P.J.W	0.25	0.75	0.40	0.25	0.20	0.35	0.25	0.10	0.05	0.15	0.10	0.25
J.W.T.W	0.05	0.10	0.25	0.20	0.35	0.10	0.10	0.20	0.10	0.25	0.12	0.20
J.G.W	0.50	0.65	0.10	0.25	0.30	0.65	0.50	0.50	0.10	0.20	0.20	0.40
Mean for each room	0.29	0.53	0.28	0.20	0.28	0.32	0.25	0.29	0.13	0.22	0.16	0.26
Occupier	0.50	1.00	0.50	0.10	0.30	0.10	0.25	0.25	0.50	0.25	0.08	0.40

Room Number	74 -- S.G.F.	74 -- 3rd F	74 -- G.F	130 -- 3rd F.	133 -- S.G.F	133 -- G.F	133 -- 1st F.	133 -- 2nd F.	Mean for 20 Rooms	Weather Conditions
	Per cent	Per cent	Per cent	Per cent	Per cent	Per cent	Per cent	Per cent	Per cent	
P.W.J	0.15	0.60	0.55	0.25	0.05	0.15	0.10	0.25	0.32	Blue Sky, White Clouds
J.M	0.10	0.30	0.20	0.35	0.10	0.07	0.08	0.15	0.19	Moderately Dull
J.M.W	0.15	0.45	0.15	0.40	0.03	0.10	0.08	0.05	0.21	Dull weather and Overcast Sky
P.J.W	0.40	0.50	0.10	0.40	0.05	0.10	0.08	0.10	0.24	
J.W.T.W	0.20	0.10	0.50	0.20	0.25	0.25	0.20	0.20	0.20	Dull
J.G.W	0.50	0.85	0.10	0.50	0.10	0.25	0.25	0.30	0.36	Generally Dull
Mean for each room	0.25	0.47	0.27	0.35	0.10	0.15	0.13	0.18	0.26	
Occupier	0.15	0.20	0.05	0.30	0.20	0.20	0.10	0.05	0.27	

(light green)	Denotes very clean white glazed tiles
(grey)	Denotes dull weather
(cyan)	Denotes Mirror fitted in front of window

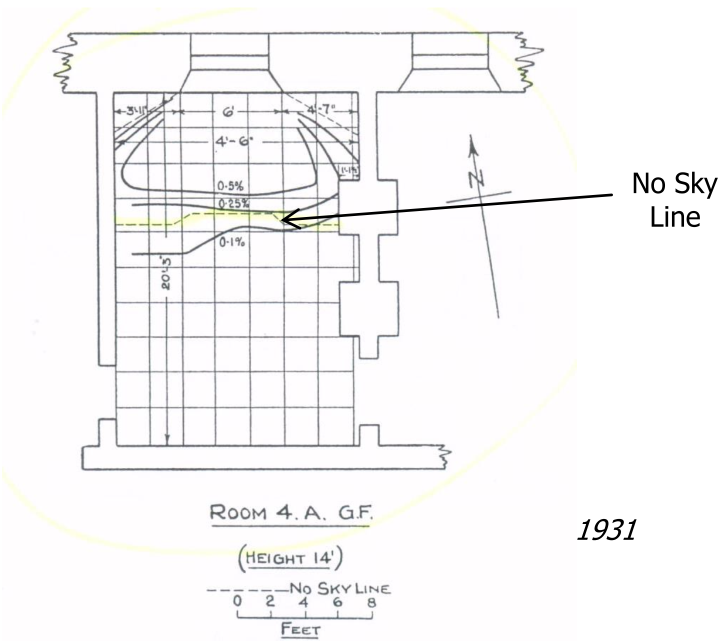
Df	satisfaction
0-0.1	27.86%
0.1-0.2	52.14%
0.2-0.3	74.29%
0.3-0.4	81.43%
0.4-0.5	92.86%
0.5-0.6	96.43%
0.6-0.7	97.14%
0.7-0.8	98.57%
0.8-0.9	99.29%
0.9-1	100.00%

Table 2.03 Percentage satisfaction at various levels of daylight factor

At page 5 of the paper, there is a plan of room 4A G.F. showing the contours produced using the measuring device. 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, is also shown on the plan and this falls mainly between the 0.1% and 0.25% contours. The only possible interpretation of this is that the daylight factor, measured, must have been reliant upon reflection from internal and possibly external sources.

The chart, reproduced below at Figure 2.05, shows the contour lines. What is not explained is why the 'no sky line' contour is nearer the window than the point at which at least 5 jury members, on the bright day, and 2, on the dull day, indicated that they had sufficient light to work by.

From this, it can be deduced that at least some of the jury members were unable to distinguish between direct light and reflected light and this casts doubt on the subjective nature of the measurement process and how this may have been used to justify the use of the 0.2% sky factor by Waldram.



In this room, the average of the minimum daylight factor required by the jury on the bright day was 0.07%, compared with 0.28% on a dull day, although the occupier on that same day expressed a requirement of 0.50%. Unfortunately there is no information upon how the daylight factors were calculated and neither are the contours shown for each of the jury members' observations. If it were to be assumed that the average minimum daylight factor required by the jury members was in fact measured at the series of points which represented the minimum value required then it might be argued that the room between this contour and the window benefited from an average amount of direct sky light and thus a contour line drawn midway between the two could be correlated to the amount of sky visible at each point on that contour. With this it might have been possible to justify Waldram's use of the 0.2% sky factor but without it, as has been stated above, this is not possible.

From the discussion above it can be seen that this 'experiment' was of extremely limited value. The range of readings between the rooms and with differing external lighting conditions and the failure to relate any of the readings to the external value, which would have permitted comparison with the sky factor, makes the results unusable in justification of any methodology; nevertheless this appears to be what happened at the time.

In 1932, the Commission Internationale de L'Eclairage (CIE) (International Commission on Illumination 1932) met at Cambridge and set out the parameters, which have been adopted ever since by 'Rights to Light' Surveyors, and these were as follows:

1 The use of contour lines should be adopted in all cases.

2 That table height should be regarded as 85 centimetres or 2 ft 9 in

3 That less than 0.2% sky factor should be regarded as inadequate for work involving visual discrimination.

The one new fact introduced at this point was the acceptance of 'table height' which is between 7.5 and 10 centimetres higher than previously recognised and which other forms of calculation normally use and it is also higher than most work surfaces which does not make sense since it is supposed to relate to the amount of light needed for work.

The significance is that a work surface at a lower level may benefit from light at a higher altitude, which comes through the top of the window, and lose light from lower angles; particularly where the cill height is above work surface height.

It was not until 1937 that the Department of Scientific and Industrial Research published the results of further research on the daylight illumination in offices, which concluded that the previous recommendation was too low. (Department of Scientific and Industrial Research 1937)

2.5 1940 to 1960

Towards the end of the second world war the 'Post-War Building Studies No. 12, The Lighting of Buildings' (Building Research Board 1944) recommended a minimum sky factor value of 1 per cent for domestic living rooms and in 1952 'Post-War Building Studies No.30 The Lighting of Office Buildings' also confirmed that a sky factor of 1 per cent was recommended for office floor areas relying exclusively on daylight illumination. (Ministry of Public Building and Works 1952). In these cases the sky factor was reported to be the direct ratio of the internal illuminance to the unobstructed external illuminance but this is appears to be incorrect as this would equate to the daylight factor.

2.6 1961 to 1980

Whilst Walsh was undoubtedly a contemporary of Waldram, he was also the author of the more recent publication, 'The Science of Daylight' which, in Chapter 5 entitled 'Daylight Calculations by Graphical Methods' (Walsh 1961), discussed the 'Unit-Sphere Principle' (Figure 2.06) and described 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.

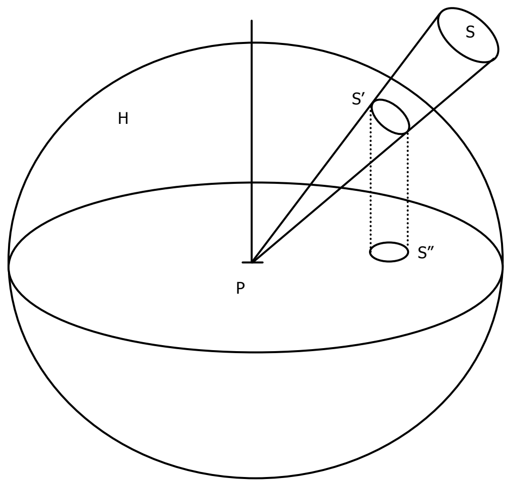


Figure 2.06 The principle of the unit sphere from Walsh 1961

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 2.07)

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 2*α*.* $\Delta\alpha$*.* $\Delta\beta$*."*

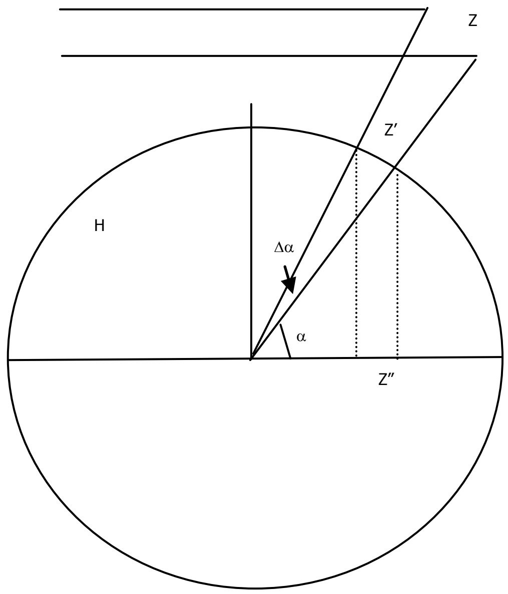


Figure 2.07 The illumination from an element of sky

He then asserted that this calculation 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 ($\alpha \pm \Delta\alpha$) 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 formula undoubtedly produces the chart at Figure 2.08 below 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), but the ratios remain the same. This equation and its derivation are examined below.

2.7 The Construction of the Waldram Diagram

The following charts have all been produced, using the original formulae, in Excel spreadsheets and charts and so may not exactly match the original drawn versions but they serve to demonstrate the points being made.

Figure 2.08 shows how the original Waldram Diagram adjusted the distance between the horizontal angles of altitude as has been explained previously in this chapter.

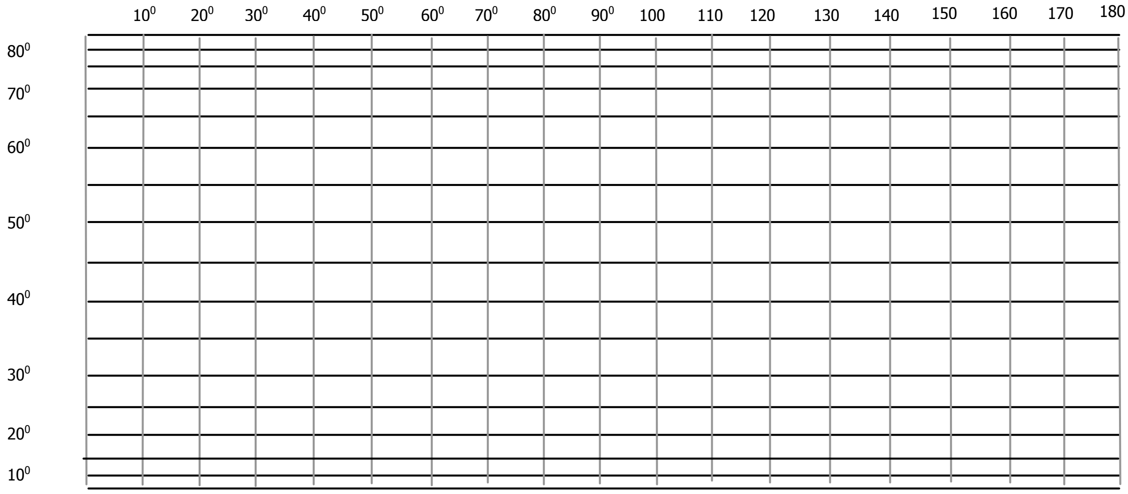


Figure 2.08 Waldram diagram original form (The rectangular diagram described by Waldram)

The more familiar 'droop' version of the Waldram diagram is constructed using basic trigonometry. The diagram below shows how the vertical angle of a fixed point decreases as it is moved away from the normal and it is the relationship between the vertical angle in the normal position to its angle either side that creates the droop lines.

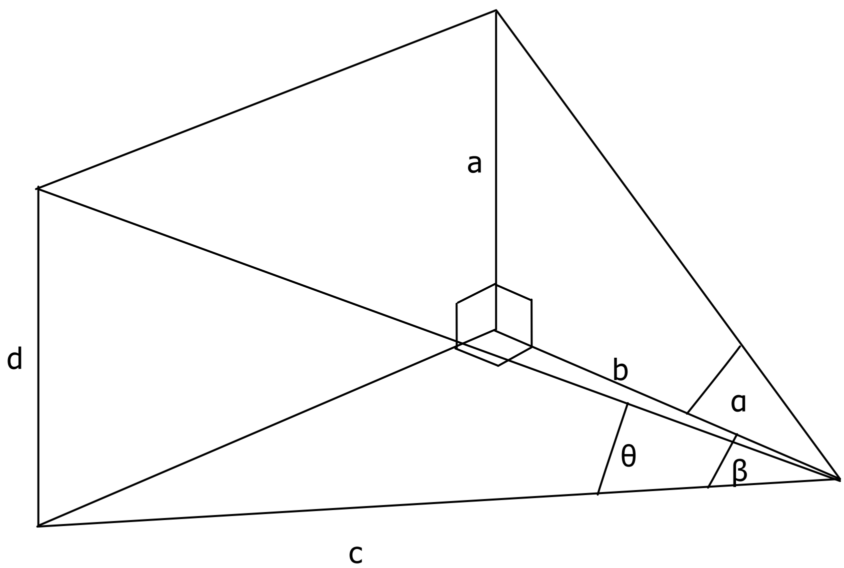


Figure 2.09 Geometry of the Waldram Diagram

Tan α = a/b; Cos β= b/c; Tan θ = d/c

Since the droop lines represent a horizontal line, d = a and therefore

$\text{Tan } \theta = \text{b Tan } \alpha/\text{b}/\text{Cos } \beta = \text{Tan } \alpha * \text{Cos } \beta$

If this formula is used for each angle of altitude it would create a droop diagram where the spacing between each line of altitude is equal. This is best understood by looking at the spacing on the vertical line at 0 degrees azimuth in the figure below. (Figure 2.10)

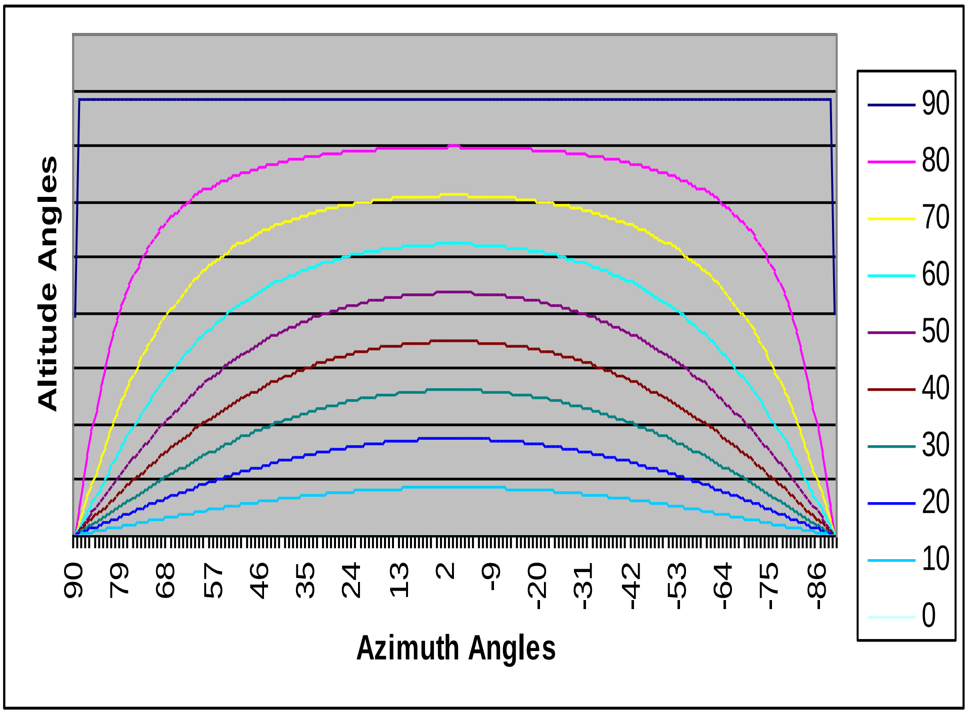


Figure 2.10 Equivalent Vertical Angles

However, according to the initial Waldram diagram, the value of the luminance near the horizon and near to the zenith should be lower and therefore the adjustment factor of 1- Cos 2θ should be applied to the equivalent vertical angle for each point.

The chart for this at Figure 2.11 shows how the lines are closer together near the zenith and horizon but open out in the mid sky zone centred around 45 degrees.

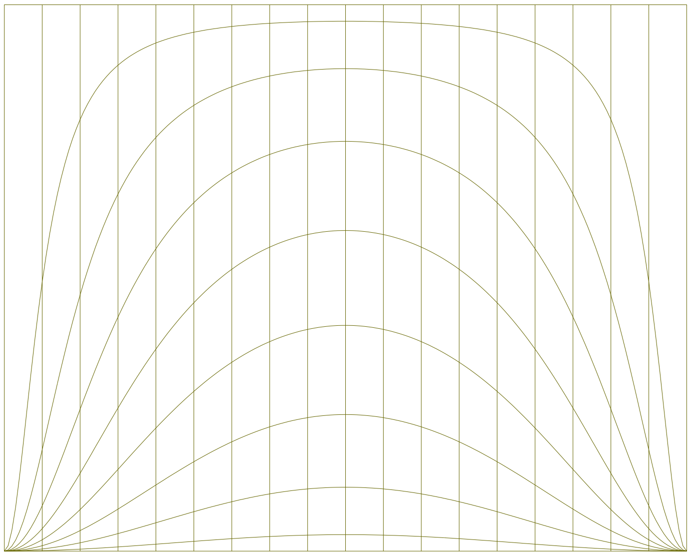


Figure 2.11 Basic Waldram diagram with Droop lines

It is possible to construct this diagram using Microsoft Excel although the mathematics has to be adjusted to convert through radians using the following formula:

P = 1-(COS((2*(DEGREES(ATAN(TAN((α)*PI()/180)*COS((β)*PI()/180))*PI()/180)))))

This formula creates a chart, which looks essentially the same as the above with the exception that the value at 90 degrees Azimuth and 90 degrees altitude is not quite at the edge of the chart. This is purely the result of the complex mathematics.

This chart is now referred to by 'Rights to Light' surveyors as "The Waldram Diagram" and for years this was printed by the BRE/HMSO with the main modification being the inclusion of droop lines for obstructions at right angles to the window wall (these lines are effectively the same droop lines moved across horizontally through 90 degrees) and vertical guidelines to assist hand drawing of perpendicular surfaces or edges such as window frames, together with a grid divided into 500 squares to make calculations easier. Figure 2.12 shows how this now appears

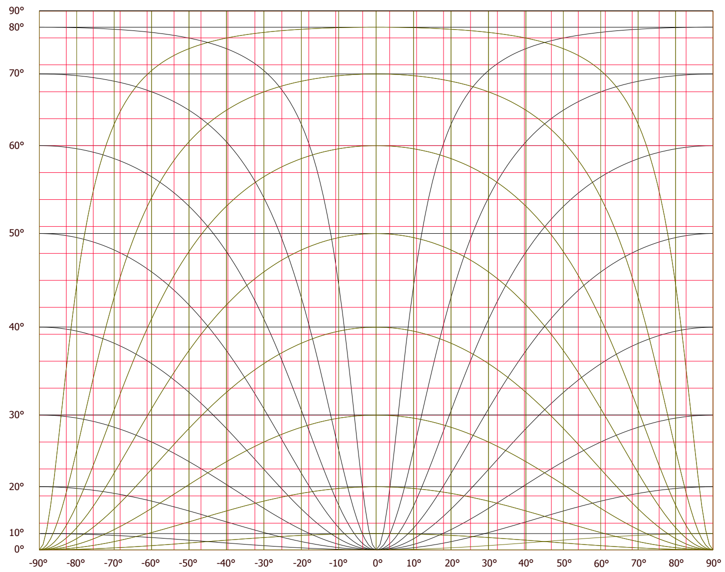


Figure 2.12 Waldram Diagram with 90 degree droop lines and grid

Note that the size of the diagram has been modified to measure a total of 500 square units. This will be discussed later in this paper but the value of the units is actually irrelevant if the grid, which is used as an overlay, uses the same units.

The Waldram diagram, above, still pre-supposes a sky of uniform luminance to provide a sky factor but an overcast sky has a different luminance distribution and this was described by Walsh as being represented by the formula $L\gamma=Lz(1+\sin\gamma)/3$ where γ is the angle above the horizon and, if this were used, it would have the effect of modifying the rectangular diagram described by Waldram and thus the Waldram Diagram at Figure 2.12, and this modification will be explored in a later chapter.

Heights of Ordinates in the Waldram Diagram					
Angle (deg)	**Uniform sky**	**Overcast sky**	**Angle (deg)**	**Uniform sky**	**Overcast sky**
5	0.008	0.004	50	0.587	0.508
10	0.030	0.015	55	0.671	0.602
15	0.067	0.039	60	0.750	0.693
20	0.117	0.073	65	0.821	0.777
25	0.179	0.120	70	0.883	0.853
30	0.250	0.179	75	0.933	0.915
35	0.329	0.249	80	0.970	0.961
40	0.413	0.329	85	0.992	0.990
45	0.500	0.416	90	1.000	1.000

Figure 2.13 Comparison of ordinate heights for uniform and overcast skies (Anstey 1963)

Figure 2.13 above illustrates the comparison between the heights of the ordinates for uniform and overcast skies. It can be seen that the lower levels benefit most from the uniform sky approach but that all levels differ slightly and thus results using the overcast sky would always be different from those using a uniform sky.

In summary, the concerns, which arise out of the existing methodology, are with the following assumptions.

- total amount of light provided by the Sky Dome should be assumed to result in an illuminance of 500 foot-candles to an unobstructed point on the horizontal plane
- a Uniform Sky can be assumed for the purposes of these calculations
- Lambert's 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 foot-candle illuminance adequate
- it is appropriate to ignore window frames and glazing
- internal reflectance should be ignored

In part B of this thesis, the use of the Waldram Diagram is explored in chapter three, showing how the results produced by the use of the diagram are translated into a contour plan showing the 'grumble line' and then how this relates to the presently available alternatives methods. Chapter four will then examine two of the fundamental factors leading to the development of the Waldram Diagram i.e. how much light is needed and how much is available.

Part B
The Current Methodologies and Research

Chapter Three
Existing Methods and Available Alternatives

I need not say much about the methods employed for they have been used in these Courts at any rate since the year 1922, when Mr Waldram devised his method of measuring light coming through a window. Broadly speaking, the test is still the same that he devised, although the nomenclature has somewhat changed, and I propose to say no more about it than if you have a point in any room where the daylight factor, as it is now called, is 0.2 per cent that is just sufficient to form a satisfactory light.

Upjohn J 1954 in Cory v City of London Real Property Co.

3.1 Introduction

In the previous chapters, the legal and theoretical backgrounds have been discussed to establish the context of the calculation process in 'Rights to Light' cases. This chapter will now explain how the Waldram Diagram is used to calculate loss in practical situations and then compare this method with other available methods of establishing daylight values in the UK and elsewhere.

Having established the theoretical position in respect of these calculation methods, the potential sources of error are also discussed.

3.2 Using the Waldram Diagram

The Waldram Diagram for 'Rights to Light' cases needs to be distinguished from other 'so called' Waldram Diagrams which are used for daylight calculations for planning purposes and also those which are modified to allow for the reduction in light which is caused by the transmission through glass for example.

The following three figures demonstrate how the complete form of the Waldram Diagram is created. Figure 3.01 is the basic diagram, created in AutoCAD, showing the droop lines based on the original Waldram Diagram which was illustrated in the previous chapter; Figure 3.02 has the additional droop lines which act as guidance for obstructions which run at right angles from the window elevation and Figure 3.03 has the measuring grid overlaid.

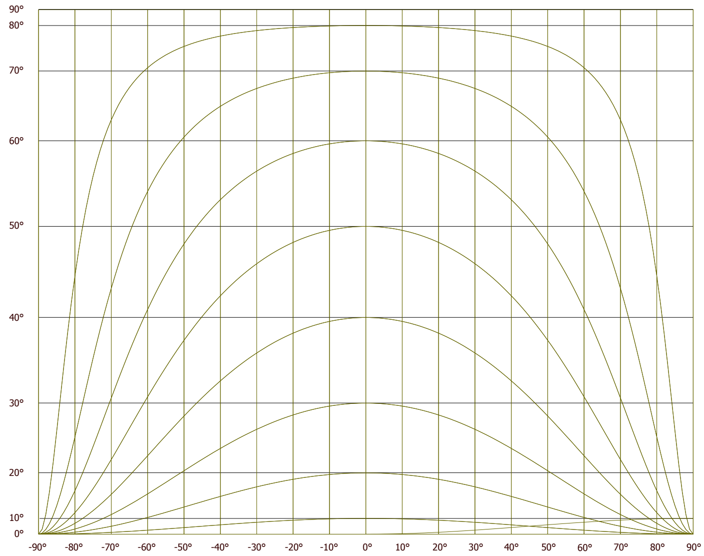


Figure 3.01 – Basic Waldram Diagram showing Droop Lines on the original rectangular version

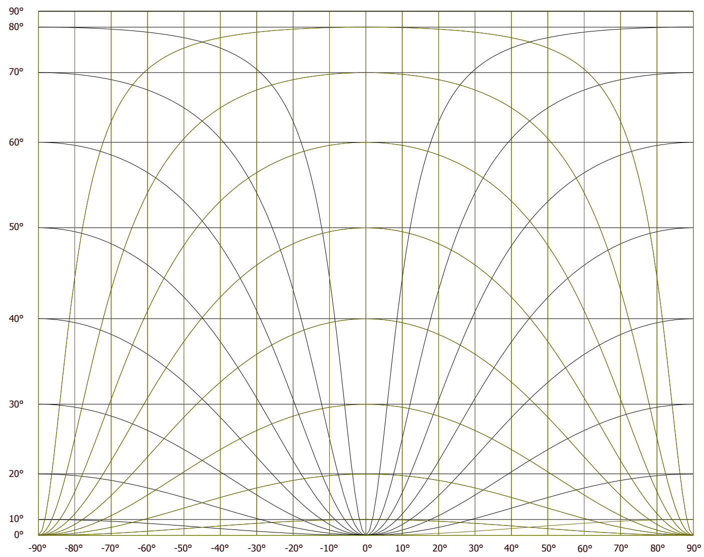


Figure 3.02 – Droop Lines added for obstructions at right angles

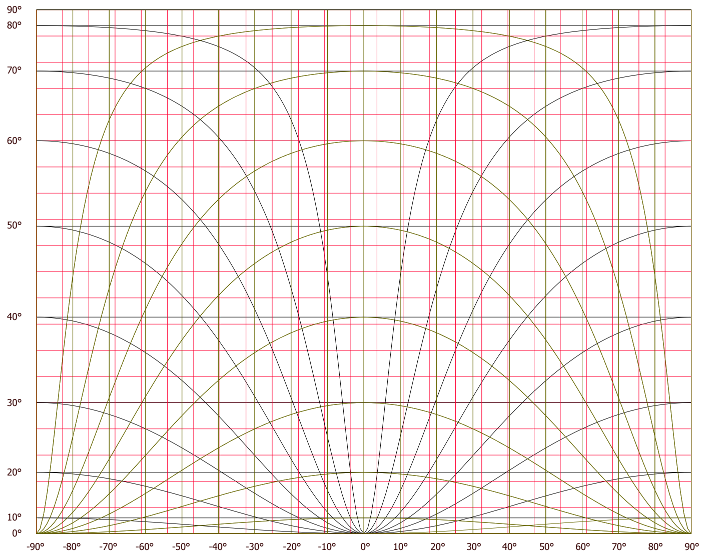


Figure 3.03 – Waldram Diagram with a 500 square grid overlaid

The Waldram Diagram is used to analyse the amount of sky visible from individual points within a room. The results for each of these points are then used to create a contour line for the series of points from which 0.2% of the chart (2 squares) are within the area of the window and not obstructed externally. Most 'Rights to Light' Surveyors would simplify this statement to refer to the series of points from which 0.2% of the sky is visible but, as has been seen in the previous chapter and will be discussed further below, this is not an accurate nor a correct statement.

The starting point in the calculation process is to prepare a drawing of the room being considered and of any external obstructions, which are visible from within the room. Later in this chapter there will be a discussion of the practicalities involved but on the assumption that this is possible, a drawing such as that shown in Figure 3.04 is produced at sufficient scale that distances and angles can be calculated through sections and plans and a grid is defined for the room itself. The grid can be at any suitable centres and it is usually a matter of practical experience to decide what is suitable and thus the fastest way to produce a result. Figure 3.05 below shows the sample room with a 1 metre centre grid set out from the front corner of the room. This grid is actually set out at 850 mm above floor level and in this case the window cill height is slightly less than 850 mm above floor level. Thus the lowest point of the window, showing on the Waldram diagram will always appear to be at altitude zero degrees. If the grid height were to be 750 mm above floor level then the cill height of the window would appear above altitude zero degrees.

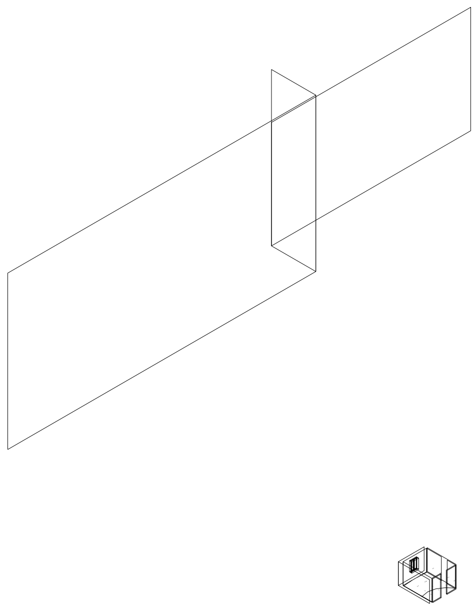


Figure 3.04 – Thumbnail of room being considered and external obstruction opposite window wall

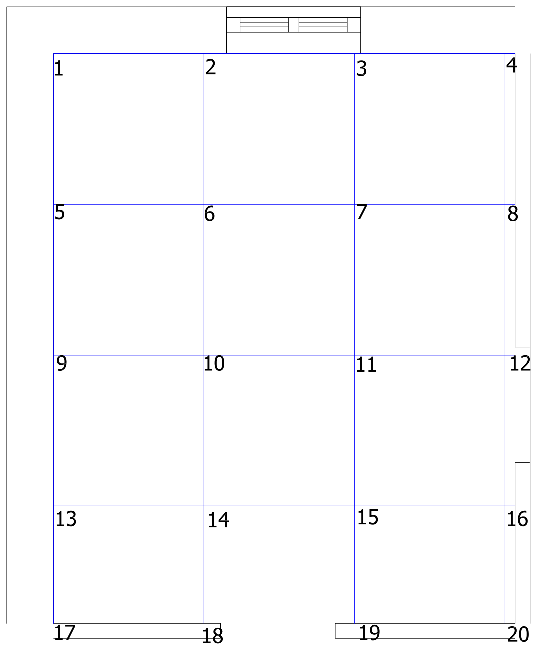


Figure 3.05 – Room with Grid overlaid at 1000 mm centres from front corner

From each grid point (numbered sequentially from left to right from front elevation), the outline of the window is defined in terms of angles horizontally and vertically and then plotted onto the Waldram Diagram. Similarly the external obstructions are also defined in the same terms and plotted onto the Waldram Diagram.

Tables 3.01 to 3.03 below show the relative angles of the window sides and head and each of the obstructions sides and top calculated using basic geometry from each grid point.

It is often easier when drawing these onto the Waldram diagram; to plot the whole obstruction but in fact it is only that part which lies within the window aperture, as seen from the selected grid point that is important. The importance of all measurements being relative to the location of the grid point in three dimensions should be noted.

Worksheet for relative angles of each grid point to window									
Grid point	**distance from front wall (m)**	**distance to left side of window (m)**	**distance to right side of window (m)**	**Height of window above grid (m)**	**Height of Cill above grid (m)**	**Angle of left side of window (°)**	**Angle of right side of window(°)**	**angle of head (°)**	**angle of cill (°)**
1	0	1.15	2.02	1.21	-0.03	90.00	90.00	90.00	-90.00
2	0	0.15	1.05	1.21	-0.03	90.00	90.00	90.00	-90.00
3	0	-0.85	0.05	1.21	-0.03	90.00	90.00	90.00	-90.00
4	0	-1.85	-0.95	1.21	-0.03	90.00	90.00	90.00	-90.00
5	1	1.15	2.02	1.21	-0.03	48.99	63.66	50.43	-1.72
6	1	0.15	1.05	1.21	-0.03	8.53	46.40	50.43	-1.72
7	1	-0.85	0.05	1.21	-0.03	-40.36	2.86	50.43	-1.72
8	1	-1.85	-0.95	1.21	-0.03	-61.61	-43.53	50.43	-1.72
9	2	1.15	2.02	1.21	-0.03	29.90	45.29	31.17	-0.86
10	2	0.15	1.05	1.21	-0.03	4.29	27.70	31.17	-0.86
11	2	-0.85	0.05	1.21	-0.03	-23.03	1.43	31.17	-0.86
12	2	-1.85	-0.95	1.21	-0.03	-42.77	-25.41	31.17	-0.86
13	3	1.15	2.02	1.21	-0.03	20.97	33.95	21.97	-0.57
14	3	0.15	1.05	1.21	-0.03	2.86	19.29	21.97	-0.57
15	3	-0.85	0.05	1.21	-0.03	-15.82	0.95	21.97	-0.57
16	3	-1.85	-0.95	1.21	-0.03	-31.66	-17.57	21.97	-0.57
17	3.78	1.15	2.02	1.21	-0.03	16.92	28.12	17.75	-0.45
18	3.78	0.15	1.05	1.21	-0.03	2.27	15.52	17.75	-0.45
19	3.78	-0.85	0.05	1.21	-0.03	-12.67	0.76	17.75	-0.45
20	3.78	-1.85	-0.95	1.21	-0.03	-26.08	-14.11	17.75	-0.45

Table 3.01 – Measurements from each grid point to window sides and head, converted into angles

Obstruction 1							
Grid point	distance from face of wall (m)	distance to left side of wall (m)	distance to right side of wall (m)	Height of roof above grid (m)	Angle of left side of wall (°)	Angle of right side of wall (°)	angle of roof (°)
1	41.51	-10.2168	30.45555	20	-13.83	36.27	25.73
2	41.51	-11.2168	29.45555	20	-15.12	35.36	25.73
3	41.51	-12.2168	28.45555	20	-16.40	34.43	25.73
4	41.51	-13.2168	27.45555	20	-17.66	33.48	25.73
5	42.51	-10.2168	30.45555	20	-13.51	35.62	25.20
6	42.51	-11.2168	29.45555	20	-14.78	34.72	25.20
7	42.51	-12.2168	28.45555	20	-16.03	33.80	25.20
8	42.51	-13.2168	27.45555	20	-17.27	32.86	25.20
9	43.51	-10.2168	30.45555	20	-13.21	34.99	24.69
10	43.51	-11.2168	29.45555	20	-14.46	34.10	24.69
11	43.51	-12.2168	28.45555	20	-15.68	33.18	24.69
12	43.51	-13.2168	27.45555	20	-16.90	32.25	24.69
13	44.51	-10.2168	30.45555	20	-12.93	34.38	24.20
14	44.51	-11.2168	29.45555	20	-14.14	33.50	24.20
15	44.51	-12.2168	28.45555	20	-15.35	32.59	24.20
16	44.51	-13.2168	27.45555	20	-16.54	31.67	24.20
17	45.29	-10.2168	30.45555	20	-12.71	33.92	23.83
18	45.29	-11.2168	29.45555	20	-13.91	33.04	23.83
19	45.29	-12.2168	28.45555	20	-15.10	32.14	23.83
20	45.29	-13.2168	27.45555	20	-16.27	31.22	23.83

Table 3.02 Measurements from each grid point to first external obstruction sides and top, converted into angles

Obstruction 2							
Grid point	distance from face of wall (m)	distance to left side of wall (m)	distance to right side of wall (m)	Height of roof above grid (m)	Angle of left side of wall (°)	Angle of right side of wall (°)	angle of roof (°)
1	47.31	30.45555	55.67882	14	32.77	44.16	16.48
2	47.31	29.45555	54.67882	14	31.91	45.52	16.48
3	47.31	28.45555	53.67882	14	31.03	45.53	16.48
4	47.31	27.45555	52.67882	14	30.13	45.54	16.48
5	48.31	30.45555	55.67882	14	32.23	43.41	16.16
6	48.31	29.45555	54.67882	14	31.37	45.52	16.16
7	48.31	28.45555	53.67882	14	30.50	45.53	16.16
8	48.31	27.45555	52.67882	14	29.61	45.54	16.16
9	49.31	30.45555	55.67882	14	31.70	43.41	15.85
10	49.31	29.45555	54.67882	14	30.85	45.52	15.85
11	49.31	28.45555	53.67882	14	29.99	45.53	15.85
12	49.31	27.45555	52.67882	14	29.11	45.54	15.85
13	50.31	30.45555	55.67882	14	31.19	43.41	15.55
14	50.31	29.45555	54.67882	14	30.35	45.52	15.55
15	50.31	28.45555	53.67882	14	29.49	45.53	15.55
16	50.31	27.45555	52.67882	14	28.62	45.54	15.55
17	51.09	30.45555	55.67882	14	30.80	43.41	15.32
18	51.09	29.45555	54.67882	14	29.97	45.52	15.32
19	51.09	28.45555	53.67882	14	29.12	45.53	15.32
20	51.09	27.45555	52.67882	14	28.25	45.54	15.32

Table 3.03 Measurements from each grid point to second external obstruction sides and top, converted into angles

It will be clear that angles and measurements taken from the face of the window wall will not provide useable results and for this reason, decisions are often taken to set out at a half interval from the wall. In this case the grid might be set out from 0.5 metres from the front wall. This same factor applies to the electronic form of calculation that will be discussed later.

Grid point 10 in this room is approximately halfway back into the room and will give a good first impression of the amount of light available as a spot check. Figure 3.06 below shows how the window and obstructions would appear on the Waldram Diagram from grid point 10.

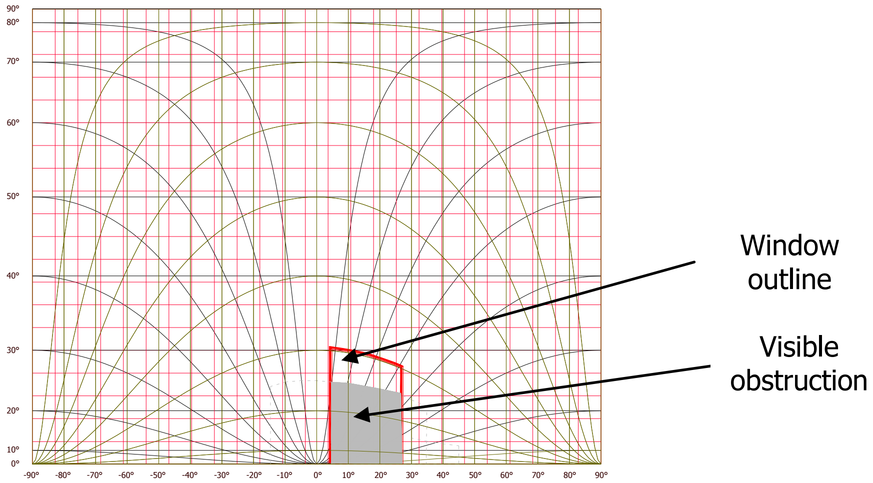


Figure 3.06 Waldram Diagram for Grid point 10

Bearing in mind that each grid square is 1/500th of the half hemisphere and the whole hemisphere, according to Waldram, provides a value of 500 foot-candles then two squares will produce 1 foot-candle (or Lumen when referred to by 'Rights to Light' surveyors)

It is possible to see from figure 3.06 above that the area within the window opening that is not obstructed is approximately three grid squares in area and therefore, according to Waldram there would be 0.3% or 15 Lux, (1.5 foot-candles) illuminance, at the point being considered. It is often assumed that a reading such as this, in the centre of the room, would indicate that the room will be adequately daylit. It is necessary to continue and check all points to produce a contour showing the line between the areas, which achieve sufficient levels, and those, which do not.

Figure 3.7 below shows the readings for each point on the grid and the contour line representing 1 foot-candle of illuminance.

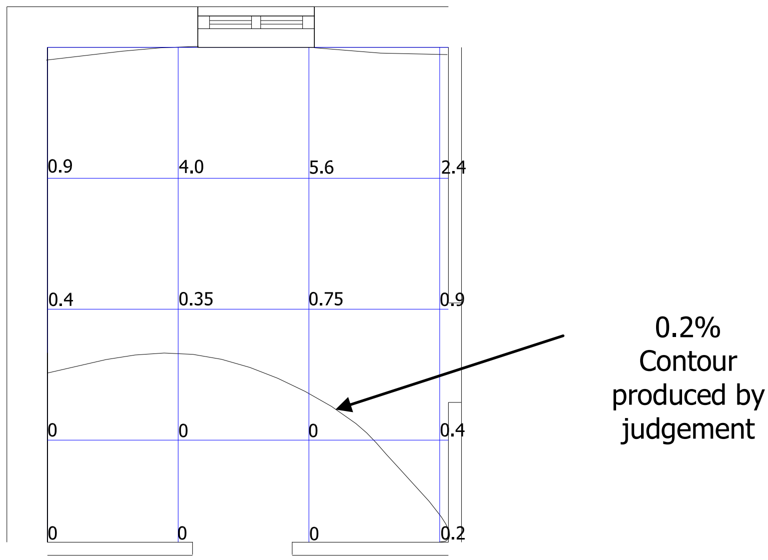


Figure 3.07 Floor plan showing values at each grid point tested and contour lines representing 1 foot-candle of illuminance.

The contour lines in this case are created through judgement based on the ratio of the adjacent grid point values to the distance between. It is thus quite common for two surveyors to come up with different contour lines. Slightly greater relative accuracy can be achieved by a smaller grid pattern or by using this first estimate as a guide and increasing the number of readings in the vicinity of the predicted contour line.

'Rights to Light' surveyors would produce two sets of these calculations, one for the existing condition and the other for the condition after the external obstructions are changed and then compare the two values to determine the loss. This use of the relative values is one of the arguments for accepting a methodology which may not be accurate but it cannot be ignored that accuracy becomes important when considering a situation where the level of illuminance which is left after any changes in external obstruction is potentially injunctable and small movements in the contour lines could become very important to one of the parties involved.

3.3 Computerised Systems

Several practices now have computerised calculation systems for calculating 'Rights to Light' areas, which no longer use the Waldram diagram as their basis. The modern method relies upon rays projected through the window at the skydome and then counting the number, which pass unobstructed. Ultimately the result still depends upon the assumption that the light from the sky is uniform.

Figure 3.08 below shows the results for a room using a computerised system taking readings at 1 metre centres and comparing this with the traditional method. Figure 3.9 shows the computerised results taking readings at 100 mm centres again compared with the traditional method.

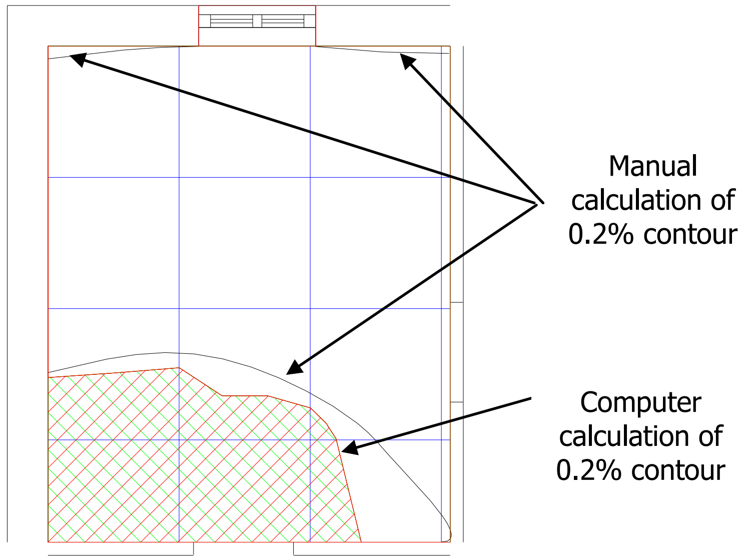


Figure 3.08 Computerised results at 1 metre centres showing hatched area below 1 foot-candle

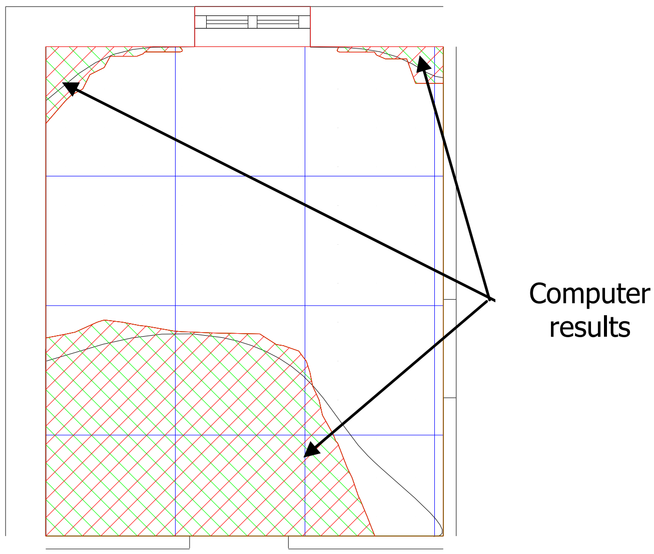


Figure 3.09 Computerised results at 100 mm centres showing hatched area below 1 foot-candle

As can be seen, the computerised result at 100 mm centres is a closer match to the traditional method at 1 metre centres using experience to plot the contour but there is still a measurable difference.

The most significant variation between the two is at the bottom right hand corner of figure 3.9. This is due to the difference between the practitioner making judgements based on limited information and the computer having greater information and following a defined set of rules. In this case the computer was using 76 more readings in that rectangle alone.

3.4 Potential Errors

It can be seen, just from this limited example, that there is considerable scope for inaccuracy in the manual use of the Waldram Diagram.

- The measurements of angles to the obstructions can be wrong.
- The guess at the curve could be wrong
- The measurement of areas could be wrong

Each of these factors has an affect on the end result and cumulatively could have a significant affect or possibly even cancel out the affect of the others.

In addition, this method is very time consuming and hence computer programmes were first written about twenty years ago, based on this process, which shortened the time quite dramatically but there are still potential problems with the use of the computerised systems.

The potential for inaccuracy with computerised systems is similar to the original method in that the source measurements used for the model could be wrong but the calculation is usually to 3 decimal places whereas the original will have been to one place at best.

More problematic is that until two practices of surveyors run identical calculations (unless they have the same software) no-one knows if the software has been written correctly. In fact it is perfectly possible to replicate one set of results but not a second set owing to software differences and only by regularly comparing the results with those produced traditionally is it possible to have confidence in the software.

For this reason it is worth examining some of the areas of potential error, which might affect the results of any calculation.

3.4.1 Areas of Potential Error in Manual Calculations.

There are several areas of potential error, which are worth considering. Those being considered in this chapter are:

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

3.4.1.1 Waldram Diagrams.

There are many versions of the Waldram Diagram, which might be used, and it is not difficult to use the wrong one incorrectly. In fact there is an example in one of the more recent leading books on the subject where the diagram, adjusted for the reduction caused by windows, has been used as an illustration, quite incorrectly.

The main alternative diagrams in circulation are an unadjusted form which merely represents the droop lines on the chart and can be used to identify the 'no-sky' line, the droop chart adjusted by the factor of 1-cos 2θ and this same chart further adjusted to allow for the passage of light through glass which results in compression of the upper parts of the chart The other chart, in circulation but significantly different to the previous charts is the version commonly used for assessment of the vertical sky component which, because it is used on the face of the window, adjusts the values at the top and either side of the diagram as well.

3.4.1.2 Lack of Information.

In practice it is rare to obtain measured information from both sides in a Right to Light case. When considered from the developer's perspective there are often fully detailed designs for the proposed obstructing buildings and often survey information for the outside of any existing buildings but there is rarely survey information from within the affected buildings. The reason for this is usually that the developer will not wish to raise the issue of 'Rights to Light' with the adjoining owner or owners until such time as it becomes absolutely necessary.

From the other side, an affected owner is unlikely to be presented with detailed information about a proposed development and so in each case the 'Rights to Light' practitioner will be making educated guesses as to either the layout of rooms within a property or the massing of a proposed development and these guesses can very easily be wrong. For example, a window on an elevation may serve a room where the window is in the centre of the wall but equally the window can be off to one side and in the latter case there will be one section of the room which is more dependent upon light from an acute angle to the window.

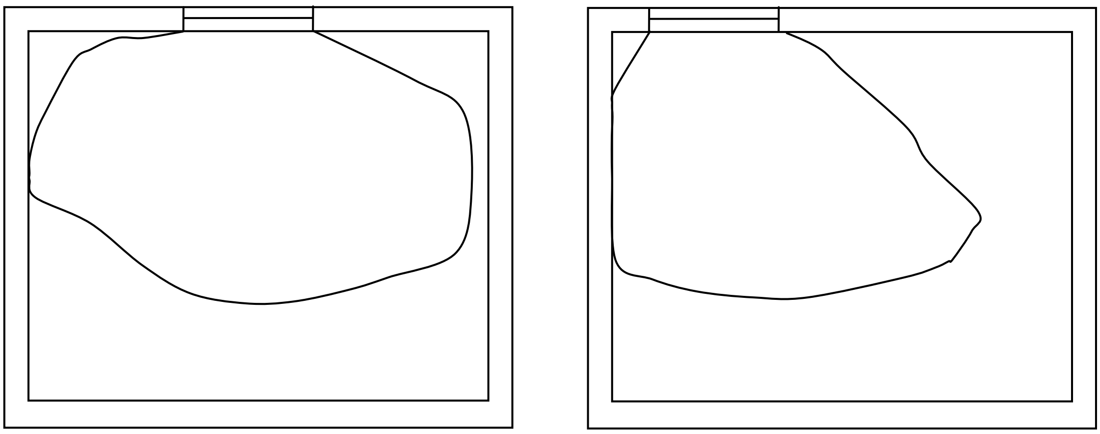


Figure 3.10 Comparative contours for different window location

In addition, the room size may be significant; for example, the deeper the room the more reliant it is upon light from a shallow angle to reach the rear of the room.

3.4.1.3 Assessment of Angles.

The next most common area for errors is the plotting of angles onto the chart. The chart may be set out with droop lines marked at ten degree intervals both horizontally and vertically but the likelihood of the window fitting exactly on these lines is extremely small and even if it did for one point on the grid in the room, it would not for the remainder. The practitioner therefore has to assess, by eye, the ratio between vertical or horizontal angles to plot the shape of the window and the same for any external obstructions. Small errors will inevitably creep in to the drawings from each grid point.

3.4.1.4 Using Different Datum Levels

It is also not uncommon to commence calculation of the angles of elevation using an alternative datum level; for example, setting the levels at 750 mm rather than 850 mm. (This is a technique, which can 'improve' results without being too obviously wrong. The lower level makes the window head level proportionately higher and thus opens up the sky above any obstruction. Figure 3.11 below shows a cross section of the affect at 850 mm and Figure 3.12 shows the same cross section with the affect at 750 mm) Of course it is debatable that this is in fact a more correct level. It might also be argued that the floor could be used, as was demonstrated in *Tamares (Vincent Square) Ltd v Fairpoint Properties (Vincent Square) Ltd (Moss 2007)* where the 'Rights to Light' expert witness produced a diagram showing the effect on the light on the surface of a staircase and this appeared to be accepted by the judge.

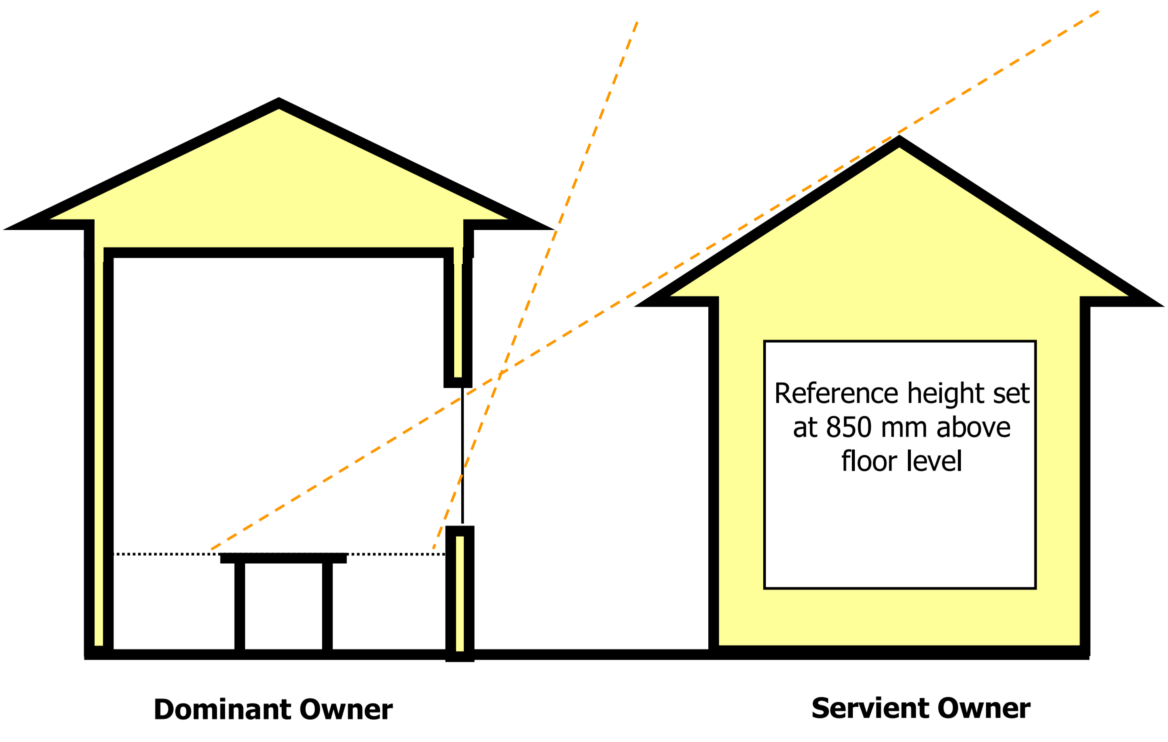


Figure 3.11 light penetration through window onto working plane at 850 mm

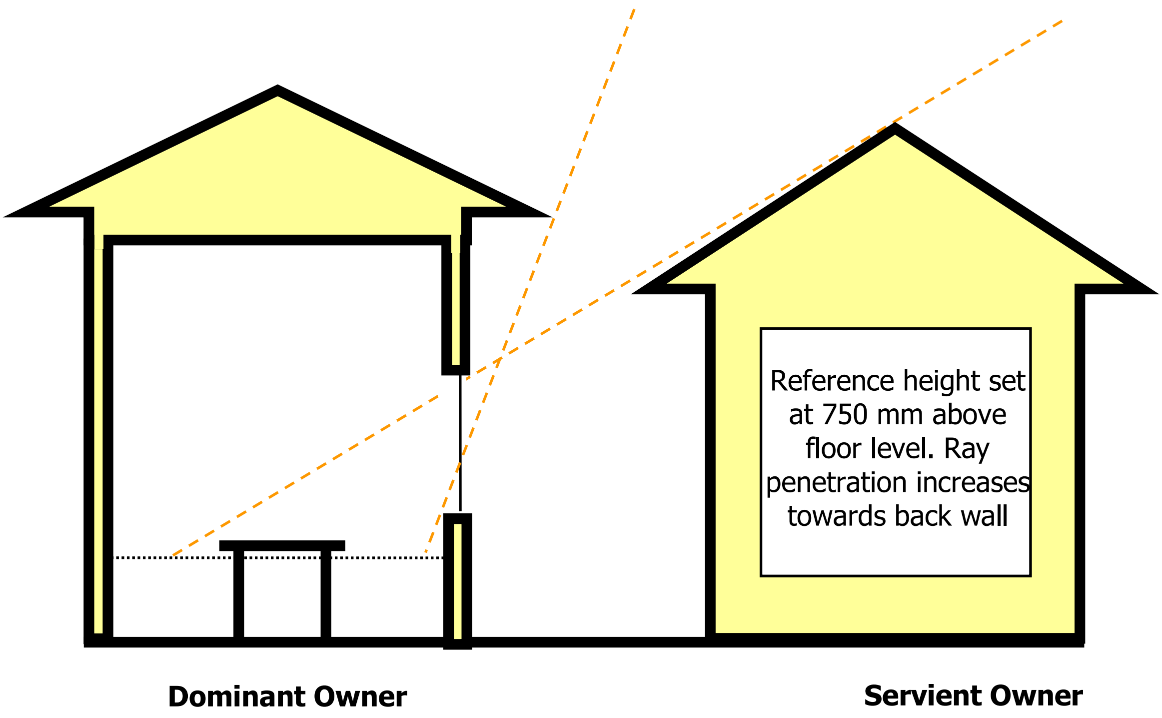


Figure 3.12 light penetration through window onto working plane at 750 mm

3.4.1.5 Grid Spacing.

The next most common error arises out of the grid spacing selected. It is a fact that the larger the grid spacing, the more approximate the measurement, as has been demonstrated above. If the grid spacing is at say 1 metre centres as was common for a first appraisal, then the practitioner would be using their judgment to find a point between each measurement which represents the value of 0.2% of the sky dome. A smaller grid of say 100 mm spacing is more likely to locate a series of points which are very close to or equal to 0.2% and would require very little interpretation. Unfortunately, this would be too time consuming and the most common compromise was to do the calculations at 500 mm centres and, for a skilled practitioner, each point could be assessed in approximately 15 minutes. The other problem arising out of this is the affect of boredom or tiredness that results from the number of calculations being performed and this introduces the further possibility of errors.

3.4.1.6 Distant Obstructions.

It is very easy to concentrate on obstructions, which are close to the affected building, and to ignore those, which are more distant. Buildings such as those at Canary Wharf block the sky line for some distance around and should be taken into account.

3.4.1.7 Calculation of Contour Areas.

The contour lines produced on the floor plan will always be irregular shapes and it is necessary to calculate the areas within these polygons to establish the value of the loss. It is relatively easy for the experienced practitioner to recognise when the area poorly lit exceeds half the area of the room but this is not sufficient when assessing compensation and a degree of accuracy is required. Occasionally, the area of poorly lit room is so close to 50% of the room area, commonly used as the benchmark, that any small difference could tip the balance and, as has been stated previously, this could result in Court action and it is a matter of concern that the inaccuracies outlined above may have serious consequences for a client.

3.4.2 Areas Of Potential Error In Computerised Calculations

Whilst there are undoubted benefits in using computerised systems of calculations, there are some areas of potential error to be considered. In fact, as many leading practitioners now have the use of a computer based method for determining the well lit areas of rooms, the Waldram Diagram is rarely used and the majority of practices do not even use a computerised version of the Waldram Diagram preferring to use a ray counting method.

The problem with this is that there is no paper trail which can be audited i.e. the result is printed out both by way of contour plan overlaid on the floor plan and by a results table. For the majority of practices there are no individual charts for each point assessed to enable a third party to see that all obstructions have been included and that the window is the correct size and location, for example, although at least some programmes have the facility to look in from outside the sky dome as a checking method.

Where the experts for both sides have computer programmes it is rare for them both to perform the calculations. They each assume the other is correct unless there is an obvious mistake when, in gentlemanly fashion this is pointed out, put down to computer glitch, rerun and accepted.

For those practices without the software, the commonest method is to check one point and if it looks about right, to accept the diagram and get on with negotiations.

Many of the potential errors using the traditional method can still happen, using computerised methods. There is also the potential for some errors to arise out of the algorithms being used (or not used). The following paragraphs identify some of the commonest areas of error although some might be more correctly termed areas of user manipulation.

3.4.2.1 Algorithms.

If the algorithm for adjusting the value of the light from different parts of the sky has not been used to modify the value of the rays, or the wrong algorithm has been used then the end results will differ slightly from the manual method but this would probably not be critical, unless the well lit areas are close to 50% of the floor area, since the programmes are measuring change on a like for like basis.

3.4.2.2 Lack of Benchmarking.

Great reliance is placed on the calculations produced by the various computer programmes, which have been written for 'Rights to Light' practitioners, but very few have been checked against any accepted standard. In fact most are checked occasionally by comparison with manual calculations or by comparison with the results from other practices which, unless they use the same programme and the same model, stand very little chance of producing identical results and usually rely upon a close similarity between the results to indicate their relative validity. It should also be noted that, to date, no authority, such as the BRE, has certified any of the programmes.

3.4.2.3 User Interface.

With most programmes using grids, the grid start point can be adjusted and the programme interprets values outside this grid. Taken to extremes, a grid can be started at 990 mm from a wall on a 1,000 mm grid meaning that the programme has to interpret where the contour might go between the grid and the wall giving a large margin for error. Programmes using linear calculation processes (these perform the calculations on a series of lines at fixed centres rather than a grid) could still be manipulated in the same way unless the programme contains safeguards.

Using the manual method, window reveals are largely ignored as the surveyor will be using the outside edge of the window opening in his measurements. However, computers have to be instructed electronically that the outside edge of the window opening is not in the same plane as the wall surface, which defines the room. Some early programmes did not have this capacity but later ones allow any thickness of wall to be specified. Operator error can therefore select the wrong thickness of wall or even no thickness, which will have the effect of allowing 'light' to reach points close to the wall at either side of the window, which would otherwise have been blocked by the reveals of the window.

Despite all the potential for error, most practitioners have argued that it is the comparison which is important because they are dealing mainly in assessing levels of compensation rather than dealing with evidence of absolute levels in Court and, in this respect, so long as the same constants are used for both 'before' and 'after' calculations then any errors are self corrected.

The methodology has the advantage of its relative simplicity and ease of comprehension when displayed as a chart. For this reason many rights to light computer programmes now print Waldram Diagrams showing the windows and obstructions as well as the floor plan with the contour lines. It is highly likely therefore that any alternative methodology will need to replicate this facility if they are to be acceptable to the Courts.

3.5 Daylight Calculations Using BRE Guidance

3.5.1 The Vertical Sky Component (Waldram Method)

The starting point for general daylight calculations is to calculate the vertical sky component (VSC) at the face of the window rather than internally within a room and it is usually measured from the centre of affected windows. The VSC is the ratio of direct sky illuminance falling on the vertical wall at a reference point, to the simultaneous horizontal illuminance under an unobstructed sky. The maximum value is 40% for a completely unobstructed vertical wall.

This methodology is only intended to provide an estimate and most practitioners recognise that there are more detailed and perhaps more accurate methodologies and that the 'Waldram' diagram for VSC, which represents 40% of the skydome value, is only 'approximately' 400 square centimetres with each square centimetre representing a value of 0.1%. In fact the actual chart is 18 centimetres high by 22 centimetres wide giving an area of 396 square centimetres.

According to Littlefair (1991), for a room with non-continuous obstructions, there is the potential for good daylighting provided that the VSC at the window position, 2 metres above ground is not less than the value for a continuous obstruction of altitude 25 degrees which is equal to a VSC of 27%. The guidance also suggests that if the VSC of 27% is achieved within 4 metres horizontally from any window then sufficient daylighting is still likely to be achieved.

In Figure 3.13 below, Building B, which is a continuous building with roof at 25 degrees altitude from the centre of the window, would leave a VSC of 27%. Alternatively, Buildings C, D and E in combination would leave a VSC of 27%. The amount of light incident on the outside face of the window being considered is quite clearly well in excess of the 0.2% being considered under 'Rights to Light' calculations but it is impossible to assess, from this diagram, the effect once the light has passed through the window opening and indeed a small window, or a window set in one corner of a room may produce undesirable results.

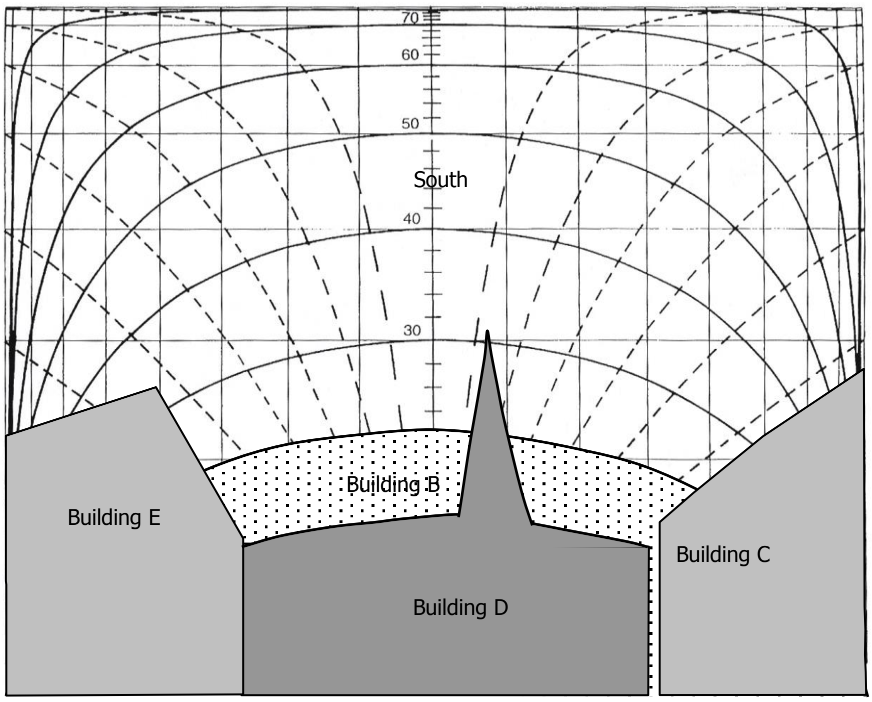


Figure 3.13. Typical Waldram Diagram for VSC calculations

Waldram also proposed an approximate formula in his booklet entitled 'A Measuring Diagram for Daylight Illumination' published by Batsford in 1950, shortly after his death. The formula stated that the sky factor percentage was equal to ($\Phi(1\text{-}\cos 2\theta)/7.2$) and so for an example where the width of an opening is 20 degrees and the height is 30 degrees, the sky factor would be 1.39% which, if it were accepted that a factor of 0.2% equalled 1 foot-candle, would itself equate to about 7 foot-candles.

Whilst this method is useful in that it provides an easily comprehended chart showing the existing and proposed conditions, it provides no indication of the actual daylit conditions of the room behind the window and, as mentioned above, this might be significant in awkward shaped rooms or particularly deep rooms and would provide no basis for assessment of compensation.

3.5.2 Sky Component (BRE Method)

The BRE have provided a simplified graphical method for estimating the sky component at points in rooms lit by vertical windows. It relates only to the CIE standard overcast sky and the following information is needed to use the table:

- $h_{w,}$ the effective height of the window head above the working plane after allowing for any obstructions
- H_{wp}, height of working plane above floor

- W_1, W_2, the effective widths of the window on each side of a line drawn from the reference point normal to the plane of the window, taken separately.
- D1, the distance from the reference point to the plane of the window (this is the plane of the inside or the outside of the wall, whichever edge of the window aperture limits the view of the sky).

The ratios h_w/D_1, W_1/D_1 and W_2/D_1 are worked out and the sky component can then be read directly from the table. In general, the sky component at any other reference point can be obtained by addition or subtraction. If the window sill is above the working plane, the sky component blocked by the wall below the sill are calculated in the same way and subtracted.

This provides a numerical result, which is accepted as being a good approximation, but there is no visual output and the assessment of the difference in illumination for negotiation purposes would not be possible as, once again, there is no relationship to the floor area.

3.5.3 The Average Daylight Factor

The average daylight factor is expressed as a percentage of average illuminance within a room divided by the unobstructed illuminance outside the room and takes account of how clear the glass is; the net area of the window (omitting glazing bars for example); the total area of room surfaces including is all of the walls, floors and ceilings. This area is then factored by giving it an average reflectance value. (As many clients have realised, magnolia is quite good for reflectance values). The amount of light is then adjusted by taking account of the previously calculated VSC and converting this into the equivalent 'visible angle' to produce an end result.

It is easiest to visualise the 'visible angle' as the conversion of a complex skyline into a single line such as Building B in Figure 3.13. In other words, where the VSC equals 27%, the angle of obstruction will be the equivalent of 25 degrees and the value used in the daylight factor calculation is what remains of the 90 degrees i.e. in this case the visible angle is 65 degrees. It is possible, however, to achieve acceptable average daylight factors with a room like a tunnel (that is where the window is at the end of a long room such that only the half of the room nearest the window benefits from any daylight) provided that the window is large enough, so it is also important to check that a room receives enough light for the majority of its depth.

The recommended ADF, for a generally daylit appearance, is 5% but it is accepted that most rooms are lit with electric bulbs and here the recommended level can be reduced to 2% but the average levels for Living Rooms and Bedrooms is lower (1.5% and 1% respectively) and we find that Planning Authorities are accepting anything above these levels as being acceptable. It is still not possible to relate this back to the 0.2% used in 'Rights to Light' cases but there is no doubting that this method of measurement has its own validity and should be considered when reassessing the existing basis of 'Rights to Light' calculations.

However, in much the same way as has been described above, there is no direct relationship between the average daylight factor and the area of floor, which would no longer be well lit. Since negotiations are based upon the loss, it would prove extremely difficult to persuade practitioners that this method, whilst potentially more accurate, should be adopted.

3.5.4 No Sky Line

Where the windows are not considered to be of sufficient size or are not in the most ideal location to provide light to the room inside, it is usual to assess the "no sky" line within the room. In almost the same way that Rights of Light analyses are undertaken, it is possible to calculate the contour within the room where no sky is visible rather than the notional 0.2%, which is used for Rights of Light. This measurement is taken at desk top height (which, for the purposes of this exercise, may be taken to be anywhere from 0.75 to 0.85 metres above floor level) and it is possible to do this physically on site with existing buildings by moving around the room and marking on a plan the points where the sky is no longer visible. Where the buildings do not yet exist or there are several rooms to do, the process is made less arduous by using computer software but the ability to model the complexities of real buildings is essential for the daylighting software to be accurate. (Ubbelohde and Brager 2004)

Whilst it is tempting to use the more exact assessment, since there is no doubting the points at which no further sky light is visible, the 'no sky' line gives no indication of the area of the room which is adequately lit. A room with the 'no sky' line enclosing an area of one third of a room may be well lit if the average for the room exceeds the minimum level but equally may be poorly lit if the average is below the minimum level but there is no way to determine what the average might be. In effect the measurement process needs to identify the average for the room such that an area in excess of half the area should be illuminated to a predetermined level in the same way as is accomplished using the present methodology.

3.6 Useful Daylight Illuminance

Current discussions amongst some practitioners surround a proposal for a new paradigm referred to as 'useful daylight illuminance' by Nabil and Mardaljevic (Nabil 2004)

The approach formulated by Mardaljevic has been tested against the BRE-IDMP validation dataset and is used in a climate based model. (Mardaljevic 2001)

For the experiment they used a model where the reflectivities of the walls, ceilings and floor were set to be 0.7, 0.8 and 0.2, respectively and the window had standard 6 mm clear double glazing with a transmittance of 0.76. The calculation points lay on the working plane (0.75m from the floor) and along a straight line from the window to the back of the office.

Hourly sky and sun conditions were derived from the direct normal and diffuse horizontal irradiation data in the Kew-84 (51.47°N, 0.28°W) Test Reference Year for every daylight hour in the year (i.e. where the irradiation is greater than zero – out of 8760 hours, and there were 4316 daylight hours in this particular test). From these results they determined that a daylight illuminance of 500 Lux was achieved for ~70% of the working year (at a point 2.25m from the window).

In another part of their experiment (Nabil 2004; p46), the cumulative plot showed that 500 Lux was achieved in the middle of the office for ~70% of the working year. However, the 'stacked' plot showed that for ~35% (of the working year) the daylight illuminances were greater than 2000 Lux.

This climate based approach appears to demonstrate that higher values of illuminance are being achieved than those predicted using other methods.

It has been argued, by Nabil and Mardaljevic, that the useful daylight illuminance paradigm preserves much of the interpretive simplicity of the familiar daylight factor approach as only three metrics are needed to characterise the daylighting performance of an internal space in its entirety, including the propensity for discomfort due to high levels of illumination. Unlike daylight factors however, the useful daylight illuminance (UDI) metrics are based on absolute values of time-varying daylight illumination for a period of a full year.

The debate, so far as Nabil and Mardaljevic are concerned, is whether to prolong and apply anew the Daylight Factor (DF) criterion with its ratio based either on the traditional uniform or overcast sky luminance patterns, or should it be expressed in the form of the Daylight Coefficient (DC) concept respecting arbitrary luminance distributions in a range of realistic skies with the sun present or absent. The approach, which appears to be preferred, by Nabil and Mardaljevic is to change the daylight design and assessment system to absolute illuminances in Lux with their changes in annual profiles to simulate local seasonal and daily variations.

'Rights to Light' surveyors would question the relevance of this method in that there is no way to demonstrate just how representative the 'averaged' hourly irradiance or TRY datasets may be and they would point to the issues of rapid cloud movements and changing sky luminance patterns, which are so characteristic for daylighting in England as making such a system impossible to model and to use with any effect.

It is worth noting however that the refined DC implementation formulated by Mardaljevic was validated using the BRE-IDMP dataset and proven to be highly accurate: within ± 10% of measurements (the accuracy was comparable to that of the measuring instruments themselves).

Despite this apparent accuracy, the UDI methodology does not provide the simplicity necessary for establishing compensation levels where the requirement is for a straightforward comparison and it risks causing confusion in Court when trying to explain that at some parts of a day the room will be sufficiently lit whilst at others it will not and that this can vary in exactly the ways that Waldram described.

3.7 Summary

From this brief analysis it becomes apparent that there are three different ways in which the affect of daylight within a room may, at present, be assessed. The first is essentially the existing method for 'Rights to Light' cases, using a notional uniform sky to predict the illuminance on the working plane; the second uses a CIE overcast sky as part of an assessment of the average daylight factor and the third uses the daylight coefficient proposed by Nabil and Mardaljevic. Only the Waldram method produces a simple contour diagram on the floor plan, which can be used in the assessment of compensation although others are potentially more accurate.

One possible alternative which does not appear to have been considered in present methodologies is to use the CIE sky model to provide the sky factor within the room (ignoring the internal reflectance and losses through the window), to predict illuminance on the working plane and this will be explored in a later chapter but before considering this possible alternative it is necessary to establish, if possible, how much light is actually available and how much light is needed for normal usage and this will be examined in Chapter 4.

Chapter Four
How Much Light is Needed and How Much is Available?

'… I think the judge was entitled to have regard to the higher standards expected for comfort as the years go by. … In these days I would not myself be prepared to regard the 50:50 rule of Mr. Waldram as a universal rule. In some cases a higher standard may reasonably be required.'

Lord Denning MR 1967 in Ough v King

4.1 Introduction

From the preceding chapters it will have become apparent that the definitions of how much light is needed and of how much is available is not a simple matter.

There are few authorities for the amount of daylight which is considered to be necessary and equally, it is important to recognise that the Courts have determined, for 'Rights to Light' cases, that there should be sufficient for ordinary needs. By inference this excludes extraordinary needs but there is a risk in such a subjective statement in that what to one person is ordinary might be extraordinary to another and what was considered extraordinary, when Denning made his ruling in *Ough v King* (1967), may now be considered ordinary.

In this chapter some of the authorities on daylight are examined in an attempt to determine the basic values that might be used in any alternative methodology. These authorities include Surveyors, Services Engineers, Psychologists, Ophthalmologists and the British Government through such organs as the British Standards and Building Regulations.

4.2 How Much Daylight is Needed?

Surveyors have, for many years, based their opinions upon the levels of daylight, which Waldram stated were adequate or otherwise, not questioning the fact that he originally expressed the view that a room should have at least one foot-candle of illuminance in all parts (Waldram 1909a) and that this was later changed to a minimum of one foot-candle, <u>over half the room</u>. In addition, he originally posited a sky value of 1,000 Foot-candles (10,000 Lux) but this was subsequently changed to 500 foot-candles (5,000 Lux). (Waldram 1923) and this was later modified when he said 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. (Waldram 1925; p14)

At a meeting of the Daylight Group in London, Chynoweth (2007) presented a useful comparison of the current thinking on daylight requirements, according to The Chartered Institute of Building Services Engineers (CIBSE), The British Standards (BS) and Waldram with an additional comparison for task lighting, which is recognised by both CIBSE and BS but was not recognised by Waldram. (Table 4.01).

It is difficult to relate the Daylight Factors (DF) of CIBSE and BS to the Sky Factor (SF) of Waldram except by comparison through a real example. The Daylight Factors take into account the losses from transmission through the window as well as internal reflectance values of the room being considered and are based on sky values, for a CIE overcast sky, measured on the face of the window and related to the whole room, whereas the Sky Factor used by Waldram is based upon a Uniform Sky but is measured from within the room and relates to a 'contour line' enclosing a minimum of 50% of the floor area. It also ignores windows and frames and takes no account of internal reflectance, nor is the use of the room considered relevant. For this reason, the relative values in table 4.01 are compared, in chapter 7, with those obtained during the experimental research.

		CIBSE/ BS		**WALDRAM**
GENERAL ROOM LIGHTING	General Offices	2% DF_{min}	5% DF_{av}	0.2% $SF_{50\%}$
	Kitchens	0.6% DF_{min}	2% DF_{av}	0.2% $SF_{50\%+}$
	Living Rooms	0.5% DF_{min}	1.5% DF_{av}	0.2% $SF_{50\%+}$
	Bedrooms	0.3% DF_{min}	1% DF_{av}	0.2% $SF_{50\%-}$
TASK LIGHTING	General Offices	500 Lux		10 Lux (1 foot-candle)
	Kitchens	500 Lux		10 Lux (1 foot-candle)

Table 4.01 Comparison of CIBSE/ BS standards with Waldram, Chynoweth 2007

The task lighting requirement by CIBSE/ BS is not a daylight requirement nor is it a minimum requirement.

According to Littlefair (1991), a habitable room is likely to be well lit if a window, or a point within 4 metres horizontally from the centre of the window, has a 27% Vertical Sky Component (VSC). If it is accepted that the Daylight Factor DF is in direct relationship to the Vertical Sky Component (VSC) and that the maximum VSC is 40% as explained by Littlefair, then these standards might be applied to a real example to establish whether there is a relationship between the Daylight Factor (DF) used by British Standards and the Sky Factor (SF) used by Waldram.

As can be seen from table 4.01 above, separate values for task lighting have been established by CIBSE and within the British Standards in relation to offices which establishes a more specific standard of lighting which the law, in relation to 'Rights to Light', would appear to ignore. It is assumed, however, that task lighting will involve the use of artificial lighting as a supplement to natural daylight but, in historical terms, Waldram would not have been considering artificial lighting when he advocated the level of light necessary to be able to work as being the equivalent of 10 Lux.

Various authorities around the world have subsequently sought to establish adequate levels of lighting for offices which recognise the use of artificial light and the health and safety implications of insufficient lighting and this is illustrated in Figure 4.01 below, which shows how the recommended value of lighting for offices has changed since the 1930's in the UK, USA and Russia. If the law were interpreted that the right to light implied that daylighting should be sufficient to any of the standards since 1930, without the addition of artificial light then the levels established by Waldram are clearly too low.

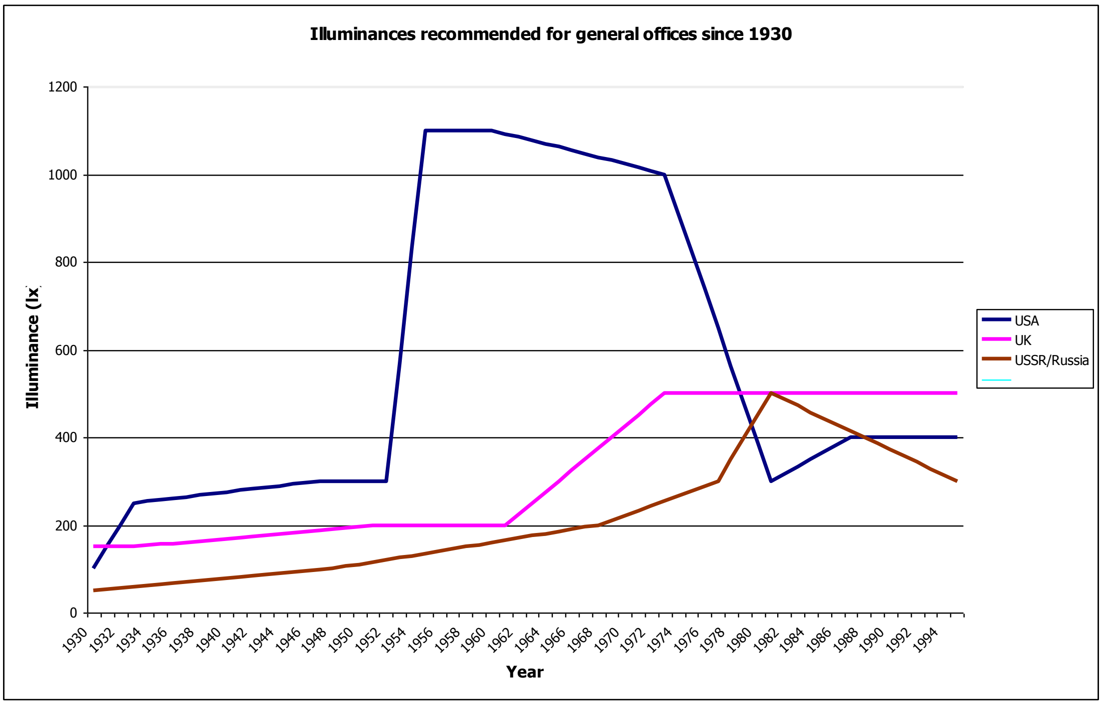


Figure 4.01 Boyce, Human Factors in Lighting, 2003 (after Mills & Borg, 1999)

4.2.1 The Government Standards

The view expressed by various U.K. governments over the years has evolved and is continuing to evolve. Many practitioners remember the Building Regulations (1972), which stipulated the area of glazed window required for a habitable room as 10% of the floor area, half of which had to be openable for ventilation, but the Regulations did not deal with sky visibility or daylight factors. In 1999, a discussion paper was issued through the Office of the Deputy Prime Minister (ODPM) in connection with the future updating of Building Regulations relating to natural daylight. Since that time the Building Regulations have been amended and no longer make reference to size of windows for daylight. They do however deal with heat loss and permeability, which has had the net result of reducing window sizes. Planning law has, however, allowed Local Authorities to adopt standards for daylighting and sunlight and, almost without exception, they have adopted the guidance issued by the Building Research Establishment (BRE) (Littlefair 1991). In some cases the guidance is used unequivocally and in others purely as guidance, which may be ignored if the results are unsatisfactory but the political need requires approval.

Littlefair referred to the 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 (which is the same site as the location of Century House mentioned elsewhere in this document). (Littlefair 1993) The Health and Safety Executive, (HSE) guidance documents suggest good practice only and are not mandatory but may still be used in the same way as the CIBSE guide.

According to the British Standard, BS 8206 Part 2: Code of Practice for Daylighting, *Daylight is required for two separate purposes: to give a light airy appearance to a space and to provide enough light for specific tasks.* (British Standards Institution 1992). A more recent international standard, BS ISO 8995:2002, Lighting of Indoor Workplaces, also considers daylighting and sets a minimum daylight factor of 1% on the working plane 3 metres from the window wall and 1 metre from side walls. (CIE 2002).

4.2.2 The Lighting Engineering Standards

The Chartered Institute of Building Services Engineers (CIBSE) advises that the only legal requirements are that daylighting should be *'sufficient and suitable'* but in their guide, *Volume A Design Data (1988), Table A1.6*, they set out levels of illuminance for various activities which could be used in assessing what level of lighting should be provided naturally.

CIBSE have also published document LG10 '*Designing for Daylight'* 1999 p29 which states that '*A well daylit space needs both adequate lighting levels and light that is well distributed. In some rooms, the lighting level at the back falls dramatically below the level close to a window, to such an extent that occupants feel deprived even though their actual task illuminance is* *otherwise acceptable.*' This actually contradicts the principles of 'Rights to Light' calculations, which implies that up to 50% of a room may be inadequately lit before it becomes a problem for the occupants. (CIBSE 1999)

Section 1 of the guide deals with the role of windows in building design and section 2 deals with more general design issues. Section 3 concentrates on daylight calculations and, in the main, reiterates the methodologies established by BS 8206 Part 2.

Whilst the guide recognises some of the historical factors relating to daylight usage and design, it cites more recent evidence that this was a simplistic view of daylight's contribution to user comfort and satisfaction. According to the guide, a survey showed that 80% of the staff wanted to sit by an openable window and refers to the Building Research Establishment Environmental Assessment Method, which recognises good daylight as contributing to healthy building design, which in turn has implications for absenteeism and productivity. However, it produced no new evidence to support the levels of light, which are actually needed, relying instead on a quotation from Louis Kahn, one of the 20th century's foremost architects, to indicate its importance. Kahn stated that he could not define a space really as a space, unless he had natural light, which gives mood to space by nuances of light in the time of day and the season of the year as it enters and modifies the space. (CIBSE 1999)

Nabil (2004) observed that there is a large range of lighting conditions over which the human eye performs satisfactorily, and that there is a large range of variation among individuals as to what comprises satisfactory conditions. They confirmed that there are no conclusive studies which correlate daylighting provision and occupant satisfaction with the environment and worker productivity but noted that there is anecdotal evidence that workers appreciate offices that provide daylight and a view of the outside, and that glare-free and thermally comfortable spaces have quantifiable effects on workers' satisfaction and performance

Nabil and Mardaljevic referred to the Cost-Effective Open-Plan Environment (COPE) field study, conducted by the Institute for Research Construction (National Research Council Canada) that illuminances larger than or equal to 150 Lux were categorised as 'appreciable daylight' and that the Illuminating Engineering Society (IES) of North America recommended 50-100 Lux, provided directly on the individual task area, as the general range of illuminance required for working with CRT screens but that people tend to tolerate much lower illuminance levels of daylight than artificial light, particularly in diminishing daylight conditions at the end of the day, such as continuing to read at levels as low as 5 Lux (0.5 Foot-candles)

In a survey of published findings, on occupant preferences and behaviour, it was confirmed that daylight illuminances of less than 100 Lux are generally considered insufficient to be either the sole source of illumination or to contribute significantly to artificial lighting and that daylight illuminances in the range of 100 to 500 Lux are considered effective either as the sole source of illumination or in conjunction with artificial lighting.

4.2.3 The Psychologists Standards

Psychologists appear to concentrate most on the affect of lack of daylight leading to depression and other related illnesses.

The condition now known as SAD has been examined in the context that modern people get less light (Kripke 1997). Kripke confirmed that our eyes adjust over such a range of lighting that it is hard to comprehend how much brighter it is outdoors, than in, and he cited the example that a camera indoors would require a 1 second exposure whereas outdoors it requires 1/1000th of a second. In other words there can easily be a thousandfold difference.

Kripke's research, using a group of 318 volunteers aged between 40 and 64, showed that men were, on average, exposed to 350 Lux over a 24 hour period and women 278 Lux. The average during daylight hours was probably around 500 Lux. It was his opinion that more people were reporting depression where they were receiving less than the median daytime illumination.

Farley and Veitch considered that the fact that windows appear to be ubiquitous in most places designed for human occupancy indicates, at the very least, a preference by people to see outside and that this preference could be explained as a production of evolution that favoured humans who looked to nature for food and safety. They also referred to research that indicated the importance of daylight in hormone production and regulation. (Veitch 2001)

Collins (1975) reviewed a considerable amount of literature in relation to peoples attitudes to daylight and gave examples of studies which had found that windows occupying 10% or less of the window wall were regarded as extremely unsatisfactory and that satisfaction was greater for a window occupying 20% or more of the wall and that larger (more an 20% of the wall) windows were evaluated as most satisfactory.

She found a number of studies that dealt with daylight and sunshine from windows as sources of illumination but that the literature on sunshine focused on its psychological effects compared to the work on daylight, which tended to look at the amount and quality of illumination provided. Various examples demonstrated that when research participants were asked directly about their desire for daylight, they generally expressed a strong preference for daylight over artificial light in their offices but that this was often confused with sunlight.

Veitch and McColl (2001; pp 6-18) suggested that many people believe that daylight is superior to electric lighting in its effects on work performance, mood and health and cited media attention which had contributed to this notion, with articles and news items in prominent publications showing headlines such as *'New York Schools Consider Installing Full-*

Spectrum Lighting to Help Students', 'A Case of Daylight Robbery'; 'Natural Prozac', 'Report Card on School Lighting'. They recognised that the variability in illuminance and spectral qualities of daylight over the course of the day and with weather conditions is considerably greater than any difference between fluorescent lamp types and thus that it is impossible to characterise precisely to which stimulus conditions subjects responded if they were in rooms with windows.

They made a useful point in respect of laboratory experiments, which have included controls for this problem by using windowless rooms and pointed out that field studies were inconsistent in reporting the presence or absence of windows in the target setting.

Their hypothesis suggested that any deviation in daily light exposure from daylight risks causing abnormal function and that the existence of physiological mechanisms that respond to light is taken as evidence for the hypothesis, '*regardless of the action spectrum for the process or its relation to daylight (or moonlight) conditions'.*

Veitch and McColl concluded that '*the evolutionary hypothesis holds that general cognitive performance should be best under lighting similar to daylight'.* Their research, however, identified how difficult it is to create a valid measurement of the affect of light on performance when they described an attempt to measure academic achievement. They identified one problem common to almost all such field studies as the impossibility of controlling the selection and maturation biases because random assignment of students to classes is usually not permitted. Nor could they allow for the possibility of bias from history effects such as differential instruction. Other factors, which would affect their research, included cases in which different lamp types are installed in different schools but differences in socioeconomic status, school policy, teacher behaviour, and history would be particularly difficult to control.

This all goes to suggest that psychologists in general are unable to provide a satisfactory statement as to appropriate lighting levels and despite considerable efforts including internet searches and personal enquiries it has not been possible to obtain any view from qualified ophthalmologists as to a suitable minimum level of lighting let alone daylighting.

4.3 Further Research Plan

The various authorities, who might be able to recommend adequate levels of daylight for medical reasons, appear not to be able so to do and it has not been possible to discover the source of the various standards used by the community of engineers and surveyors and thus to determine its validity in connection with rights to light cases.

From this analysis there appears to be a justification for some controlled research along the lines of the 'jury' approach referred to in earlier chapters.

Unlike the original research, which was undertaken in an uncontrolled environment, it is proposed that this approach within a controlled environment could lead to the identification of an acceptable benchmark level of lighting for ordinary purposes.

The approach taken for this experiment involves the use of a room with no windows or with good blackout blinds. The lighting will be controlled by rheostat dimmer switch allowing fine adjustment of lighting levels.

In the centre of the room, positioned under the light, will be a desk upon which there will be a copy of the Times newspaper with a section of text outlined and a Lux meter adjacent. Each volunteer will be guided to the desk and sat in a chair under low light conditions (there should be sufficient light to avoid trip hazards and to locate the desk but no more). The lighting will then be adjusted to the point where the volunteer confirms that the lighting is adequate to be able to read the outlined text without strain.

The experiment will be repeated with each volunteer but with the lighting starting at a more than adequate level, based upon the previous results, and reducing the light to the point where the volunteer states that it is no longer comfortable reading the text.

Each volunteer will complete a questionnaire (anonymously) giving age, gender, basic health and eyesight (i.e. do they need glasses for reading) and the readings for both tests will be recorded on the form.

A more detailed description of the experimental approach appears in Chapter 5, the results obtained from the experiment appear in Chapter Six and the analysis of the results in Chapter Seven.

4.4 How Much Daylight is Available?

Surveyors currently base their opinions upon the level established by Waldram and as described in Chapter 2, at a value of 500 foot-candles (approximately 5,000 Lux), notwithstanding the fact that this does not represent an absolute minimum nor an average of the recorded values for the working day. Waldram also made the assumption that the sky was of uniform brightness whereas it has been shown to be non-uniform even when overcast.

There has been much research by the Building Research Establishment (BRE) and Commission Internationale de L'Eclairage (CIE) over a considerable number of years whereby measurements were taken both horizontally and vertically. Horizontal measurement with a photocell provides the value of light from an uninterrupted sky dome. The vertical measurement provides the value for half the sky dome in the direction of the photocell and thus may be assumed to provide a more accurate representation of the amount of light available to a window although it needs to be recognised that the altitude of the available light also varies and a window which sits high up within a wall of a room will allow a different amount of light to pass through than a window of the same size set lower into the wall.

Earlier chapters have described some of the research, which was undertaken to establish the values used by 'Rights to Light' surveyors. In this section, the principles of daylight measurement and some of the available empirical data is examined.

4.5 Principles of Measurement of Daylight

Daylight can be measured in a multitude of ways but the most usual way is in terms of illuminance i.e. the amount of light falling on a surface and is measured on either a horizontal plane or a vertical plane.

Modern photometers measure in Lux, which is a measurement of how brightly things are illuminated. One Lux provides approximately the same illuminance as the light from a candle one meter away in a darkened room. An older measure and the one, which is used in 'Rights to Light' cases, is the foot-candle, which measures approximately the affect of one candle at one foot away. In fact One Lux is only 0.0929 of a Foot-candle.

It is commonly accepted that the light from the sky, on a bright summer day when the sun is high in the sky, can be in the range 10,000 to 20,000 Lux, towards the horizon but, as has been stated elsewhere, the amount of light from the sky varies from moment to moment and throughout the year. Thus it is necessary when taking measurements, to take sufficient of them over a long enough period of time to be able to derive a representative sample from which useable averages can be adduced.

These measurements are considered to be valid in terms of using the whole sky dome for unobstructed horizontal illuminance and for vertical illuminance but do not relate to the real situations where light is funnelled through a window aperture because the sky is not uniformly bright (or dull), despite Waldram's use of that assumption.

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

The CIE and others have sought to model the sky in such a way that the illuminance provided by the visible sky at various altitudes can be predicted and many daylight calculations are now based on the CIE overcast sky. This represents the illuminance distribution of the sky under heavily overcast conditions which is symmetrical in azimuth and its luminance L increases with altitude γ in the sky according to the formula $L_\gamma = L_z(1+\sin_\gamma)/3$. The horizontal luminance is, therefore, only a third that of L_z the zenith luminance.

The use of an overcast sky is more realistic than a uniform sky but even this is only a theoretical model and the sky varies considerably in luminance, or brightness distribution but as a generality and for non-overcast conditions, the horizon will be brighter than the CIE overcast sky predicts so that more light will be received in side lit rooms and the area of sky nearest the sun will be brighter over an average day and therefore a south facing room will receive more light than a north-facing one.

Orientation correction factors have been provided by the CIE, which can be used to take account of both these effects.

Within this thesis it is necessary to relate the absolute value of illuminance in Lux with the Average Daylight Factor (ADF) derived using the BRE methodology and in site measurements. Whilst the experiments recorded in Chapter 6 do provide comparison between values in Lux and the ADF for the room examined, it is apparent that physical measurement of the illuminance provided from daylight is too erratic. It is, however, valid to compare the value in Lux, which might be achieved from a 5,000 Lux sky where the room has a known ADF. Thus, for example, an ADF of 2% would be expected to achieve an average illuminance of 100 Lux (see appendix 1 definition of ADF). Whilst a room may not be symmetrical in shape, or conveniently centred on a window, a starting premise might be that if 50% of the room is illuminated to a level of 100 Lux or more then the average might equate to approximately 100 Lux and this proposition is examined in chapters six and seven.

4.6 Published Data

In 1937, the Department of Scientific and Industrial Research published their technical paper number 17 entitled 'Seasonal Variation of Daylight Illumination' in which they recorded that the outdoor illumination from the whole sky varied between a value of less than 500 foot-candles in December to about 3,750 foot-candles in June or July. The analysis showed that the value of the light during the day at various times of the year remained within a relatively small range and thus it was deemed acceptable to take a mean figure for the variation of 500 to 3,500 between mid-winter and mid summer. (Department of Scientific and Industrial Research 1937)

The paper went on to analyse the seasonal averages by what are referred to as Octants. The North, East, South and West Octants differ significantly with the maximum value for the South being more than twice that of the North and half as much again as the West. There is also a variation between 3 pm and noon of 100%, in the South, and 25% in the North. The minimal variation in the North was found to be confirmation of the reason why artists prefer the light from the North.

Anstey (1963; p42) provided two diagrams illustrating how the illumination in January does not fall below 500 Lumens between 9.30 a.m. and 2.30 p.m., whereas in December the corresponding times would be 10 a.m. and 2.00 p.m. He also noted that there was a rapid jump in November and February and that by April the period during which 500 Lumens could be received from the sky had gone up to 11 hours and the maximum intensity had risen by more than three times that of December.

The value of sky brightness by angle of altitude was summarised by Anstey in a small table which predicted a sky brightness factor at 5% altitude of 0.5 and at 80 degrees altitude of 1.27 which is similar to the values predicted for a CIE overcast sky

Littlefair (1993) reported on the study, which was undertaken by the BRE, which formed part of the International Daylight Measurement Programme of the 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 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 went on to describe the nature of daylight firstly by reference to a diagram which shows the variation with time of the global daylight distribution, pointing out that even within one hour the daylight levels can change significantly particularly under cloudy skies. He confirmed that these changes make it difficult to measure the daylight performance of a building in a reliable and repeatable way.

Littlefair also stated 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. There is no direct evidence in this document that the statement has actually been verified.

In his thesis, Littlefair (1984) published the results of his measurements of daylight, which are reproduced below in tables 4.02 to 4.07. The results are measured in Kilolux. Beneath each of these tables is a chart, produced using the Microsoft Excel function, which clearly illustrates the relative values in each case.

From table 4.02 and the appended chart, it can be seen that the peak hours for unobstructed illuminance on the horizontal plane for any month are between 11.00 a.m. and 1.00 p.m. with the amount of available light tailing off significantly after about 2.30 p.m. The hours when the average illuminance did not exceed 5,000 Lux are highlighted in the table. Table 4.03 and Chart 4.03 show results for the Horizontal Illuminances (diffuse cell uncorrected), which demonstrates an overall reduction in illuminance from using the diffuse cell, and again the hours when the average illuminance did not exceed 5,000 Lux are highlighted in the table.

Tables 4.04 to 4.07 show the results from the external vertical cells facing South, West, North and East respectively. The Charts clearly illustrate the relative Illuminances for each orientation and the affect of the sun giving higher readings in the East in the morning and in the West in the evening.

Since these cells are effectively measuring only half the sky dome, the highlighted readings are those below 2.5 Kilolux.

Table 4.08 analyses the results from tables 4.02 to 4.07 by the percentage of time when the readings exceeded the specified Lux values over the period of the readings.

The 5 Kilolux reading from the uncorrected diffuse cell was exceeded over 90.63% of the time and this would tend to support the definition used by Waldram and others that a minimum of 500 Foot-candles was achieved on all but the dullest of days, during working hours. Similarly, using the external vertical cells, the reading of 2.5 Kilolux is exceeded for more than 90% of the time for all orientations.

Horizontal Illuminances unobstructed (Kilolux)

	9-10	10-11	11-12	12-13	13-14	14-15	15-16	16-17
February	12.245	18.515	22.411	22.899	20.156	15.904	8.985	3.109
March	26.201	33.223	37.831	36.562	32.129	27.267	18.131	10.208
April	41.090	46.382	50.925	49.090	43.615	40.475	28.177	19.103
May	46.294	50.682	52.588	47.200	49.528	42.433	36.525	27.221
June	52.169	59.468	57.368	56.885	55.967	48.266	42.481	30.928
July	51.623	59.733	63.694	62.755	58.583	51.787	42.846	31.471
August	48.207	58.871	63.462	62.241	56.198	46.352	37.904	24.786
September	32.001	36.797	42.449	42.071	36.912	30.975	20.500	12.167
October	21.620	26.446	30.707	29.752	24.528	18.570	9.111	3.040
November	9.513	14.406	18.118	17.596	14.088	8.366	2.810	0.233
December	6.377	10.617	12.590	12.970	9.724	5.463	1.457	0.023
January	7.105	12.633	16.493	16.567	13.602	8.741	3.602	0.430

Table 4.02 Horizontal Illuminances Unobstructed

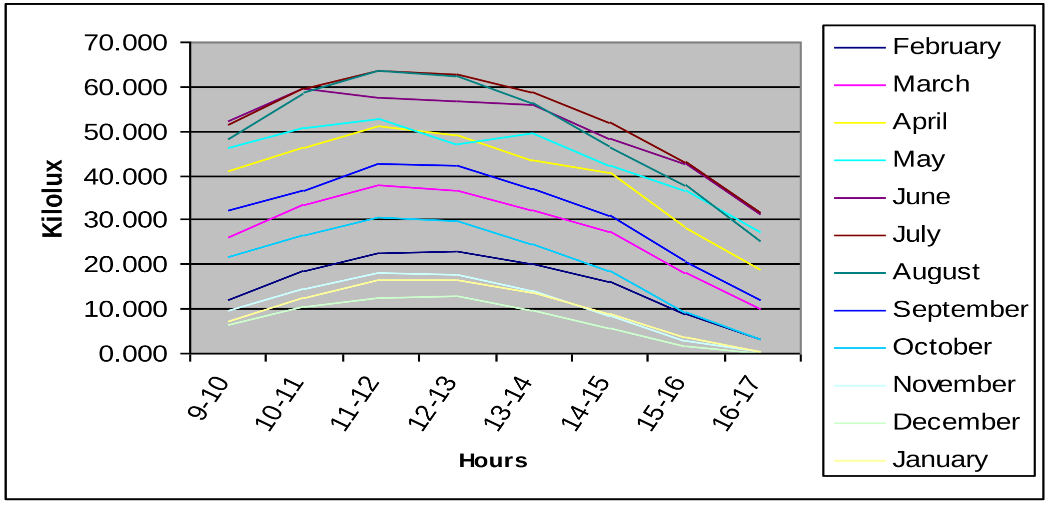


Chart 4.02 Horizontal Illuminances Unobstructed

Horizontal Illuminances diffuse cell uncorrected (Kilolux)

	9-10	10-11	11-12	12-13	13-14	14-15	15-16	16-17
February	9.611	13.227	15.409	15.041	13.887	11.402	7.067	2.727
March	14.940	18.919	21.243	21.140	19.306	16.084	11.654	7.176
April	22.353	25.595	28.648	28.293	25.903	23.344	17.996	13.275
May	26.524	29.606	30.818	29.055	29.384	25.967	23.469	18.341
June	29.930	33.370	32.869	32.558	32.748	28.647	25.366	19.407
July	28.809	32.759	35.062	34.487	32.868	29.133	25.201	19.503
August	24.808	28.263	30.907	30.603	29.324	25.246	21.577	15.699
September	16.835	19.714	21.795	22.813	20.312	17.945	12.942	8.157
October	12.826	15.756	18.001	17.597	15.235	11.824	6.997	2.613
November	7.412	10.708	12.163	11.810	9.886	6.395	2.564	0.221
December	5.187	7.650	8.662	9.454	7.669	4.746	1.411	0.032
January	5.439	8.832	11.142	11.198	10.018	7.284	3.255	0.391

Table 4.03 Horizontal Illuminances Diffuse Cell Uncorrected

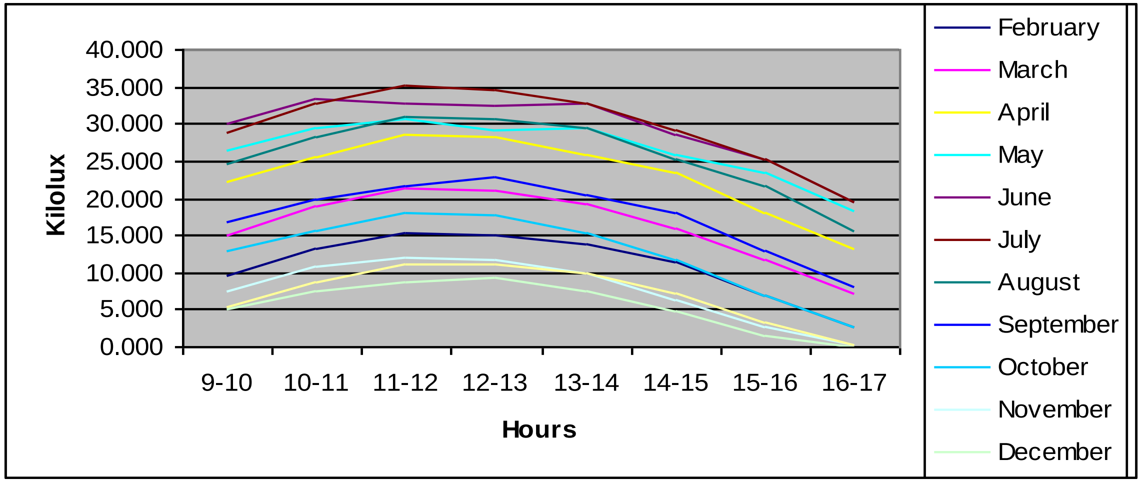


Chart 4.03 Horizontal Illuminances Diffuse Cell Uncorrected

External Cell – Vertical South (Kilolux)

	9-10	10-11	11-12	12-13	13-14	14-15	15-16	16-17
February	14.117	22.613	27.241	29.058	24.689	20.107	10.592	2.996
March	24.894	30.813	35.814	34.424	29.606	26.176	16.335	8.405
April	28.285	33.998	37.798	36.439	31.023	28.265	18.229	10.837
May	24.074	28.318	30.578	27.180	28.394	23.256	18.336	11.791
June	24.146	30.464	30.428	30.700	30.042	24.311	19.483	12.123
July	25.370	32.331	36.694	36.947	33.347	27.947	21.162	13.067
August	30.354	39.933	45.589	45.297	39.090	31.346	23.472	13.104
September	28.713	32.562	38.943	37.698	32.632	26.247	16.443	8.895
October	26.759	31.133	36.285	34.516	28.287	22.491	9.447	2.659
November	12.768	19.610	27.433	27.183	22.179	13.080	3.035	0.165
December	10.901	20.775	24.229	22.709	15.765	7.604	1.423	0.010
January	12.988	23.706	29.376	28.621	21.877	11.959	4.384	0.349

Table 4.04 External Cell Vertical South

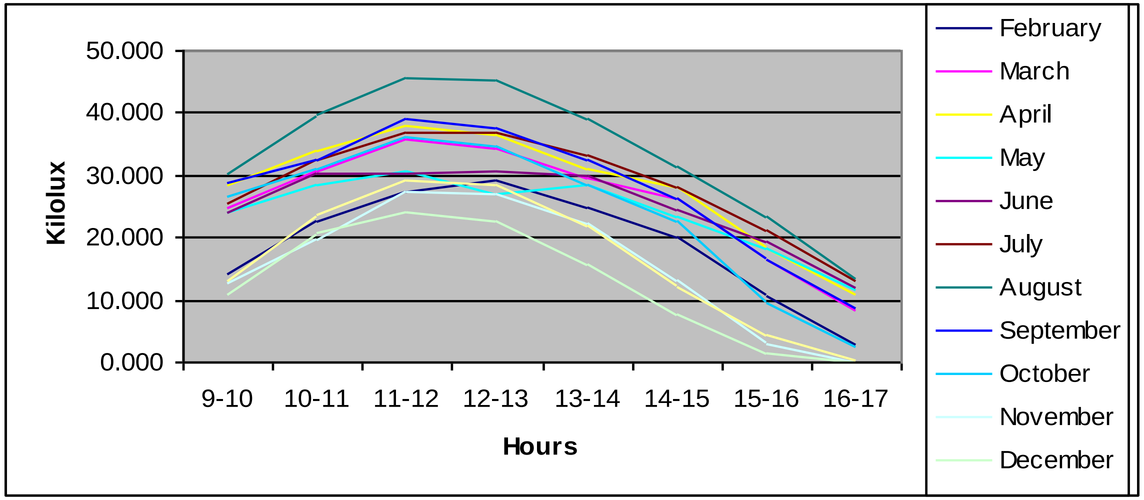


Chart 4.04 External Cell Vertical South

External Cell – Vertical West (Kilolux)

	9-10	10-11	11-12	12-13	13-14	14-15	15-16	16-17
February	4.113	5.898	7.441	9.254	12.974	15.554	11.142	4.072
March	6.413	8.344	10.119	12.643	17.931	23.083	20.536	15.181
April	8.793	10.572	13.085	17.110	22.896	30.303	27.515	23.124
May	10.287	12.066	13.677	16.311	23.374	27.277	30.181	28.031
June	11.147	12.739	14.077	17.698	25.256	29.722	34.350	31.553
July	10.221	12.431	14.588	18.631	26.371	32.493	35.732	32.762
August	9.654	11.322	13.865	18.667	27.206	32.945	36.506	29.405
September	7.251	8.989	10.878	15.819	22.067	26.018	22.883	16.953
October	5.647	7.168	9.120	13.686	17.976	20.764	11.696	4.153
November	3.356	4.943	6.417	9.937	12.885	11.025	3.354	0.209
December	2.424	3.794	4.820	7.485	8.480	5.979	1.424	0.021
January	2.622	4.368	5.800	7.889	10.581	8.958	4.310	0.404

Table 4.05 External Cell Vertical West

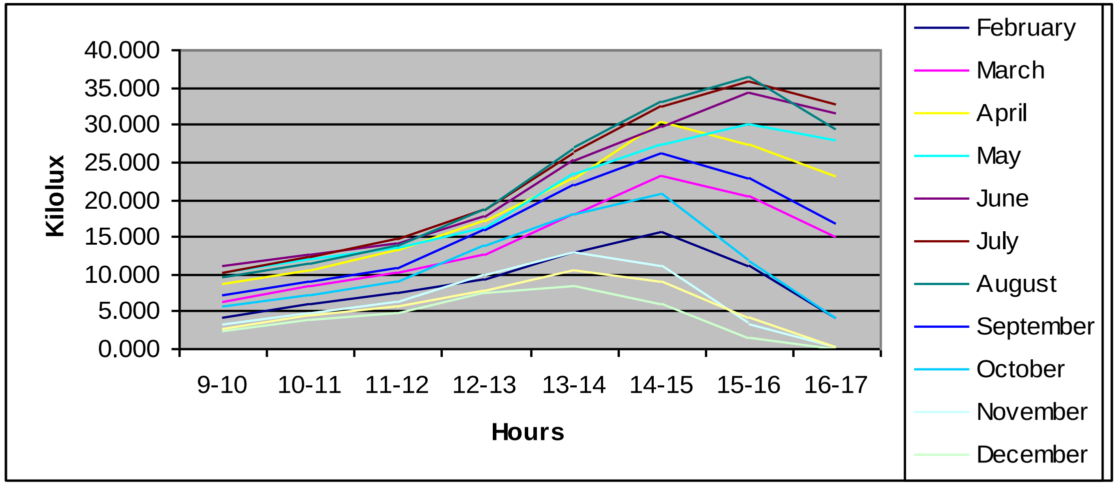


Chart 4.05 External Cell Vertical West

External Cell - Vertical North Kilolux

	9-10	10-11	11-12	12-13	13-14	14-15	15-16	16-17
February	3.934	5.178	5.872	5.821	5.452	4.536	2.972	1.224
March	6.318	7.598	8.354	8.351	7.774	6.735	5.196	3.412
April	9.018	9.730	10.641	10.779	10.211	9.478	7.758	6.283
May	10.923	11.575	11.802	11.536	11.618	10.986	10.415	8.876
June	12.666	12.984	12.719	12.768	13.037	12.167	11.507	9.772
July	11.492	12.117	12.354	12.298	12.228	11.559	10.837	9.415
August	10.140	10.608	11.077	11.153	11.006	9.940	9.239	7.512
September	7.024	7.966	8.777	9.065	8.447	7.613	5.879	4.185
October	5.371	6.310	7.031	7.006	6.153	4.946	3.103	1.213
November	3.138	4.377	4.948	4.799	4.126	2.792	1.130	0.100
December	2.260	3.278	3.681	3.973	3.213	1.996	0.584	0.009
January	2.484	3.936	4.734	4.708	4.185	3.086	1.412	0.177

Table 4.06 External Cell Vertical North

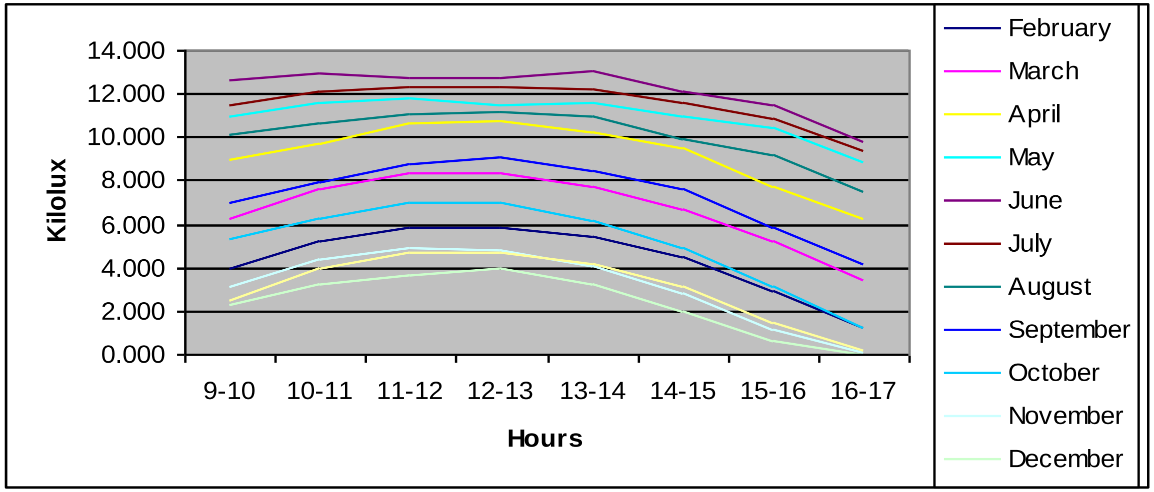


Chart 4.06 External Cell Vertical North

External Cell - Vertical East (Kilolux)

	9-10	10-11	11-12	12-13	13-14	14-15	15-16	16-17
February	12.813	14.143	11.301	7.521	5.799	4.617	2.861	1.121
March	26.400	21.827	16.038	10.374	8.400	6.762	4.848	3.015
April	33.239	26.291	18.881	13.017	10.781	9.078	6.838	5.062
May	31.796	24.836	18.290	13.096	12.083	10.326	8.970	7.095
June	34.008	28.194	18.914	13.835	12.548	10.425	9.074	6.998
July	37.411	30.853	22.437	15.585	12.869	10.863	9.101	7.106
August	39.544	33.492	22.978	14.580	11.979	9.643	8.020	5.896
September	27.660	20.705	14.785	10.599	8.961	7.336	5.383	3.576
October	21.557	16.218	11.258	8.035	6.575	4.955	2.949	1.154
November	9.067	9.635	7.508	5.533	4.360	2.778	1.082	0.091
December	7.572	9.542	6.415	4.581	3.446	2.012	0.571	0.009
January	10.013	12.461	9.475	5.699	4.495	3.092	1.370	0.166

Table 4.07 External Cell Vertical East

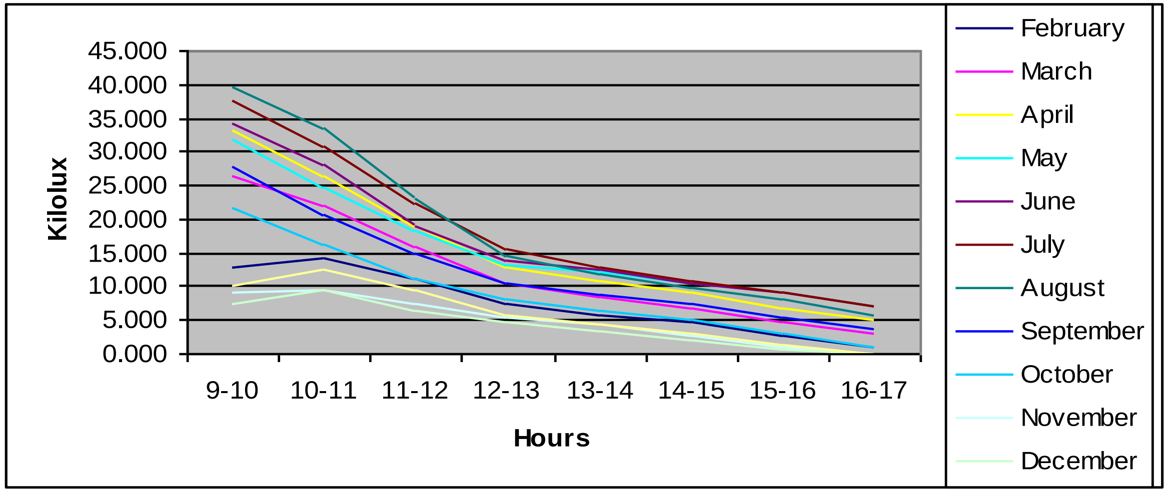


Chart 4.07 External Cell Vertical East

Horizontal Illuminances unobstructed Percentage of Readings above Lux Values		Horizontal Illuminances diffuse cell uncorrected Percentage of Readings above Lux Values		External Cell - Vertical South Percentage of Readings above Lux Values		External Cell - Vertical West Percentage of Readings above Lux Values		External Cell - Vertical North Percentage of Readings above Lux Values		External Cell - Vertical East Percentage of Readings above Lux Values	
Kilolux	**%**	**Kilolux**	**%**	**Kilolux**	**%**	**Kilolux**	**%**	**Kilolux**	**%**	**Kilolux**	**%**
				2	95.79	2	95.83	2	90.63	2	91.67
				2.5	95.83	2.5	94.79	2.5	90.63	2.5	90.63
5	91.67	5	90.63	5	91.67	5	83.33	5	65.63	5	77.08
10	82.29	10	73.96	10	87.50	10	62.50	10	30.21	10	45.83
15	71.88	15	58.33	15	75.00	15	38.54	15	0.00	15	23.96
20	62.50	20	40.63	20	67.71	20	27.08	20	0.00	20	17.71
25	55.21	25	30.21	25	50.00	25	18.75	25	0.00	25	11.46
30	48.96	30	11.46	30	30.21	30	9.38	30	0.00	30	7.29
35	41.67	35	1.04	35	12.50	35	2.08	35	0.00	35	2.08
40	35.42	40	0.00	40	2.08	40	0.00	40	0.00	40	0.00
45	27.08	45	0.00	45	2.08	45	0.00	45	0.00	45	0.00
50	18.75	50	0.00	50	0.00	50	0.00	50	0.00	50	0.00
55	12.50	55	0.00	55	0.00	55	0.00	55	0.00	55	0.00
60	4.17	60	0.00	60	0.00	60	0.00	60	0.00	60	0.00
65	0.00	65	0.00	65	0.00	65	0.00	65	0.00	65	0.00

Table 4.08 Summary of Tables 4.02 to 4.07

The above analysis can be compared directly with the research by D.R.G Hunt, (1979) also of the Building Research Establishment (BRE), who analysed the illuminance records for Kew and Bracknell for the 10 year period from 1964 to 73. 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 in much the same way as those above. Figure 4.02 below shows the cumulative diffuse illuminance availability for the standard working year (between the hours of 9 a.m. and 5 p.m.), according to his research. The 'Y' axis shows the percentage of the year for which a given illuminance was achieved. The 'X' axis shows the diffuse illuminance values with the value of 5 Kilolux being achieved in excess of 85% of the year. Contrasting this with the readings taken by Littlefair it appears that there may have been an improvement in illuminance over the intervening years and whilst it is not possible to eliminate the possibility of an exceptional year, there is anecdotal evidence of a general improvement being perceived by respected observers.

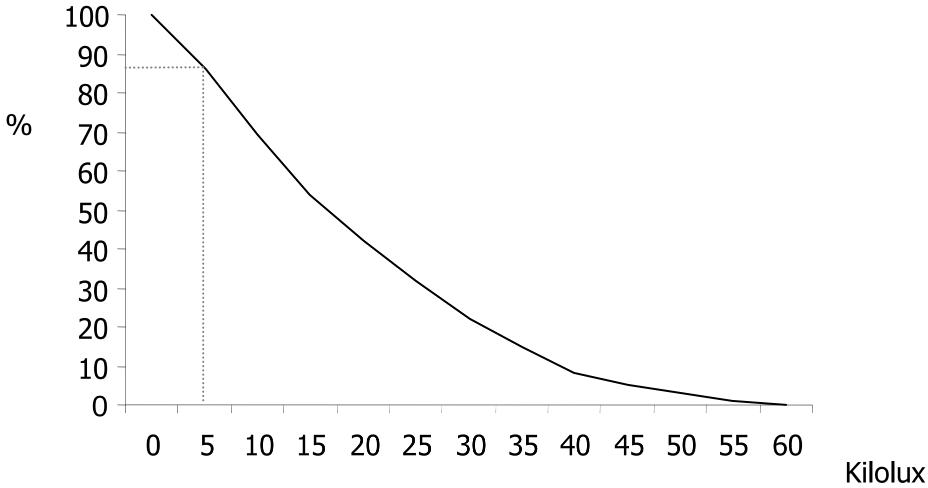


Figure 4.02 (Hunt 1979; p8)

Prior to Hunt, it would appear that 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 2nd Edition July 1972 Illuminating Engineering Society's (IES) Technical Report No 4 Daytime Lighting in Buildings and Hunt 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)*'.

Given that his data is now in excess of thirty years old and even Littlefair's is over twenty years old, then even better results may be obtained if the readings were to be taken again at the present time.

Hunt also compared the 1964 to 1973 data with the 1933 to 1939 data and, according to him, the results for Kew and Bracknell over the period 1964 to 1973 were, in fact, very similar.

If the readings from Kew and Bracknell between 1964 and 1973 are compared with those from Littlefair's study above, it can be seen that there is a degree of similarity between each of the monthly averages and the overall averages, which lend a degree of confidence in the prediction of light levels. Table 4.09

	Averages (Kilolux)			
	Watford	**Bracknell**	**Kew**	**Average**
February	11.05	11.33	10.50	10.96
March	16.31	19.26	16.59	17.39
April	23.18	26.24	23.32	24.25
May	26.65	31.23	29.10	28.99
June	29.36	30.27	30.52	30.05
July	29.73	29.91	31.38	30.34
August	25.80	25.12	27.99	26.30
September	17.56	19.69	21.48	19.58
October	12.61	12.99	14.25	13.28
November	7.65	7.69	7.95	7.76
December	5.60	5.56	5.27	5.48
January	7.20	6.59	6.20	6.66
Average	17.72	18.82	18.71	18.42

Table 4.09 averages from tables provided by Littlefair 1984 and Hunt 1979

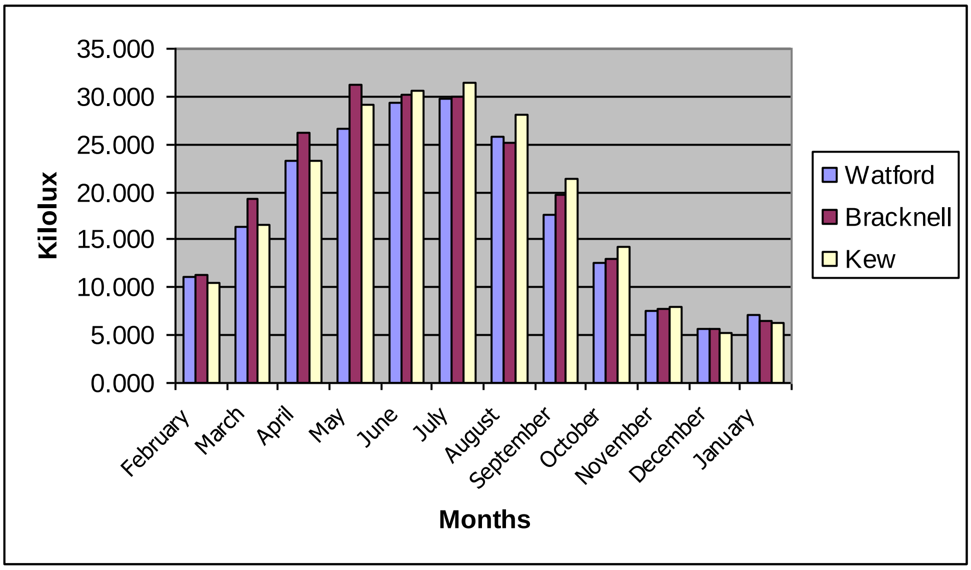


Chart 4.09 Comparison of mean illuminance for calendar months (Hunt, 1979; Littlefair, 1984).

Littlefair also 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 9.00 a.m. and 5.00 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 foot-candles. 500 foot-candles (5 Kilolux) was achieved for 85.7 percent of the time. (Table 4.10 below) (Littlefair 1984; Tables 44 and 45)

Percentage of year (0900 - 1700, BST April – October) that given horizontal illuminance exceeded			
Kilolux	Percentage	Kilolux	Percentage
0	100	11	67.9
0.5	96.6	12	64.5
1	95.6	15	55.8
2	93.4	20	43.7
3	90.8	25	34.1
4	88.3	30	25.6
5	85.7	35	17.8
6	83	40	11.4
7	80.2	45	6.7
8	77.3	50	3.6
9	74.3	60	0.7
10	71.2	70	0.1

Table 4.10 (Littlefair, 1984)

4.7 Conclusion

Whilst many standards of daylight are used by Surveyors and Engineers, there does not appear to have been a study justifying the levels used other than the 'jury' approach referred to in Chapter 2 and there is a lack of consistency in the methods used to define sufficiency exemplified by the use of the Sky Factor, or the Daylight Factor. The work by Nabil and Mardaljevic in defining Useful Daylight Illuminance has pulled together some of the published findings on occupant preferences which appears to confirm that daylight illuminances of less than 100 Lux are generally considered insufficient to be either the sole source of illumination or to contribute significantly to artificial lighting and that daylight illuminances in the range of 100 to 500 Lux are considered effective either as the sole source of illumination or in conjunction with artificial lighting. These values are somewhat greater than the 10 Lux equivalent postulated by Waldram but are possibly higher than what might be considered to be the absolute minimum for ordinary use.

The amount of available daylight appears to have remained relatively constant over the years in terms of averages although it seems possible that the percentage above 5 Kilolux may have increased from around 80% to nearer 90% over the years. However, the measurement of the whole sky dome and using this to derive a value for any portion of the sky dome, assuming a uniform sky, does not accurately represent the amount of light available to any point within a room.

Having considered the legal and historical basis for the method of calculation and taking into account the points made during the focus group discussions, it is clear that a new, more complex methodology would not find general acceptance but that a more accurate method, which uses the same principles, might well find favour. (Appendix 2)

The research to date has shown that the use of a 500 foot-candle (5 Kilolux) sky is a reasonable basis and indeed may be an improvement upon the original standard as the number of hours when the illuminance is less than this figure is probably reduced since the early research. However the use of a uniform sky is a mathematical simplification, which is not justified by reference to the research by Littlefair and others, and its replacement with a model based upon a more representative sky model such as the CIE overcast sky should be considered.

The questions, which must still be addressed, are whether the value of 1 foot-candle (10 Lux) or 0.2% sky factor using either the Waldram Diagram, or a Diagram based on the CIE sky, is sufficient for ordinary needs and should the value be calculated at worktop height or at 850 mm. In addition it will be necessary to explore whether internal reflectance and window losses should be considered.

Part C, of this thesis describes the design of the experimental research project to compare theoretical and actual measurement of daylight in a subject room and to analyse the results obtained. These results will be compared with a new diagram based upon the CIE overcast sky to determine whether this provides more accurate results.

There is also an experiment to replicate the jury approach to ascertain sufficiency of light levels in a controlled environment.

In each of these experiments there are the same issues of accuracy, which have been set out previously in this thesis, but every effort has been made to eliminate these wherever possible.

Part C
Hypothesis, Research Methodologies and Results

Chapter Five
Designing the Research Project

'The formulation of a problem is often more essential than its solution which may be merely a matter of mathematical or experimental skill. To raise new questions, new possibilities, to regard old problems from a new angle, require creative imagination and mark a real advance in science'

Einstein A (1879-1955)

5.1 Introduction

The hypothesis established from the research for the previous chapters is that the Waldram method, for calculating the availability of daylight for Rights to Light cases, is flawed and that a new method is required which is based upon the CIE sky. Further research is also required to test the amount of illuminance, which is actually necessary, how this should be measured and whether it is valid to ignore internal reflectance and window losses. In order to test the hypothesis, it is necessary to try to establish how the light is received from the sky and translated into illuminance and how this can best be represented graphically.

The historical and legal backgrounds to the established levels for daylight adequacy, discussed in previous chapters, demonstrates that the present method has not had universal support from either the courts or the practitioners but is nevertheless used to advise clients. In addition, it has been established in chapter four that whilst the amount of daylight can be assumed to be 500 foot-candles, for calculation purposes, there is a scarcity of evidence of proof of the levels of sufficiency, which are espoused by the various authorities.

Through experimental research it is intended to ascertain the minimum amount of light, which is needed for a normal purpose such as reading and how this amount of light is related to the unobstructed area of sky at the point or series of points being considered. In conjunction with this, it is also necessary to determine whether adequate light levels over any percentage of the subject room area is an indication that the whole room can be considered to be adequately daylit.

In commencing the design of a suitable research methodology, it was necessary to consider what could be achieved within the available timescales in terms of both resources and the number of results obtainable. Consideration therefore had to be given to the available methodologies and to the potential results. By following one methodology there is the potential to miss an opportunity for verification of results and by restricting the number of results for comparisons purposes there is the risk of statistical error arising out of the interpretation of those results.

This chapter examines the process from identification of the available methodologies through to the formulation of the approach taken.

5.2 Business Research Methods

This thesis has been prepared in relation to a Professional Doctorate and would thus be expected to be grounded in business practice. However, the subject matter is also of a scientific nature and any research methods adopted would need to meet the standards applicable to both.

Zikmund (1991; p61) explained how the strands of research relate and interact and that there is considerable overlap between recognised business research methods and the more scientific approach involving experimentation.

This flow chart (Figure 5.01) amended and reproduced below, illustrates that no matter what the research may be, the start is always with the discovery or formulation of a problem and from this formulation the research techniques can be selected and so on.

Research methods tend to be classified according to paradigms and before deciding the appropriate methodologies for this project, it was necessary to examine the relationship of these paradigms.

5.3 Research Paradigms

5.3.1 Positivistic and Phenomenological Research

Business research tends to place greater emphasis on interviews and questionnaires with a balance of secondary data and observation, whereas scientific research places greater emphasis on the laboratory and field research with the use of some secondary data. Thus the balance tends to shift from qualitative for business research to quantitative for scientific research. The research approaches are referred to as *positivistic* and *phenomenological* paradigms. The positivistic paradigm tends towards a numerical and factual approach with detailed quantitative data leading to a deductive approach and it is often the case that artificial devices are used in a scientific approach to eliminate the variables which occur in the real world. By contrast, the phenomenological paradigm is more relevant to the real world using qualitative data and an inductive approach where, from the use of an experience of a situation, a general assumption may be made and whereas positivism reaches an objective conclusion, phenomenology will reach a subjective conclusion. (Collis, J. Hussey, R. 2003)

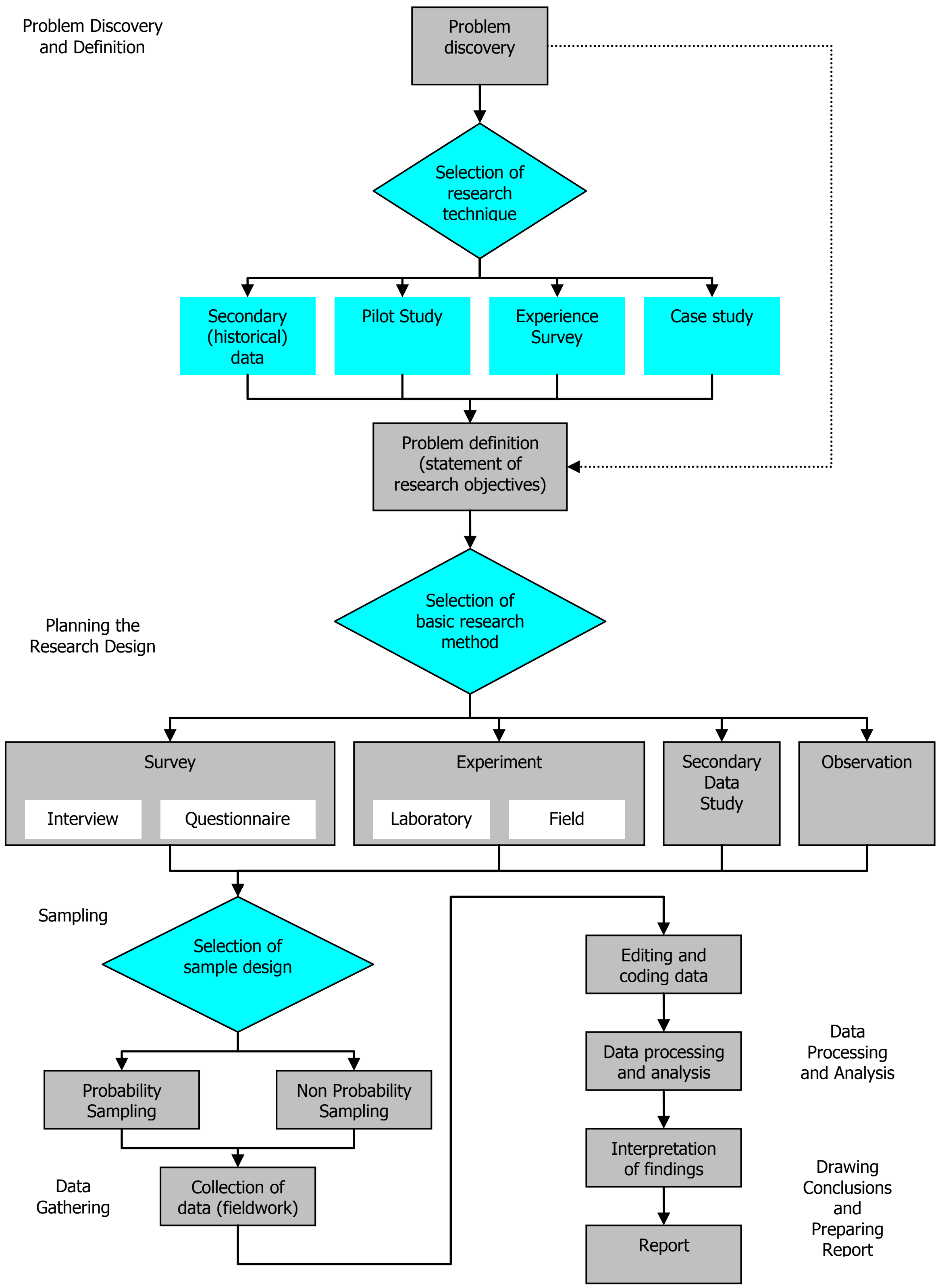


Figure 5.01 Flowchart of the Research Process Adapted from Zikmund 1991

Some commentators have argued that quantitative and qualitative researches themselves are paradigms and are thus incompatible but, according to Bryman and Bell, (Bryman 2003; p482), not only are the two research strategies compatible but that a multi strategy research is both feasible and desirable.

There are, however, two different versions of the nature of quantitative and qualitative research. These consist of an epistemological version, where they are grounded in incompatible epistemological principles, where a multi-strategy research method is not possible, and a technical version, which recognises the strengths of data collection and data analysis techniques in both forms and accepting that they are capable of being brought together. (Bryman 2004; p453)

Bryman takes this technical version further and discusses multi-strategy research, which he refers to as triangulation and this is discussed further below.

5.3.2 Triangulation

In the context of the 'Right to Light' where there are elements of both qualitative and quantitative data, there is much to be gained from using the techniques in each paradigm in a complimentary format.

The results obtained from a phenomenological, qualitative approach may provide the basis for positivistic, quantitative research and quite possibly a check of the results obtained one against the other. This process of triangulation is illustrated in Figure 5.02 below.

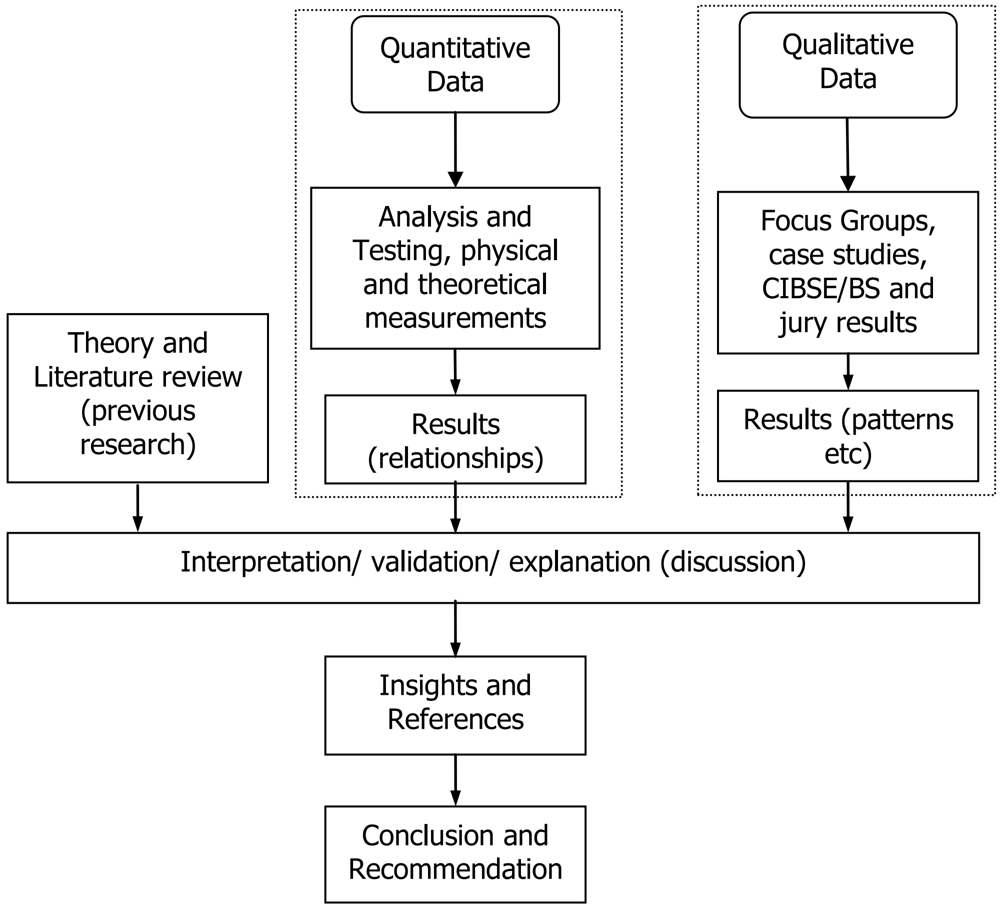


Figure 5.02 Triangulation of data

The review of relevant literature and the practical application of the law, as demonstrated in previous chapters, provide the benchmark against which all further research is to be compared. Quantitative Data is obtained through physical experimentation such as measuring the amount of light in the sky and the illuminance within a room in various ways. These results will require interpretation to be capable of direct comparison and from this it should be possible to establish a direct relationship between internal and external lighting values. The Qualitative Data will be obtained through such things as questionnaires, focus groups or a jury, as in the original research by Waldram and others. The results of this approach will tend to identify patterns such as the general impression of sufficiency of light and the methods of measurement. By combining these with the theory and literature review, it was expected to be possible to demonstrate that levels which were assumed to be sufficient, in the early Twentieth Century, are in fact insufficient and that the methodology of measurement needs to be amended.

It should be noted that whilst the jury study may be valid, it could not, within the context of this thesis, be considered reliable in isolation and that any level derived through this process would not change the proposed methodology merely affect the contour line, which would be used.

5.4 Areas of Preliminary Research and Options Available

5.4.1 Secondary Data

The earlier chapters of this thesis have set out both the historical and legal basis for the current methodologies for calculating daylight and these provide a good grounding with which to analyse the processes. There is however, a paucity of original research data, which might enable verification of results.

Beyond the initial study of secondary data, the research areas have been broadened to other interrelated disciplines such as psychology and ophthalmology and the results of this study appear in chapter four.

5.4.2 Pilot Study and Focus Group

The nature of the Professional Doctorate is such that it relies heavily upon the actual experience of the subject matter and thus each and every commission has the added advantage of providing a pilot study as no two commissions are identical and each requires individual research and analysis. It is almost inevitable therefore that this experience has been utilised in formulating the problem definition.

Whilst a questionnaire might be used to gather third party experience, the more viable alternative is a Focus Group approach where other experts, in the field, are approached to determine whether they have an opinion about what measure of light they would prefer and how this should be measured.

This latter question may reflect back upon the research methodology to be used as, for example, the preference might be for the use of the 'no sky' line. In this case the factors to be determined would include, for example, how much of the room should have sky visibility and what is the correct height above floor level to use for the assessment. Alternatively, it might be that the use of the Vertical Sky Component measurement or Sill Ratio may be more universally accepted in which case it may be relevant to state window to floor area ratios to make a linkage between the external amount of light and the internal value.

The difficulty with focus groups, especially one of experts, is the possibility that some participants would wish to dominate the process and others might not admit to a difference of opinion.

At appendix two, there is a transcript of discussions, which took place in September 2006 between certain members of the Party Wall and Rights to Light Forum, which is an internet discussion group hosted by Salford University. The thread started with the author's reference to a recent case, which had been decided in the Court of Appeal (*Regan v Paul properties Limited*) and stimulated a discussion about the methodology of calculation and the accepted levels of daylighting. It can be seen from the contents of this transcription that the discussion was carefully steered and that a total of nine people participated with no outright dominance but many areas of consensus. The outcome of the discussion demonstrates the validity of this research.

The views ranged from those who support the need for a review of the methodology to one contributor who finds the whole subject pointless as it is based upon a negative easement.

Several people supported the need for review but all who joined the discussion related their comments about sufficiency to a contour lines or percentage of area 'well lit', based upon the existing methodology. No-one appeared to identify the 'well lit' area with an average illumination.

The proposed alternative methodology of the Useful Daylight Illuminance found no other supporters and one contributor stated that the Waldram method, whilst tedious, does provide a result that both sides can achieve independently as a check on one another and comes up with a number that has certainty. There is a contour which all can see.

It was also stated that even if an alternative method or set of criteria is devised to replace the Waldram diagram and contour plan, then it is likely that the courts would simply apply the decision in *Ough v King* which accepted that, for the time being, 50% well lit meant that the room could be sufficiently well lit.

Several contributors confirmed the validity or the debate and alluded to discussions, which had been ongoing for some time.

From these discussions, it became clear that practitioners generally were expecting a solution, which defined a specific percentage of the room, which should be well lit in order that the whole room should appear well lit. A few debated the levels of illuminance, which might be sufficient by reference to percentage of sky visibility using the existing methodology.

The significance of this discussion to the thesis is that it has become clear that any method, which does not produce a contoured representation, would not find general favour and that the values derived must relate to a significant part of the room appearing 'well lit' rather than necessarily meaning that the whole of the room appeared well lit.

5.4.3 Case Study

Case law provides an extremely useful form of case study approach but it is limited by its historical nature and the fact that the courts have not generally considered the basis of calculation merely the outcome. It is not practical to take a real case, on behalf of a client, through the courts just to obtain a determination on the validity of the calculation method.

However, a case study approach may be useful as part of the triangulation process since, in undertaking professional work, it is often necessary to prepare calculations based upon the accepted methodologies and then to debate these with another professional in an attempt to arrive at an acceptable result. These discussions can often deal with the comparison between the theoretical results and the perceived results. An example of this would be where the computerised model produced by one surveyor gives a set of contours indicating that the loss of light would be actionable in law but the other surveyor could not agree and offered to meet to review the actual loss on site. The debate would revolve around what was perceived to be sufficient on the day with a general acknowledgement that the sky was suitably overcast and therefore was there enough light remaining for the use of the room in the normal manner. The surveyors would determine that, irrespective of the computerised results, the loss of light was either more or less significant than had been predicted by the first surveyor. This approach might possibly be adopted over a number of cases, by way of review, and could provide useful evidence in support of a different standard. (Defoe 2005)

5.4.4 Survey

Questionnaires may be useful for obtaining a subjective response from the people who are most likely to have an opinion i.e. they have a direct involvement in the subject and can therefore understand the context and the purpose of the questions but it would be pointless asking the man or woman on the 'Clapham Omnibus' if they think that a room would be well lit. They would almost certainly ask how many electric lights there were. Another question that has already been posed, to other practitioners, sought to discover how much calibration there has been of the software used in the calculation process, as this would determine whether the respondents understood the basic mathematical theory behind the process and whether and how accurately this has been incorporated into their practice and more particularly their software. Unfortunately this has failed to elicit a response. No doubt this is due to commercial sensitivity and this is a matter, which affects all such questions.

There is, however, one form of survey which is in fact more experimental in nature and that is to try to replicate early experiments where jury results were used to determine adequacy of daylight. With modern technology and facilities this approach could be achieved with far greater controls.

5.4.5 Experimentation

The most obviously applicable area of research for scientific study is the experimental approach. The aim of experimental design is to test a theory, hypothesis or claim with the objectives being to determine what is to be tested and what limits apply to the scope of the experiment.

In the context of light measurement, it is relatively simple to use Lux meters to determine how much illuminance there may be at any point within a room at any point in time but there are limitations to this and the control of variables is the most significant. These variables are defined below and the design of the experiment will have to ensure that these are eliminated or measured such that it is possible to concentrate on the light from the sky. However, the light from the sky is also variable, as has been discussed in earlier chapters and it will be necessary to define how this is treated in the calculations.

It is necessary, also, to determine how many readings need to be taken to provide a representative sample size as well as practical aspects such as time and costs of the tests and, to conduct a valid experiment, it is necessary to maintain constant and known conditions and it is essential that data is collected accurately.

The data analysis will have to be undertaken using appropriate techniques to analyse the results of the experiments and to test the hypotheses. Any conclusions drawn will need to be qualified by such statistical techniques as are appropriate and further research may be identified which may be necessary to test the hypotheses more thoroughly.

The conventional type of practical experiment is performed in the laboratory and this is the very essence of scientific work. The results of experiments yield values that are obtainable and repeatable under tightly controlled conditions where, for example, an artificial sky dome can be used to test an artificially small sample of an ideal uniform or overcast sky, whereas the real environment is, in fact, very variable. Whilst this conventional type of experiment is essential it is not sufficient and requires the introduction of what has been termed 'experiential practicals' (Ahmet 2005).

Ahmet explained that, in all cases, the emphasis of experiential practicals is on maximising time expenditure on relevant experience and learning and minimising time expenditure on irrelevant work such as setting up equipment. He goes on to describe, and this is particularly relevant to the professional doctorate, how experiential practicals are carried out, often passively, in everyday environments experienced by the student. The commonality is that in all cases the data is unique and gathered with ease and whilst a high technological approach is often employed and is useful, many experiential practicals can be carried out with low-cost equipment.

It might have been possible, for example, to establish a routine for the measurement of available light at pre-defined intervals over the course of a year and to determine whether the value of 500 foot-candles of illuminance from the hemisphere is valid. However, this measurement process has already been undertaken by the BRE and verified by the CIE and there seems little point in replicating the measurement process. In this instance it is more appropriate to analyse those measurements in the context of 'Rights to Light' calculations.

A better and more valid experiment would be to take a physical room from which measurements can be taken over a period of time, from within the room, which will be of known dimensions and static internal and external reflectance which will make it possible to determine how much of the available light passes through the window to the room at any point within that room and these measurements can then be compared to the predicted levels which result from current methodologies and from the use of the artificial sky dome. In turn, the average results from experiential practical experimentation can be used to modify the measurements in the artificial sky dome in an action research approach by, for example, changing the internal reflectance or removing the glazing.

Measuring equipment for the experiential approach must be sufficiently accurate and reliable to ensure consistency throughout the period of the study but it has to be recognised that the physical act of measurement can affect the results such as when, for example, a Lux Meter is used, the person taking the readings has a different surface reflectance to the surrounding room which might reduce or increase the illuminance.

Daylight measurements can also involve significant experimental errors relating to the accuracy of the instruments used since detectors are not all identical and the use of a single battery operated meter may show slight variations as the battery discharges. Self calibrating devices may overcome this sufficiently for the purposes of the study or the use of multiple sensors, but this must be assessed in advance.

5.5 Practical Considerations

5.5.1 The Nature of Consultancy

Completing this research in the work environment is by no means straightforward but each new client instruction requires research into relevant case law, followed by evaluation using the available tools including both traditional and modern methods and there is frequently the opportunity to review results produced by other practices. Approaches were therefore made to some of the main practitioners to see if they were willing to run a standard model through their calculation process. There were several offers but again, largely due to work pressures, very little materialised. There is the possibility that whilst they indicated that they would be willing to discuss the work, they may have been concerned, privately, that any differences in results might be used to commercial advantage and this might have been the stumbling block.

5.5.2 The Availability of a Test Subject

One of the key components to the research process would be the measurement of available light in a physical room. The problem with this is that any normal room might not be available at appropriate times or indeed may change over the course of time as furniture is changed or moved around. The test room would need to be stable, i.e. unchanging for the period of the test and preferably unfurnished. Through business contacts it was established that the BRE had three buildings constructed on their 'Innovations Park' at Garston and they proved most helpful by giving free choice of building and room for the measurements. In addition, opposite the buildings, there was a large monolithic building obstructing the view, which could be easily modelled.

The other part of this experiment would involve modelling the room and testing this in an artificial sky dome, which was provided by Anglia Ruskin University and on computer using the resources of calfordseaden LLP.

5.5.3 The Use of a Scale Model in an Artificial Sky Dome

The CIBSE Lighting Guide LG10, contains some useful guidance on the use of artificial skies. It identifies two types that are most commonly used, the first being the rectangular mirror type and the second the hemispherical dome both of which are designed to simulate a CIE overcast sky. The identified disadvantage of the former is the multiple reflections of the model in the mirrors and in the latter the potential for parallax errors if the model is too large in relation to the sky. (CIBSE 1999, pp73-74)

It recommends that the model for the mirror type sky should be no greater than 30% to 40% of the sky dimensions. The dome model should generally be smaller. The dome type can be adapted to low reflectance to simulate other types of sky but there is the potential for light to be directed upwards into the room from the horizon of the dome.

The guide recommends that the model should be as large as possible within the constraints of the sky but, in the context of 'Rights to Light', it has to be small enough to fit the external obstructions at exact scale because the measurement relies upon sky visibility for defined angles of obstruction to all the points in a room rather than a single point. Wall thicknesses etc should also be modelled as closely as possible.

The model needs to be light tight and the internal reflectance should be modelled accurately. In this context the model would need to be measured using the same reflectance values as the actual room and then using non reflecting material to simulate the results of the 'Rights to Light' calculation.

External obstructions should be modelled accurately in both size and reflectance, which is often difficult because of the distance from the building being studied.

The CIBSE Guide also recommends that the model needs to take account of the size of the photocells being used in suggesting that the model should be between 1:10 and 1:40 scale and that measurements should be made on the working plane of 0.85 metres for domestic dwellings and 0.7 metres for offices, although, in practice and at these scales, there is very little difference.

In the event, the Anglia Ruskin Sky Dome was a mirror type and a 1:40 scale was the largest that could be fitted in with the obstructions modelled to scale.

5.5.4 Identification of Variables

There are a number of factors in the actual calculation of daylight within a room that should be considered as variables. These variables, listed below in figure 5.3, do not necessarily appear in theoretical models but need to be considered and evaluated as part of the research process.

Internally	**Factor**	**Potential Affect**
Ceiling	Colour/ Material	The colour and material used will have its own absorption and reflectance values which affect the amount of light reaching a work surface
Walls	Colour/ Material	The colour and material used will have its own absorption and reflectance values which affect the amount of light reaching a work surface

Internally cont'd		
Floors	Colour/ Material	The colour and material used will have its own absorption and reflectance values which affect the amount of light reaching a work surface
Irregularities	Shape of room and internal features	Obstructions such as columns and chimney breasts for example will cause shadows in certain locations
Furniture	Colour/ Material	Even a desk will affect internal reflectance. Soft furnishings may tend to absorb light
People	The person measuring	The presence of a person in the room to undertake the measurement be it qualitative of quantitative i.e. subjective or objective will affect the measurement
Externally		
Obstructions	Reflectance and absorption as well as physical obstruction	External obstructions will affect the amount of light getting through a window into a room but they may also have the affect of increasing the amount of light at certain times when, for example, sunlight is reflected into a room off a glass wall.
Sunlight/ orientation	South facing rooms	South facing rooms will enjoy a generally higher level of light, even in cloudy conditions. High level windows may receive a greater amount of light from the zone in the sky where the sun passes
Cloud	Overcast or stormy skies	The amount and density of cloud is infinitely variable and unpredictable. Darker skies will result in lower light values internally. Global dimming is also said to be having an affect.
Time of day and time of year, latitude and longitude	Average amounts of daylight	The amount of light varies throughout the day and the days are shorter in the winter. Higher latitudes receive proportionally less daylight during the winter.
Windows		
Size, shape and height	Relationship to a room	Large windows tend to let more light through to a room but if the window head is low, no matter how large, less direct light reaches the worktop level. A large window in a larger room may give proportionately less light.

Externally cont'd		
Frames and Glazing bars	Size and number	Frames and glazing bars can vary considerably in size and these act to obstruct the light, which might otherwise pass through the opening.
Glass	Type/ Transmittance and cleanness	Some types of glass are designed to reflect light or to prevent certain energy from being transmitted through it. Double glazing reduces the amount of light and the glass thickness may also have an affect. Dirty glass lets through less light.
Curtains	Obstructing and absorbing	Curtains generally restrict the window opening and are made of material, which is designed to absorb light.
Measurement		
Eye sight	Age and gender and medical conditions	When people occupy a room their eyes adjust to the conditions in that room and so long as the light levels are within certain extremes, they can cope and are able to read, although the risk of eye strain exists. However, the ability of the eyes to adjust to conditions is affected by age and medical conditions such as colour blindness and may even be affected by gender.
Test method	Subjective	If people are asked to read a newspaper in a room and to identify where in that room it becomes uncomfortable to read the newspaper, then the size of print and material of the newspaper will be relevant.
Test method	Objective	The use of electronic devices to measure light is quite commonplace but there are differences in the results obtained through, for example Lux Meters and Light Meters.

Figure 5.03 Variables in Daylight Measurement

5.6 Jury Approach

Whilst the starting point, for the quantitative research, was to try to discover whether there are any pre-existing determinations of adequacy of daylight aside from that used in 'Rights to Light' cases, which might be used for comparative purposes, it would be useful to try to replicate the original research where a jury were invited to assess where in a room they believed that there was sufficient light to be able to read a broad sheet newspaper. Unfortunately, whilst the locations of some of the rooms are know and are still existing, there is no information on the internal furnishings nor the jury members age and health and so, whilst this new research can go further by analysing such things as the age and gender of the jury members to see whether this appears to affect their responses, it will not be possible to use this for comparison with the original results. It will, however, be used in comparison with the stated standards for daylighting produced by CIBSE and others.

The lack of evidence of any other similar research into the acceptable minimal level of daylight illumination means also that there is no accepted methodology for making this approach. There has however been some research, undertaken by Fanger (1970) and forming the basis of BS EN ISO 7730, which used volunteers to 'vote' on thermal comfort conditions in a controlled environment

Fanger (1970) designed an experiment in a climate chamber where people were required to record their levels of satisfaction with the thermal comfort and from this comfort voting he extended the results to predict the proportion of any population who would be dissatisfied with the environment.

In this instance there were three scaling points and those who voted outside the central three scaling points on the ASHRAE (American Society of Heating, Refrigerating and Air-Conditioning Engineers) scale were counted as dissatisfied.

Using a scale of -3 (cold) to +3 (hot), the predicted percentage dissatisfied PPD was defined in terms of the predicted mean vote PMV, that is to say, the lowest percentage dissatisfaction equates to the mean value and the readings which fell either side of the predicted mean vote represented dissatisfaction levels.

This process is not entirely compatible with the measurement of sufficiency of daylight since the scale is based on zero Lux as being the lowest possible measurement for the minimum acceptable level of illuminance (although in practice it would be higher) and the upper level would be indeterminate at the outset. Theoretically there could be too much daylight i.e. an uncomfortable level but that is not the subject of this research.

The PMV approach, where the lowest percentage dissatisfaction equates to the mean value, is not truly applicable for the assessment proposed although it is worth noting that the commentary on the research and the two standards (ASHRAE Standard 55 and BS EN ISO 7730) define a satisfaction level of 80% as being the required level. On this basis, it may be argued that an analysis of the percentage dissatisfied is the correct way to assess the results of an experiment involving a jury, with the benchmark level of required illuminance being reached when 80% of the jury members would be satisfied that they have sufficient light for ordinary use. Indeed, the results of the original jury can be analysed in exactly this was as demonstrated in Table 2.03 above.

5.7 Ethical Considerations

It is important to consider whether there are any ethical issues involved in the research process and in the context of professional work the use of material or information relating to an identifiable case and/ or client might involve the use of privileged and or confidential information. If it had been found necessary to use such information then, so far as possible, the information which might allow such identification would have been neutralised and where this was not possible then a written agreement would have been obtained from the client for the use of such information. However, this has not been necessary.

There is an issue arising out of the research in that advice being given to clients, at present, is on the basis of the law as it stands but the result of the research could be that the advice may have been different had the research been completed at the time but this is unavoidable and in the nature of professional advice.

The other identifiable possibility requiring consideration is in the area of experimentation where it is possible that people will be asked to participate in an experiment to determine sufficiency of light within a room. There is no obvious health risk involved in this but it would be wise to ensure that all members of the 'Jury' have confirmed their agreement to participate.

5.8 Adopted Research Methodologies

The review of historical literature, legal cases and current business practices was essential to identify the basis for current methodologies and to set the parameters for the further research, which is necessary, to either prove or disprove these methodologies.

The experimental approach outlined above will involve testing of models and reality. It is also possible to extend this by using an action research approach on the model to test what happens when factors are changed such as physical obstructions, windows and reflectance of internal surfaces.

The appropriate methodology should also take into account the limited time available and, for this reason, much reliance has been placed upon research data accumulated by the BRE, relating to the availability of daylight, rather than undertaking this research independently and thus enabling the concentration to be placed upon the assessment of need and the measurement of illuminance within a room.

The following three experiments will contribute to the triangulated approach.

5.8.1 Experiment One

To ascertain the amount of light needed to be able to read a newspaper comfortably.

At the lowest levels, the amount of light needed by any person is expected to vary by age, health and eye colour. There is also a possibility that gender may have an affect.

The experiment will identify each of these variables for the jury members.

It is expected that each jury member will report a slightly different level of light requirement and the results will have to be analysed to ascertain whether it is reasonable to set a common level of adequacy or to use the level which is sufficient for the weakest member i.e. the person who requires most light at the lowest level or for a high proportion of the jury members.

Daylight is infinitely variable and thus difficult to measure in the context of an experiment such as this. It is necessary therefore to eliminate daylight from the useable light levels and to rely instead upon an adjustable light source. The room will be sealed from daylight levels above a minimum level of about 1 Lux, which is necessary for safety entering the room.

It is important that the experiment take place in one room to eliminate possible variables such as internally reflected light. It is not possible however to eliminate that which might reflect off the jury members clothing nor off the person undertaking the measurement process. Both were requested to dress in darker clothing to address this problem as far as possible.

The human eye adapts rapidly to changing light levels making it difficult to determine what levels of light are reasonable or unreasonable. If, for example, a jury member walked from a brightly lit area into an area, which might be considered by the occupants to be adequately lit, they will at first, think it is poorly lit but after a relatively short while their eyes will adjust.

The experiment will therefore be conducted in two stages. The first stage will involve each jury member sitting in the room, at a desk with a newspaper placed on the desk and a set piece of text outlined to ensure that each jury member is looking at the same area. The lighting will start off at a very dim level, just sufficient for location purposes and will be raised slowly to the point where the jury member confirms that they are able to read the text. It will be raised slowly again from this point until the jury member confirms that they feel the level is sufficient that they no longer feel strain when reading.

The second part of the experiment will start with the light levels set above those levels previously recorded and reducing down to ascertain whether the levels of adequacy coincide with those previously recorded. These results were recorded on data sheets as shown at appendix four and in all cases the results were measured using a set of three calibrated digital Lux meters.

5.8.2 Experiment Two

This second experiment is a multiple triangulation of results to compare actual and theoretical values.

The requirement for this experiment is to be able to take actual physical measurements of light within a real room and to compare the results with those obtained firstly by modelling the room in an artificial sky dome, secondly by modelling the room in a computer programme designed to calculate well lit areas for both 'Rights to Light' and for planning purposes and thirdly to prepare traditional Waldram Diagrams. To provide a benchmark for comparison of different standards, the model for the artificial sky dome also had to allow changes to internal surface reflectance and the effect of windows.

The first requirement was to identify a room with a window with a view of the sky and a suitable obstruction restricting that view which would remain unchanged for a sufficient length of time. This was achieved by courtesy of the BRE who permitted the use of a room within a building on their 'Innovations Park', which had been constructed by Kingspan. The room selected had a number of positive advantages. It was decorated in relatively light colours, with a carpet but no other furnishings and it faced directly towards a large experimental research building with a relatively simple, in modelling terms, large grey expanse of wall. This was known to all as Century House.

The experiment required the detailed and accurate measurement of the room for modelling purposes. The location and size of the obstruction also had to be measured and the internal reflectance values for each of the surfaces.

5.8.2.1 Stage 1

The room was divided, theoretically, using a one metre grid and Lux meter readings were taken, on relatively dull days, from each grid point, at 750 mm above floor level and at 850 mm above floor level with the window both open and shut. The values for each condition were averaged and plotted, separately, onto a drawing.

5.8.2.2 Stage 2

Using a Megatron meter which measures the light values internally relative to the external value, i.e. the daylight factor, measuring at the centre of each one metre grid square under the same conditions as Stage 1 above and these values were plotted onto a drawing. A Hagner Meter was also used to establish reflectance values for each of the surfaces

5.8.2.3 Stage 3

The model was constructed to a 1:40 scale together with the obstructions and placed in an artificial sky dome. All internal surfaces started with the same surface reflectance but owing to scale the measurements could only be taken at one level (approximately the equivalent of

850 mm) and only five readings were possible one at the centre of the room and the other four equidistant from the corners. The window was designed to be removable. A Megatron meter was used to determine the daylight factor. This part of the experiment was repeated with the walls, ceiling and floor covered with matt black surface material to eliminate internal reflectance and thus only measure the sky value within the room.

5.8.2.4 Stage 4

The room and obstructions were modelled using AutoCAD and the model was passed through the 'Rights to Light' software firstly with a one metre grid to compare with site measured results and secondly with a finer 100 mm grid to produce a more accurate result. The results were then plotted onto a drawing and a contour prepared at a later date.

The model was then passed through the Planning software and the Vertical Sky Component and Average Daylight Factor were calculated.

5.8.2.5 Stage 5

The drawings produced on CAD were then used to prepare individual Waldram Diagrams for each grid point and the values plotted onto a drawing and a contour prepared. It is important that this contour was prepared independently of the contour in stage 4 and without seeing the results beforehand. The contours were both plotted onto a drawing for immediate comparison.

5.8.2.6 Stage 6

This final stage consists of the analysis of the individual results and then comparison between theoretical values and those actually recorded.

5.8.3 Experiment Three

To derive a formula that recognises a non uniform sky, which produces results that are justifiable by reference to the results obtained in experiment two and can be used in the calculation of illuminance at any point on the horizontal plane.

The formula for a 'paper based' solution will differ from the formula or algorithm, which would be used in a computer, based analysis.

There are three possible adjustments to the elementary formula which recognises the angle of altitude and azimuth of any point in the sky and which would lead to the illuminance of a point on the horizontal plane.

1. The reduction in the area of the sky proportional to the cosine of the angle of elevation, which would not be required in the computer based analysis using rays.

2. The increase in luminance of the sky where, according to the CIE, the value approaching 90 degrees is three times that at the horizon, which supersedes the uniform sky proposed by Waldram and others.

3. The effect recognised by Lambert's Formula, which recognises that the illuminance increases by proportion to the cosine of the angle of elevation of the source.

In a small way it may also be possible to test Lambert's formula by using a Lux meter, shining a light onto the meter from various angles of altitude in a dark room and determining how the luminance readings change but this would require time and suitable equipment and so, for the purposes of this experiment, it is assumed to be correct.

Finally, the empirical results can be tested against the predictions based upon the Waldram diagram (theoretical results) and the alternative theoretical results derived by using the formula in experiment three and making due allowances for the reduction in light levels which result from passing through glass and other variables.

5.9 Triangulation

The methodology described above will, in experiments one and two, test the existing methodologies by quantitative and qualitative measurement and compare these results with the hypothetical model resulting from experiment three.

Chapter Six
Research Details and Results

Every student of architecture will be familiar with physical scale models. While oftentimes they are only produced for presentation and visualisation of a scheme, accurately created scale models may also be used for assessing the daylight performance of a building.

Physical models for lighting are fully scalable. There are no correction factors, which need to be applied, and we can use the same instruments that we do in real buildings. A lux is still a lux.

The Low Energy Architecture Research Unit (LEARN)
of London Metropolitan University (2007)

6.1 Introduction

In previous chapters the historical background has been described largely by way of literature review and this has revealed the following results:

- The level of daylight accepted by the courts is based upon the concept of one foot-candle being sufficient illuminance provided that this is available over 50% or more of the room but the proof of this is by no means certain.
- The value of light from the sky was assumed to provide at least 500 foot candles of illuminance on all but the most overcast of days and this is supported by independent BRE research.
- The measurement of illuminance used by Waldram, in his diagram, adjusted the values on the diagram for the altitude of origin of the light in two ways, firstly for the area of sky and secondly by the use of Lambert's formula for the angle of incidence at the surface being considered but relied upon a uniform sky which is not a true representation of reality.
- There is no obvious reason for assessing illuminance at 850m above floor level as this does not coincide with general work surface levels.
- By ignoring variables such as window frames and internal reflectance, the assessment process is simplified but it is unclear whether the accepted levels are sufficient in the 'worst case'.

These results, in themselves, posed further questions, which were analysed in chapters three and four and in Structural Survey. (Defoe 2007b)

To further test the basis of the Waldram Diagram and the levels accepted by practitioners and the courts, it is necessary to perform the experiments described in chapter five.

These experiments have been designed to prove, so far as is possible, the amount of daylight required by the average person for ordinary use, the amount of daylight available directly from the sky, at any point within a room and the appropriate method of measurement.

The site measurements at Century House had to be timed when the sky was sufficiently overcast and the building was available for use and, in each of the cases where readings were taken, the number of readings has been dictated by the time available. Whilst Century House no longer exists, having been replaced by a zero carbon experimental house, further tests in the artificial sky dome and electronic modelling may be possible in the future to validate these results.

The detailed analysis of these results including graphic representation of tabled results appears in chapter seven.

6.2 Experiment One

Despite extensive literature review and enquiries with the authorities, identified in chapter four, there is no evidence available that anyone has undertaken specific research to determine the minimum illuminance levels required for ordinary use. The purpose of this experiment was to determine how much illuminance is required for comfortable use by a range of people.

In previous chapters, it has been recognised that the human eye is extremely adaptable over a large range of lighting conditions and that the original 'jury' experiments were deficient in that they relied upon the use of rooms subject to varying amounts of natural daylight and jury members for whom no data has been provided.

This experiment was designed to eliminate the vagaries of natural daylight and to record at least some information about the jury members that could permit interpretation of the results. Nevertheless the judgement of sufficiency is a subjective one and this factor needs to be considered in the analysis of the results.

For this experiment to be effective it was necessary to be able to closely control the illuminance and thus all daylight was blocked from the room. There was no window to the external environment and the view panel in the door was obscured.

Each member of the jury came from a lighted area into the darkened room with just sufficient light for them to be able to safely locate the table and chair. Prior to this they had each completed a data sheet, as far as possible, and this was handed over when they entered the room.

On the table in the room were a copy of the Times with a piece of text outlined for the jury member to read, next to this piece of text there were three Lux meter sensors with the digital displays hidden behind a low screen (see photographs 6.01 and 6.02)

The first part of the experiment involved gradually raising the lighting levels using a rheostat control on an 'up lighting' luminaire. This ensured that only diffuse light was available at the table level.

Each jury member was asked to indicate the point at which the text became distinguishable and could, with effort, be discerned and readable. Each of the readings on the Lux meters were noted at this point and, where they differed, the average was recorded. The lighting levels were then gradually increased to the point where the jury member indicated that they felt the levels were sufficient to be comfortable for longer term use. In other words, where they thought they would not suffer eye strain if these levels were maintained continuously although a higher level might be preferred. At no point could the jury member read the Lux Meter and thus affect the result.

In recognition of the possibility that these results could be affected by the adaptability of the eye, including the adaptation which was occurring the longer that they were subject to low levels of light (Ryan and Margrain 2005) and also recognising the subjective nature of the experiment, the process was repeated in reverse.

Firstly, lighting levels were taken up to 100 Lux and the jury member given two minutes for their eyes to acclimatise to this level of light. The levels were then reduced gradually and the readings recorded as before.

The original jury experiment in the early 20th Century involved only between 6 and 7 members. This experiment involved 12 members. From historical information, it can be surmised that the original jury members were all male, as is the case in the current experiment. This was not intentional and it is possible that had there been some female representation, the average results may have varied.

Prior to the experiment it was considered to be a possibility that the following factors might affect the results:

- The age of the jury member
- The colour of their eyes
- The need for reading glasses or lenses
- Their gender
- Their general health

During the session, one jury member advised that he had just had an eye test and required reading glasses but had not yet had them prescribed, another advised that he had been diagnosed as having glaucoma. On the basis that the jury members are being used as a representation of the population as a whole, it is considered that these factors are, in fact, representative.

Photographs 6.01 and 6.02 show the relative difference between 100 Lux and 10 Lux illuminance at desktop level but it has to be recognised that even this is an artificial comparison due the manner in which the camera adjusts for light levels.

Table 6.01 shows a summary of the results obtained from the jury members.

Photograph 6.01 - test room with light levels at approximately 100 Lux

Photograph 6.02 - test room with light levels at approximately 10 Lux

Jury Member	Sex	Age	Eye Colour	Glasses or lenses required	Increasing Light (Lux Levels)		Decreasing Light (Lux Levels)	
					Minimum	**Optimum**	**Optimum**	**Minimum**
1	Male	48	Brown	Yes	2	6	28	2
2	Male	53	Grey	Yes	5	20	27	5
3	Male	45	Grey	No	4	11	16	3
4	Male	32	Blue	Yes	5	21	29	6
5	Male	61	Brown	Yes	14	49	43	10
6	Male	57	Blue	Yes	1	11	12	2
7	Male	47	Blue	Yes	7	12	19	7
8	Male	47	Grey	Yes	6	17	14	5
9	Male	52	Blue	No	3	4	7	2
10	Male	45	Brown	Yes	9	36	53	7
11	Male	55	Blue	Yes	2	18	47	14
12	Male	54	Brown	Yes	2	14	20	2
Averages		**50**			**5**	**18.25**	**26.25**	**5.42**

Table 6.01 Results of Jury members' assessment of lighting level

6.3 Experiment Two

Experiment two comprises several stages, which are outlined in chapter five. A room was required that would satisfy two key criteria:

- The room should have a view of the sky but there must be a suitable obstruction restricting that view which would remain unchanged for a sufficient length of time.
- The room should be decorated in relatively light colours, with a carpet but no other furnishings.

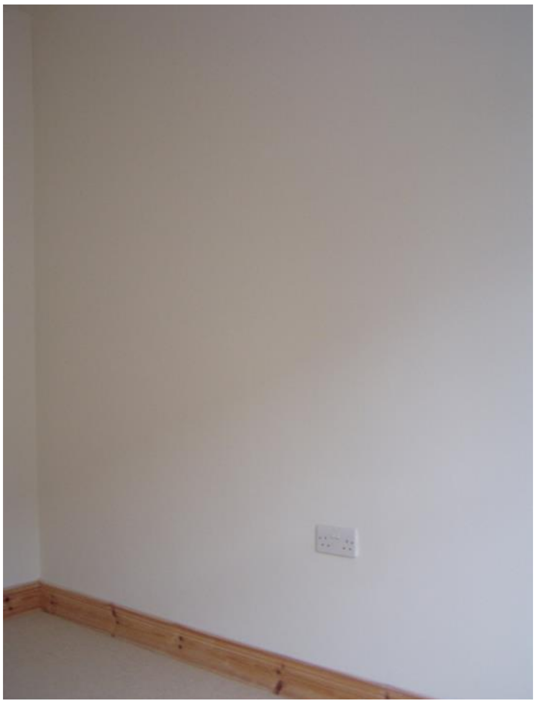
The subject room was in the first floor of a building constructed by Kingspan on the BRE 'Innovations Park' at Garston and labelled Century House and apart from satisfying the criteria referred to above, there was the added advantage that overall daylight measurements had already been recorded. (Littlefair 1984).

Photograph 6.03
Century House at BRE Garston
Top right window is subject room

Photograph 6.04
Obstructing building opposite Century House

Photograph 6.05 - Internally in subject room front corner exposed

Photograph 6.06 - Internally in subject room en-suite door



Photograph 6.07 - Internal wall of subject room

Photograph 6.08 – Main door in subject room

6.3.1 <u>Stage 1</u>

The first stage involved the accurate measurement of the room and external obstructions (The accuracy levels of the measuring equipment are defined at appendix three but for simplicity this is ignored in the results).

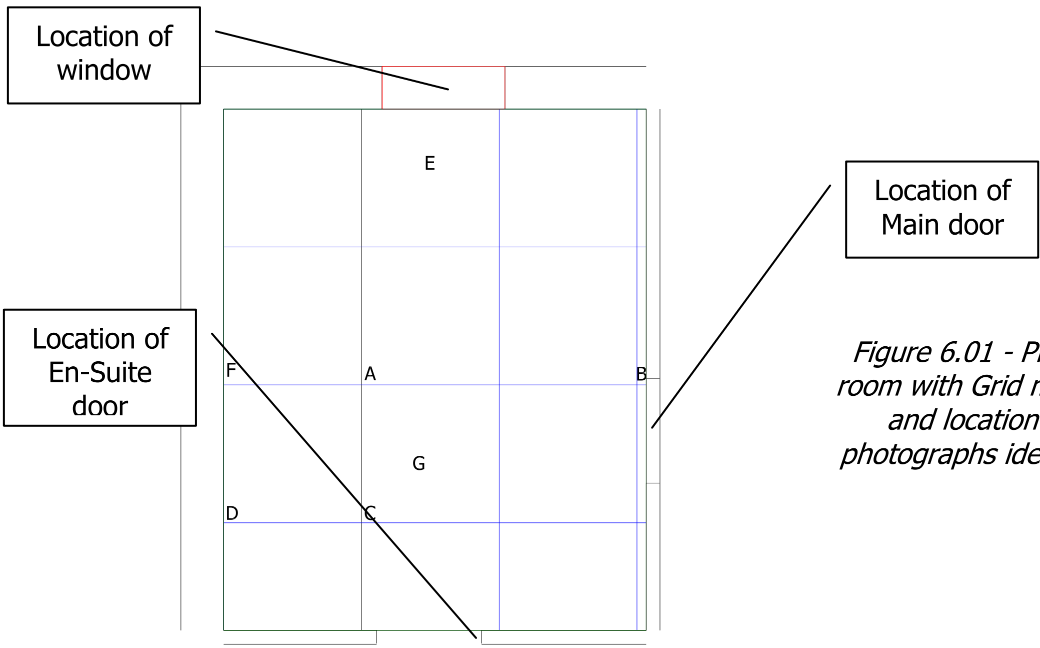


Figure 6.01 - Plan of room with Grid marked and location of photographs identified

The drawing at Figure 6.01 shows the floor plan marked with a grid at one metre centres and the locations of photographs 6.09 to 6.16.

Photograph 6.09 - Internally in subject room view from point A through window at 850mm height

Photograph 6.10 - Internally in subject room from point B through window at 850mm height

Photograph 6.11 - Internally in subject room from point C through window at 850mm height

Photograph 6.12 - Internally in subject room from point E through window at 850mm height Overcast sky visible measured at 7,500 Lux

Photograph 6.13 - Internally in subject room from point D through window at 850mm height

Photograph 6.14 - Internally in subject room from point F through window at 850mm height

Photograph 6.15 - Internally in subject room from point G through window at 850mm height

Photograph 6.16 - Internally in subject room from point H through window at 850mm height

The measurements were recorded on data sheets for future use and an initial assessment was made using a Lux meter to take the following readings:

- Lux meter readings at 1.000 metre centres at 850 mm above floor level with the window shut.
- Lux meter readings at 1.000 metre centres at 750 mm above floor level with the window shut.
- Lux meter readings at 1.000 metre centres at 850 mm above floor level with the window open.
- Lux meter readings at 1.000 metre centres at 750 mm above floor level with the window open.
- External range of readings from start to finish.

Figure 6.02 below shows the floor plan of the room with the grid points numbered. These locations correspond with the tables of results below with readings taken at each intersection to replicate the methodology normally used with the Waldram diagram.

Although the Lux meter requires a correction factor of 0.95 for daylight conditions, i.e. the readings should be reduced to 95% of the value obtained, the unadjusted readings are shown below at table 6.02.

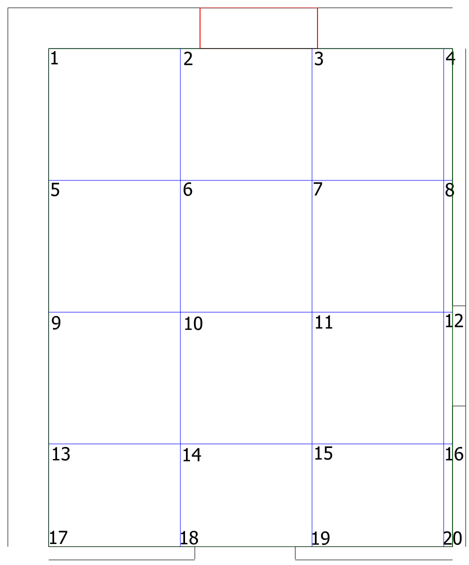


Figure 6.02 - Location of grid points by number

location	850 window shut	750 window shut	850 window open	750 window open
1	20	11	39	22
2	40	14	68	26
3	324	11	402	22
4	15	10	28	20
5	49	43	98	72
6	150	99	320	139
7	84	157	127	250
8	39	36	76	104
9	42	31	91	70
10	27	40	54	131
11	35	56	103	142
12	28	41	49	130
13	20	18	48	43
14	24	17	50	57
15	22	19	45	53
16	18	24	40	61
17	10	15	21	30
18	12	16	21	31
19	13	18	24	34
20	14	20	25	35

Table 6.02 - Unadjusted readings, in Lux, taken on 23.01.06

These readings were replicated on further occasions using only the Lux Meter, by way of comparison and the results appear in the following tables and are discussed in chapter seven.

location	First set				Second set	
	850 window shut	750 window shut	850 window open	750 window open	850 window open	750 window open
1	120	60	70	70	53	68
2	170	70	530	80	287	97
3	920	60	760	70	285	69
4	80	60	240	70	49	54
5	240	220	300	250	180	261
6	340	240	500	320	268	297
7	390	300	250	440	489	456
8	260	170	180	230	235	208
9	230	140	230	140	137	214
10	240	180	280	190	162	236
11	310	170	260	220	240	293
12	170	180	120	290	247	303
13	190	100	130	120	87	140
14	210	120	170	180	106	180
15	210	140	190	230	111	200
16	110	80	90	220	163	215
17	120	90	100	120	75	117
18	130	10	120	140	89	161
19	100	70	120	130	88	185
20	90	60	100	120	65	165

Table 6.03 - Unadjusted readings, in Lux, taken on 10.02.06

location	850 window shut	850 window open
1	40	70
2	64	127
3	1090	1800
4	39	71
5	118	198
6	220	385
7	372	640
8	115	188
9	105	176
10	112	217
11	168	308
12	112	195
13	54	84
14	59	93
15	65	103
16	70	121
17	64	74
18	59	86
19	61	84
20	69	116

Table 6.04 - Unadjusted readings, in Lux, taken on 20.03.06

6.3.2 Stage 2

The next sets of readings at Century House were taken using a Megatron BRS Daylight Factor Meter which measures light both internally and externally, simultaneously thus producing the result as a daylight factor.

Photograph 6.17 - Megatron BRS Daylight Factor Meter

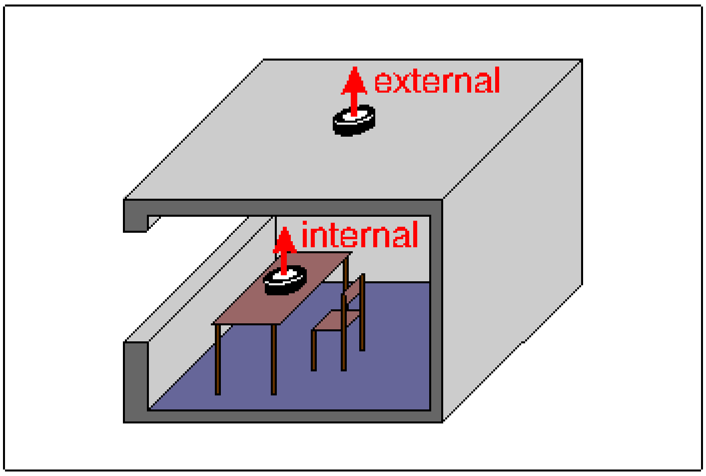


Figure 6.03 – Diagram of use of Megatron BRS Daylight Factor Meter

The internal sensor was placed centrally to each metre square, at a height of 850 mm above floor level and readings were taken with the window open for the first trial of this method. The external sensor could not be placed upon the roof and so it was necessary to place it as far as possible from the building and in an open area of land nearby. The results are shown at table 6.04 below. The weather on the day of the readings did not provide an overcast sky and thus the session was curtailed pending more favourable conditions.

Window open 850	
square	DF
1,2,5,6	6
2,3,6,7	15.5
3,4,7,8	3
5,6,9,10	3
6,7,10,11	4.1
7,8,11,12	4.1
9,10,13,14	1.05
10,11,14,15	2.05
11,12,15,16	2.55
13,14,17,18	1.5
14,15,18,19	1.75
15,16,19,20	2

Table 6.05 – Readings (%DF) taken with Megatron on 13.06.06

More favourable conditions were available on the 17th October 2006 and the readings from that session are shown at table 6.06 below

Sky near uniform overcast			
Window shut 850		Window open 850	
Square	DF	square	DF
1,2,5,6	3.0	1,2,5,6	5.0
2,3,6,7	8.0	2,3,6,7	16.0
3,4,7,8	8.0	3,4,7,8	13.5
5,6,9,10	2.5	5,6,9,10	4.5
6,7,10,11	3.0	6,7,10,11	5.0
7,8,11,12	3.0	7,8,11,12	7.5
9,10,13,14	2.0	9,10,13,14	8.0
10,11,14,15	1.5	10,11,14,15	5.0
11,12,15,16	1.5	11,12,15,16	3.0
13,14,17,18	1.0	13,14,17,18	3.5
14,15,18,19	1.0	14,15,18,19	3.75
15,16,19,20	1.0	15,16,19,20	3.0

Table 6.06 - Readings (%DF) taken on 17.10.06

The average reflectance of internal finishes was recorded using a Hagner Universal Photometer.

Photograph 6.18 - Hagner Universal Photometer

Luminance of surface L = E x R/π
Reflectance R = L x π/E

	Carpet	Radiator	Ceiling	Wall
L (Candela/ sqM)	80	90	100	150
E (Lux)	580	350	360	550
R	0.43	0.877	0.872	0.856

Table 6.07 Results using Hagner Universal Photometer

Each of the values is then applied to area of carpet, radiator, ceiling and walls.

Thus $(A_{ca} \times R_{ca} + A_r \times R_r + A_{ce} \times R_{ce} + A_w \times R_w)$/ Total area = $R_{Average}$

The unadjusted average for the room is 0.78

These values were then applied to the physical and electronic models.

6.3.3 Stage 3

The results from the above might not facilitate direct comparison one with the other and it is not easy to use action research principles, in a real house, to determine what happens when fundamental factors are changed. To this end, it was deemed essential that the model be tested in a controlled manner using an artificial sky dome. The model, including obstructions was constructed at 1:40 scale, replicating all essential features including internal reflectance.

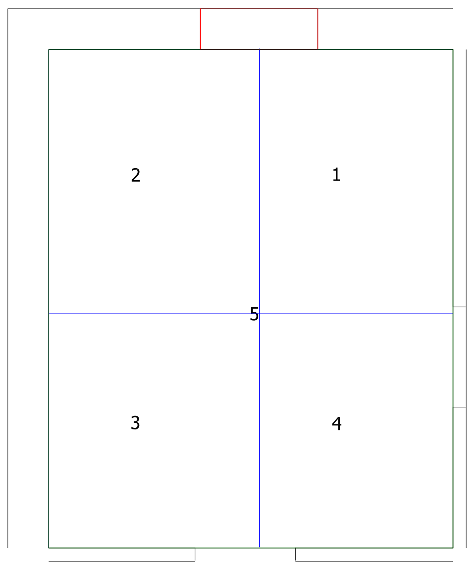
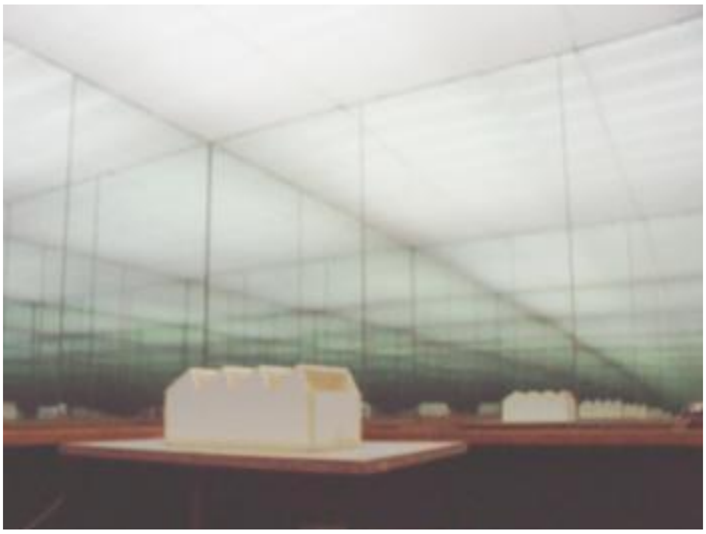


Figure 6.04 Locations of sensors in model in sky dome

Even with a smaller sensor used for models, it was not possible to replicate the locations of the sensor readings in the physical room. It was therefore decided to divide the room into four regions as shown in figure 6.04 above, to take readings in the centre of each of these regions and at the intersection of each of the regions, at the centre of the room which, it was assumed, would approximate to the average value.

Photograph 6.18 shows the model on first introduction to the artificial sky dome with the light tight lid removed. The internal sensor was placed with its top surface at the equivalent of 850 mm above floor level and readings taken in each of the four quarters and in the centre.

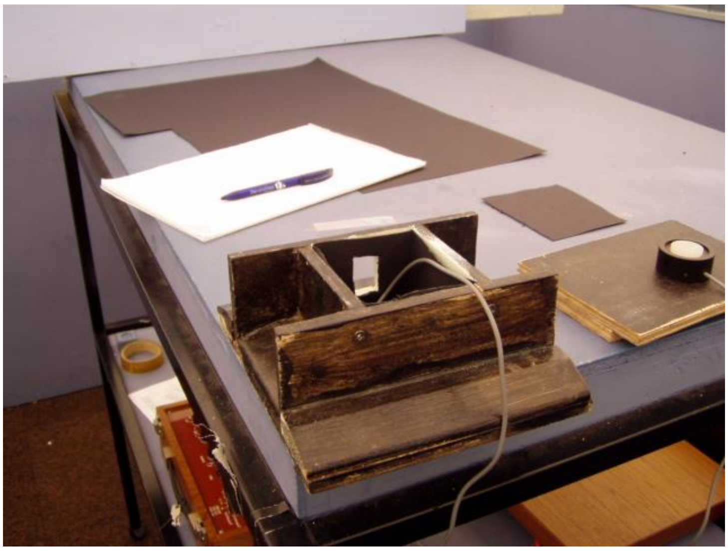
Photograph 6.19 – Model being prepared for artificial sky dome with internal and external sensors



Photograph 6.20 Typical view of an artificial skydome

The available sky dome was a rectangular type as described in chapter five. To provide an accurate comparison with the real room and to satisfy the requirements of 'Rights to Light' calculations, the obstructions were also modelled to scale and set out at scale distances from the model as illustrated in photograph 6.20.

Photograph 6.21 - Model in artificial sky dome with obstructions to scale



Photograph 6.22 – Model with all internal surfaces covered with matt black card

Readings were taken using the model without simulated glazing, then with simulated glazing. Following this the experiment was repeated with the internal faces masked by matt black card to eliminate internal reflectance and thus measure only the illuminance provided by the sky dome. These results are shown in table 6.08 below.

Daylight factor readings with obstruction (%DF) (no glazing)						readings with glazing	blacked out no glazing
location	1st set	2nd set	3rd set	average	check readings		
1	11.5	11.85	11.0	11.45	10.5	5.5	8.5
2	6.75	6.75	6.5	6.67	6.5	3.0	4.5
3	3.0	2.75	2.5	2.75	2.5	1.25	0.5
4	2.25	2.5	2.0	2.25	2.25	1.0	0.5
5	3.5	3.5	4.25	3.75	4.0	1.75	1.5

Table 6.08 – Readings taken in artificial sky dome

Daylight factor readings without obstruction (%DF) (no glazing)						readings with glazing	blacked out no glazing
location	1st set	2nd set	3rd set	average	check readings		
1	12.25	12.5	11.5	12.1	12.0	6.0	10.5
2	9.0	10.0	9.25	9.4	9.5	4.5	8.5
3	3.25	3.75	3.5	3.5	3.5	1.5	3.5
4	3.25	3.5	3.5	3.4	3.5	1.5	3.5
5	6.75	6.25	6.25	6.7	6.5	3.0	6.0

Table 6.09 – Readings taken in artificial sky dome with obstructions removed

The second set of readings were taken to try to establish the overall effect of not having an obstruction in front of the window, in much the same way as, in rights to light calculations, the before and after values are compared. However, there was no way to test this against the real conditions and these results were unused.

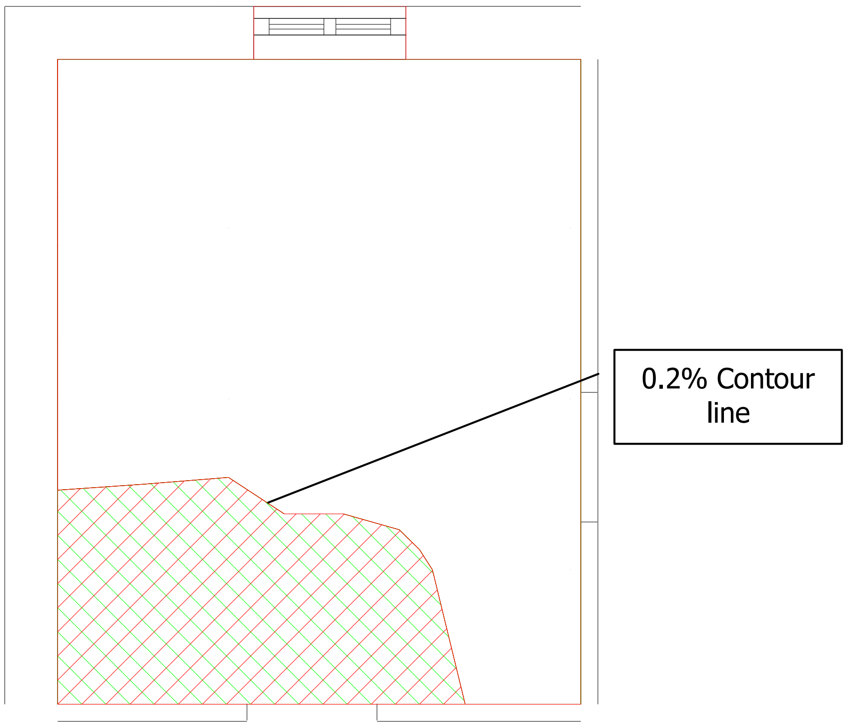
It should also be noted that it was difficult to model the reduction in daylight factor from the introduction of glazing and this may have lead to some divergence from the results obtained on site. This is discussed further in chapter seven.

6.3.4 Stage 4

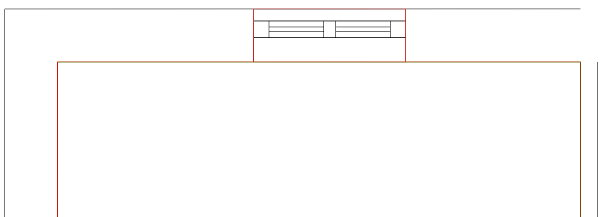
Using the physical measurements taken at the original inspection, the room and obstructions were modelled into AutoCAD and a specialist software programme was used to calculate the 'well lit' area according to the Waldram principles. Another function in the same programme was also used to calculate the 'Vertical Sky Component (VSC)' and the 'Average Daylight Factor (ADF)'.

Figure 6.05 shows a plan with a contour line produced by computer set for one metre grid spacing. The hatched area receives light from less than 0.2% of the sky dome.

Figure 6.06 is the rerun of the programme with the grid spacing set at 100 mm. The area sufficiently lit was 7.787 square metres and the room area was given as 11.593 square metres.



Fi



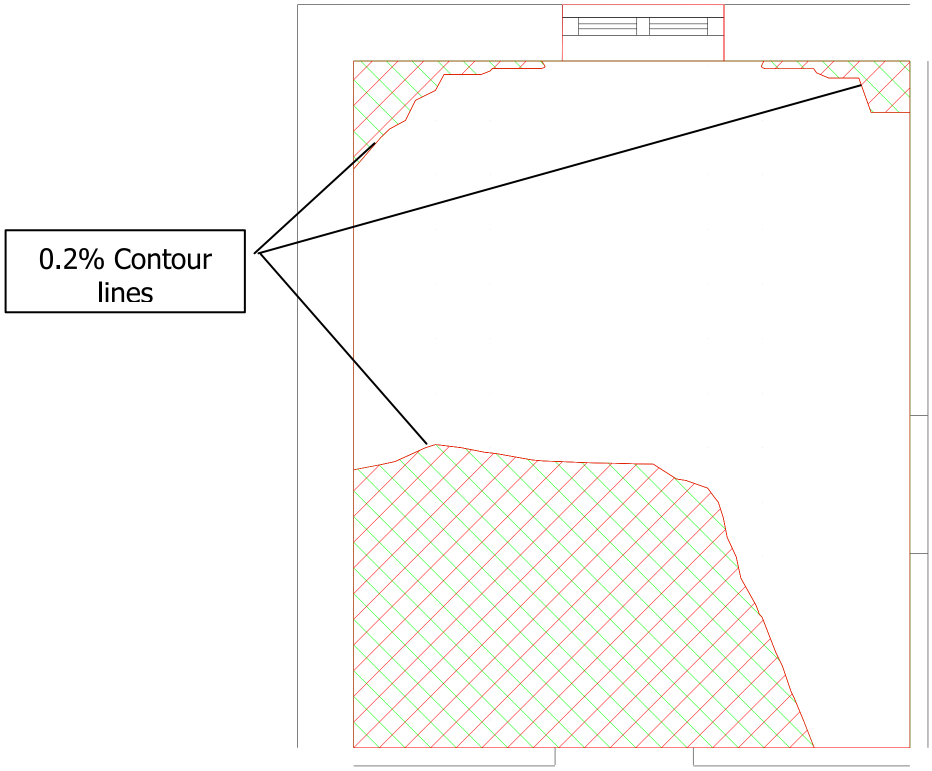


Figure 6.06 Contour Line produced by Computer set at 100 mm centres

Using the other functions of the computer programme, the Vertical Sky Component VSC was found to be 30.981 % and the Average Daylight Factor 1.616

6.3.5 <u>Stage 5</u>

For direct comparison, the same data was used to undertake a traditional analysis using the Waldram Diagram. A chart was plotted for each point except those on the front wall where the readings, apart from number three, would have been zero. Each of the charts is reproduced below in figures 6.07 to 6.22. The window is outlined in blue for readings 5 to 8, red for readings 9 to 12, green for readings 13 to 16 and yellow for readings 17 to 20. The visible obstruction appears as a block of grey.

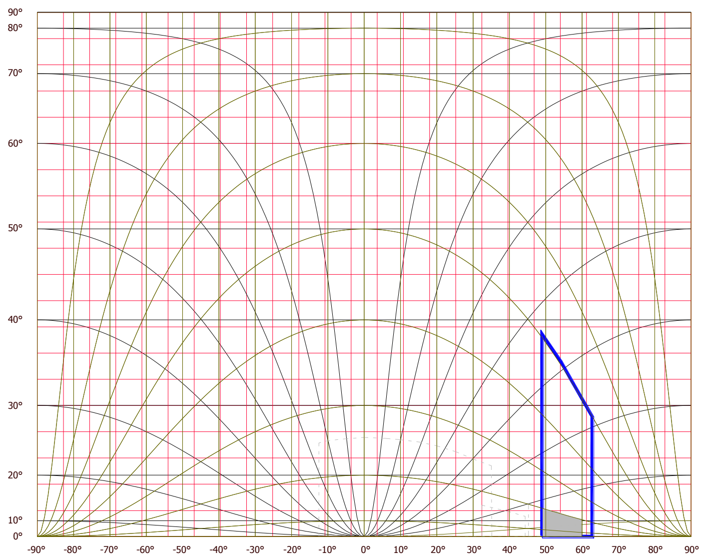


Figure 6.07 Waldram Diagram at Point 5

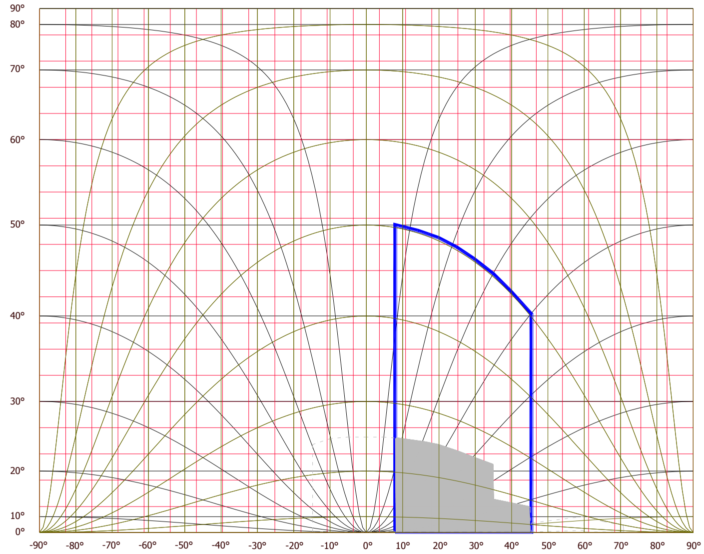


Figure 6.08 Waldram Diagram at Point 6

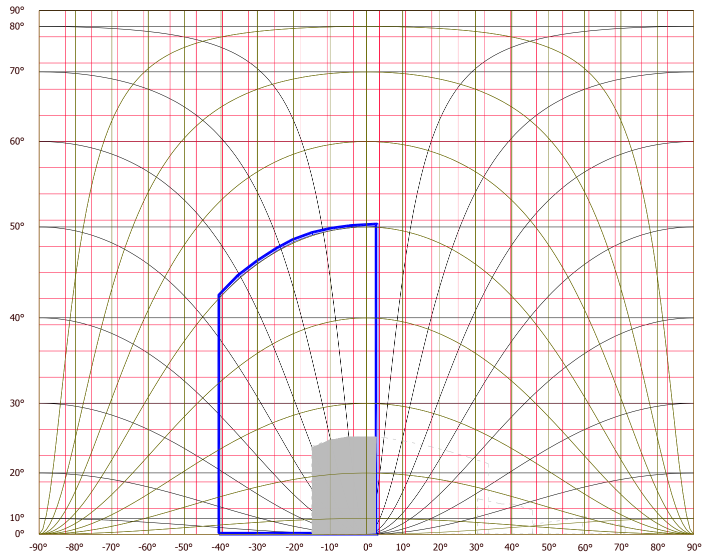


Figure 6.09 Waldram Diagram at Point 7

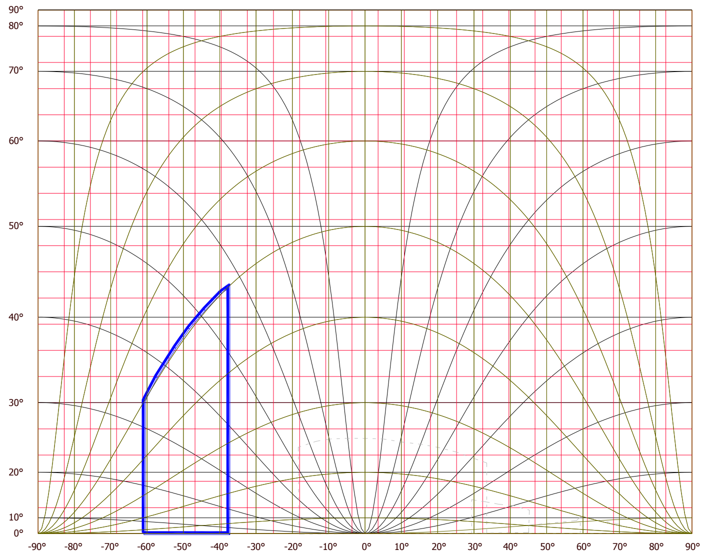


Figure 6.10 Waldram Diagram at Point 8

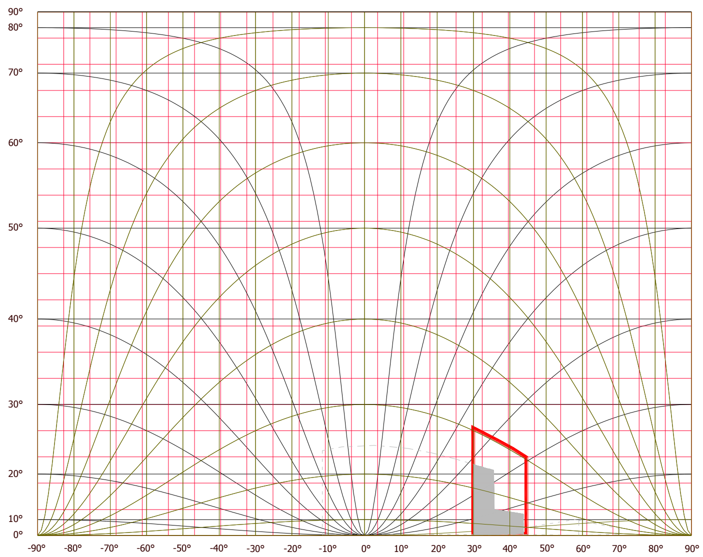


Figure 6.11 Waldram Diagram at Point 9

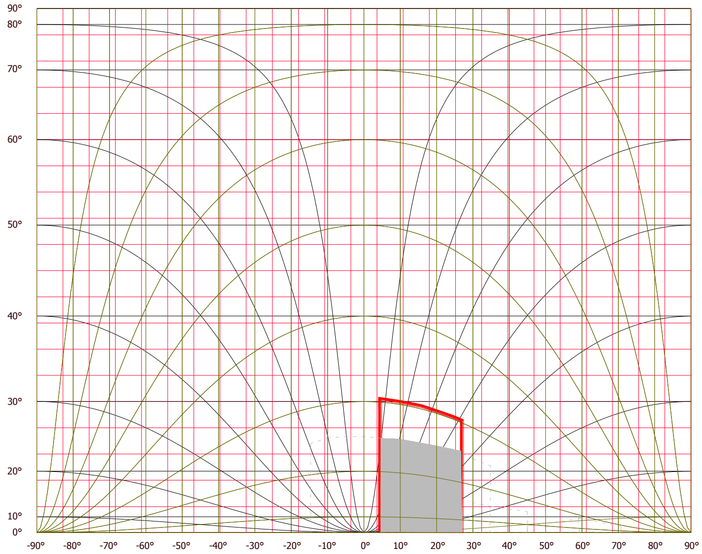


Figure 6.12 Waldram Diagram at Point 10

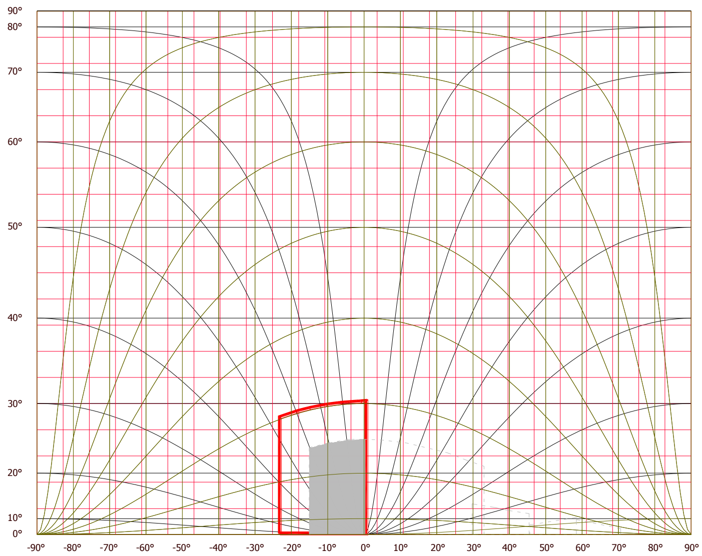


Figure 6.13 Waldram Diagram at Point 11

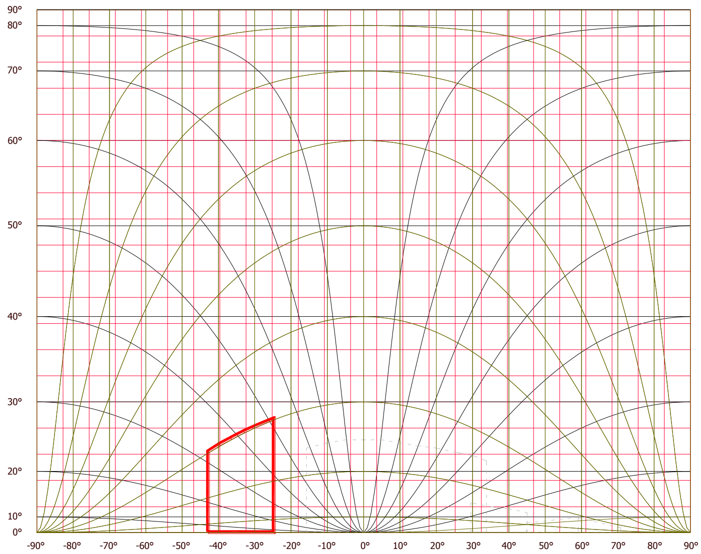


Figure 6.14 Waldram Diagram at Point 12

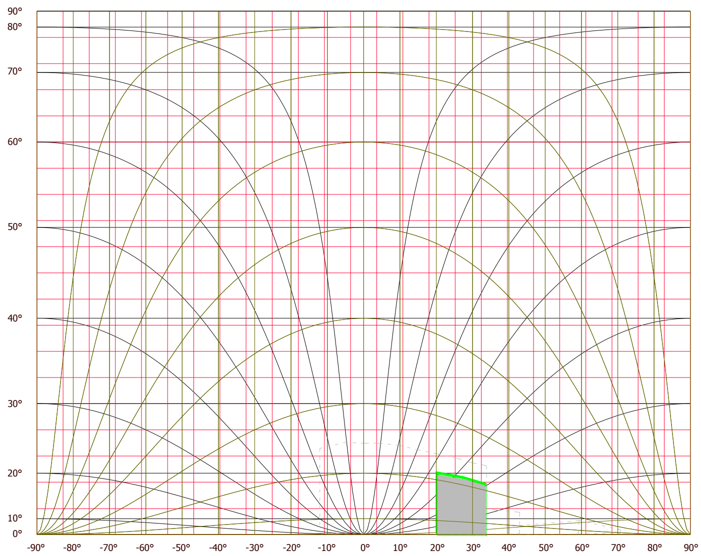


Figure 6.15 Waldram Diagram at Point 13

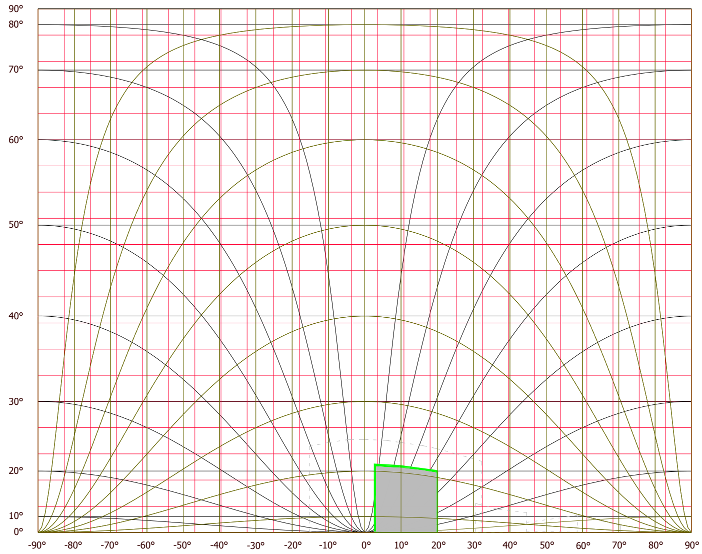


Figure 6.16 Waldram Diagram at Point 14

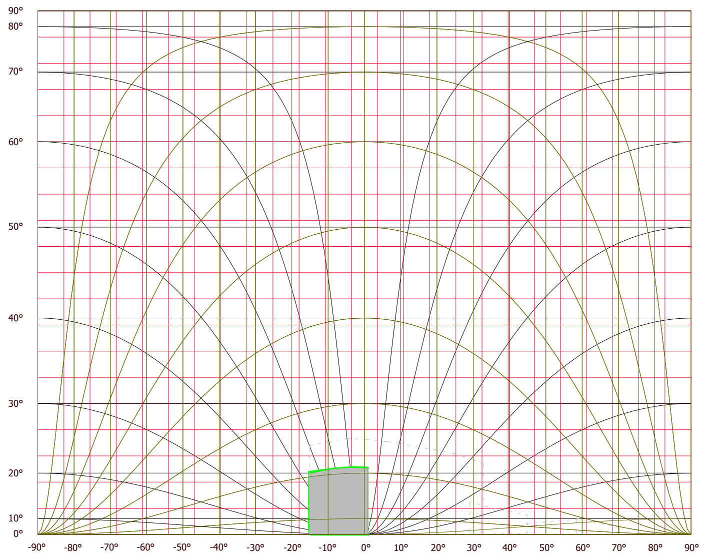


Figure 6.17 Waldram Diagram at Point 15

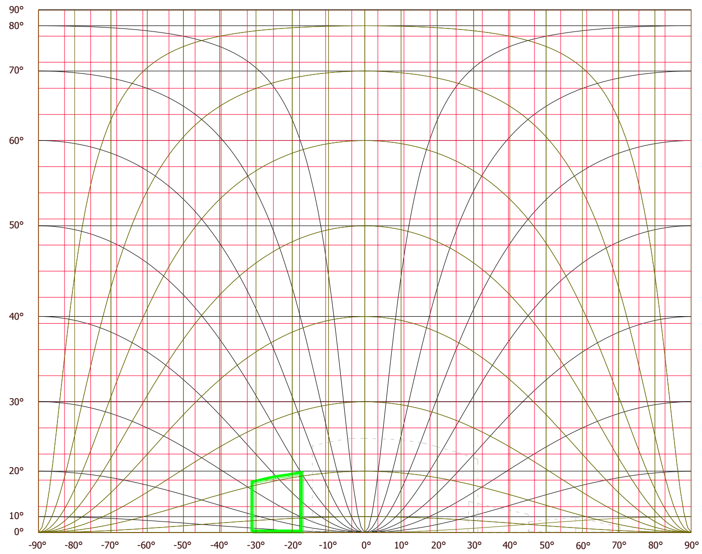


Figure 6.18 Waldram Diagram at Point 16

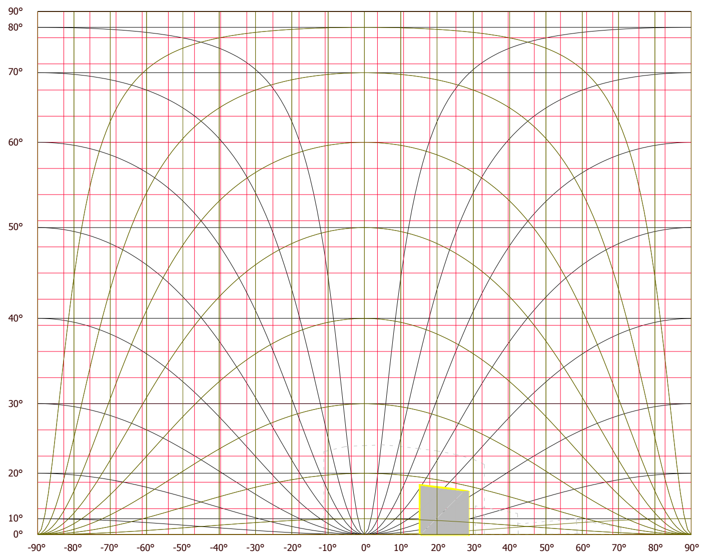


Figure 6.19 Waldram Diagram at Point 17

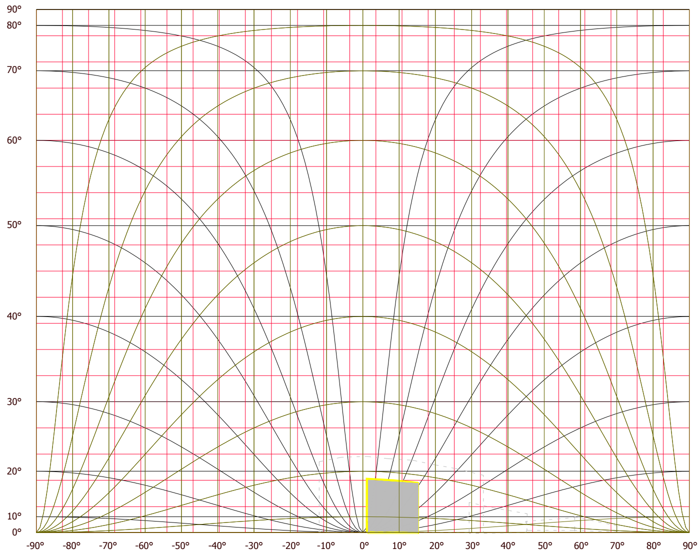


Figure 6.20 Waldram Diagram at Point 18

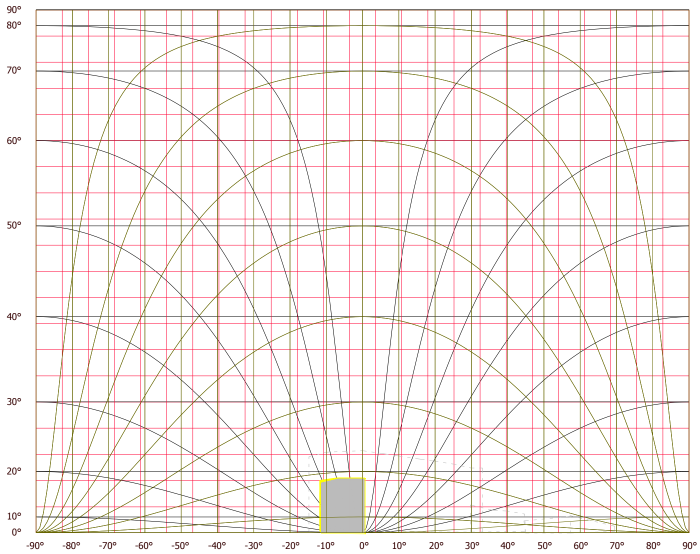


Figure 6.21 Waldram Diagram at Point 19

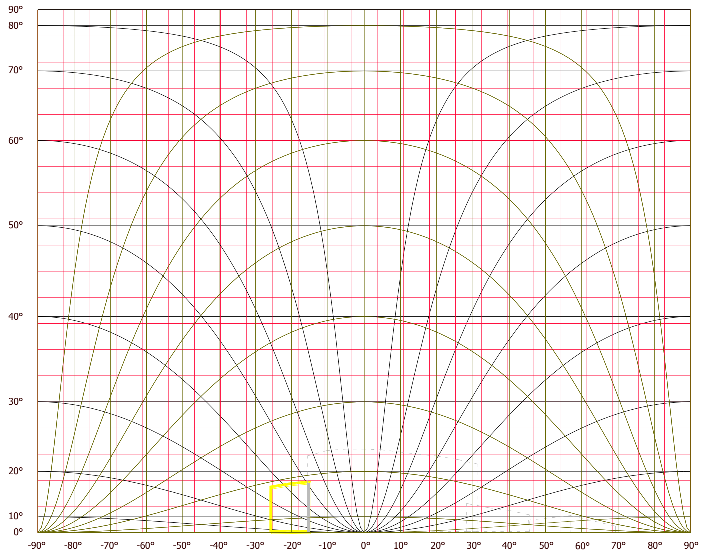


Figure 6.22 Waldram Diagram at Point 20

The results obtained by manually counting the unobstructed squares on each chart were then transcribed onto the floor plan grid and using experience the 0.2% contour was constructed and this is shown in figure 6.23 below.

The principle applied is that the light levels will follow an almost linear change between adjacent points on the grid. With experience being used to modify the contour where the information is insufficient. It is normal practice to take this as a starting point and then to analyse the results at closer centres in the predicted region of the contour.

This preliminary result compares very favourably with the computerised result at figure 6.06 above.

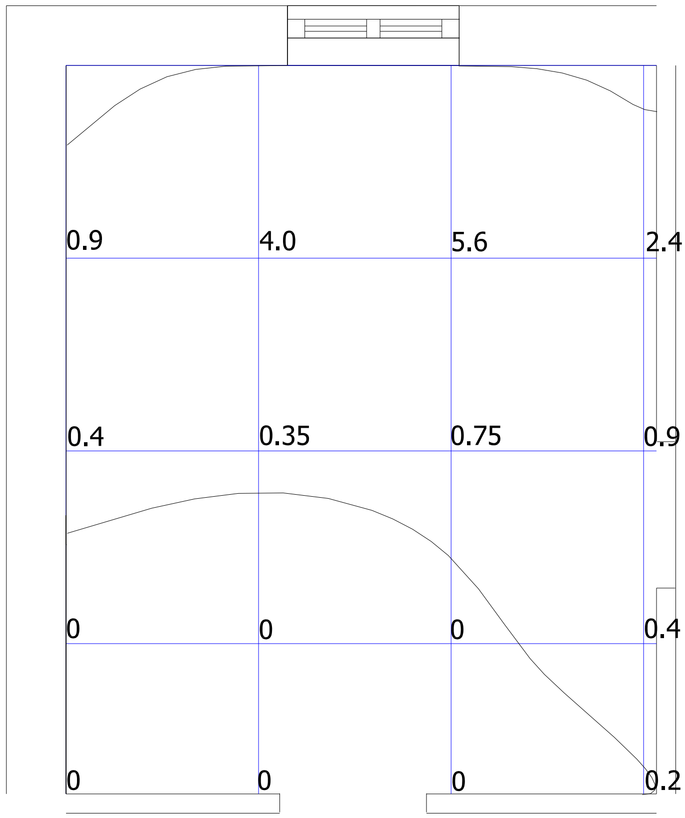


Figure 6.23 – Manually calculated contour lines

The areas enclosed by the contours lines can be calculated manually by measurement and in this case equate to approximately 4 square metres leaving approximately 7 square metres sufficiently lit. This can be compared with the computerised calculation at figure 6.06. The differences being due primarily to interpretation of values by experience on the one hand and computer based logic on the other, as is explained elsewhere in this thesis.

6.4 Experiment Three

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 experiment 2. 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):

6.4.1 Assumptions

Horizontal Angle = β

Vertical Angle = α

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

Cos(α) dα dβ

The CIE Standard Sky transformation can be represented by (1+2Sin(α)). The constants 0.33Lz have been dropped.

6.4.2 Skydome Modified by CIE values

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

Cos(α) (1+2Sin(α)) dα dβ.

6.4.3 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(α) (1+2Sin(α)) dα dβ

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

The vertical scale is proportional to

$\int_0^{\alpha} \cos(\alpha)\,(1+2\sin(\alpha))\,d\alpha$ = **(Sin(α)- ½ Cos(2α)+ ½)**

6.4.4 Points to Note

It is important to recognise that the Waldram Diagram is more than just the flattened sky dome; it also contains the Lambert Cosine Law transformation or the CIE Standard Sky transformation. The surface area of the Waldram Diagram is not a direct representation of the surface area of the sky dome as it has additional stretching caused by the Lambert Cosine Law transformation.

6.4.5 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:

$\mathrm{Cos}(\alpha)\ \mathrm{Sin}(\alpha)\ d\alpha\ d\beta$

(Note that the angle from the vertical is: $(90-\alpha)$ and $\mathrm{Sin}(\alpha) = \mathrm{Cos}(90-\alpha)$)

If the CIE Standard Sky is added then this produces $(1+2\mathrm{Sin}(\alpha))\ \mathrm{Cos}(\alpha)\ \mathrm{Sin}(\alpha)\ d\alpha\ d\beta$

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:

$(1+2\mathrm{Sin}(\alpha))\ \mathrm{Cos}(\alpha)\ \mathrm{Sin}(\alpha)\ d\alpha\ d\beta$

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.

$(1+2\mathrm{Sin}(\alpha))\ \mathrm{Cos}(\alpha)\ \mathrm{Sin}(\alpha)\ d\alpha$ denotes the rate of change of the area along the vertical axis.

The vertical scale is proportional to:

$\int_0^{\alpha} (1+2\mathrm{Sin}(\alpha))\ \mathrm{Cos}(\alpha)\ \mathrm{Sin}(\alpha)\ d\alpha = \mathbf{(-\tfrac{1}{2}\ Cos^2(\alpha) + \tfrac{1}{2}\ Sin(\alpha) - 1/6 Sin(3\ \alpha) + 1/2)}$

From this a modified Waldram Diagram (or CIEL Diagram) might be constructed using Microsoft Excel as previously.

6.5 CIE Overcast Sky

A 'one off' experiment was conducted at the BRE to assess whether the sky, during one set of readings, did correspond to the CIE model to any degree. Once again the Megatron was used but on this occasion the sensor attachment used a cylindrical scope on an inclinometer to measure the value of the light at different angles of elevation. This was possible on two bearings East and South East and the results are shown in table 6.10 below.

It was not possible to perform more tests and it is proposed to accept the research by CIE as being sufficiently thorough that it can be relied upon.

External light values checking CIE		
Altitude in degrees	East (**Cd/m^2**)	South East (**Cd/ m^2**)
	(1,000)	(1,000)
90	2.9	9.1
80	1.8	5.7
70	1.35	3.9
60	1.25	3.1
50	1.1	2.75
40	1.1	2.95
30	1.15	3
20	1.05	2.6
10	0.6	1.6
0	0.3	0.8

Table 6.10 Results of light values from the sky using the Megatron BRS Daylight Factor Meter

The results of the experiments and further research described in this chapter are analysed in detail within chapter seven.

Chapter Seven
Analysis of Results

Early in his career, Einstein supposedly said:
'For the rest of my life I will reflect on what light is;' and near the end of his life he said,
'Anyone who claims to understand light is fooling himself.'
(Zajonc, 2002)

7.1 Introduction

The aim of this research is to try to establish what level of daylight illuminance is actually required as a minimum for normal use, to assess the accuracy of the existing measuring methodology, defined by Waldram and others, by comparison with empirical results and to attempt to define an alternative methodology which firstly addresses the actual minimum requirement and secondly produces results which more closely reflect the physical results obtained.

The hypothesis being, at this point, that the historically accepted minimum levels of illuminance are in fact too low and that the methodology, which has been shown not to provide a true representation of the illuminance in a room should be replaced with one that provides a closer match to reality whilst still allowing practitioners to make calculations based upon the loss of illumination, to specific areas of a room, for valuation purposes.

In each of the experiments there is a large potential for errors and these have been discussed in earlier chapters. Steps taken to minimise or eliminate these potential errors include the use of more than one Lux meter in the Jury experiment, measuring Century House and its obstructions twice, using geometry to check the results and checking the Megatron calibration between each reading and taking multiple readings from which averages were determined.

There is a need, during this analysis, to be able to relate daylight factor results to levels of actual illuminance. It would be impossible to convert a level of illuminance to a daylight factor as the relationship is dependent upon the value of light from the sky, which is variable. However, the basis of the rights to light calculations is that the illuminance provided by the unobstructed sky should be assumed to be equivalent to 500 foot-candles or approximately 5,000 Lux. If this figure is used in conjunction with the daylight factor then it is appropriate to state, for example, that a daylight factor of 1% from a 5,000 Lux sky would produce an average illuminance of 50 Lux within a room and this would allow a direct comparison of the results.

7.2 Experiment One

It has been established in previous chapters that the results of a 'jury' experiment would have limited value and this is especially true in this experiment for the following reasons:

- The small number of participants.
- The adaptability of the human eye.
- Limited equipment e.g. no eyesight test equipment.

The small number of participants means that whilst the results are relevant to those who participated, it is difficult to generalise to the population as a whole. It may be possible, however, to identify a trend even from this small number.

The adaptability of the human eye means that lower light levels can be tolerated without conscious effort and thus even a subjective evaluation is variable.

Each person will have a variety of factors affecting their ability to perceive light. Mild colour blindness as well as many other medical conditions can have an affect and it is neither practical nor desirable to undertake full medical and optical assessments of the participants as part of this research.

The only valid purpose of this exercise has been to test, under controlled conditions, whether there is any possibility that the original research using a jury of people could have been wrong and to this extent it can be shown to have been successful.

Since all participants were male it is not possible to deduce whether females require the same levels of light.

Neither the age nor the colour of eyes appeared to have any affect on the results.

Despite the range of readings, the average minimum requirement is around 5 Lux with the lowest at only 1 Lux and the highest at 14 Lux and there was only a small difference between the readings with increasing values against those with decreasing values. By contrast, the level considered to be optimum was lower on average when the light was increased than when it was decreased suggesting perhaps that eyesight adjusts more rapidly to increasing light levels. The lowest optimum level was perceived to be 4 Lux and the highest 53 Lux.

By eliminating the highest and lowest readings and thus concentrating on the majority, the average minimum value is still around 5 Lux and the average optimum is around 22 Lux. An alternative measure is to identify the value, which is sufficient for different percentages of people.

In this way it is possible to identify that over 90% of the Jury were satisfied that up to 10 Lux was the minimum level at which they could discern the text but not be comfortable in so doing.

Lux Level	%
1	4.17%
2	33.33%
3	41.67%
4	45.83%
5	62.50%
6	70.83%
7	83.33%
9	87.50%
10	91.67%
14	100.00%

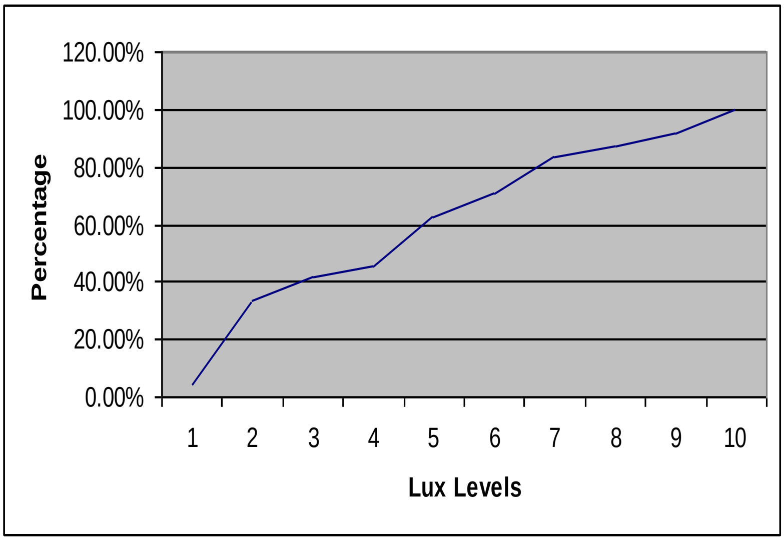


Table 7.01 and Chart 7.01 percentages of jury members able to discern text at Lux Levels

When examining the optimum level however, there was a greater spread of results and, to achieve the same level of response, the value was between 4 Lux and 47 Lux. (Table 7.02)

Significantly, it is possible to determine, from these results, that an illuminance level of 10 Lux was considered to be adequate by less than 20% of the jury members whereas 50% of the jury were satisfied that they had sufficient illumination at 18 Lux and 75% at 28 Lux.

If the principle used in BS EN ISO 7730 is applied and the level at which 80% satisfaction is expressed being used as the appropriate level then this will equate to approximately 30 Lux.

It should be stressed that these were very much minimum levels of comfort rather than optimum and if these were compared with the values suggested by CIBSE and the British Standard, using the 5,000 Lux sky, they would represent, at 18 Lux, just above the average minimum level set for bedrooms (0.3%) and at 30 Lux, just above the average minimum level set for living rooms (0.5%) and about the average minimum level set for kitchens. By contrast the average level for bedrooms would be 50 Lux (1%) and for kitchens 100 Lux (2%), using the same conversion basis.

The CIBSE/BS minimum level of 0.3% for bedrooms is unlikely to be accepted as a minimum level for ordinary use but even this exceeds the level suggested by Waldram as being adequate whereas the level suggested by the jury is close to the 0.5% and 0.6% minimum levels for living rooms and kitchens, respectively, as suggested by CIBSE/BS.

Lux Level	**%**
4	4.17%
6	8.33%
7	12.50%
11	20.83%
12	29.17%
14	37.50%
16	41.67%
17	45.83%
18	50.00%
19	54.17%
20	62.50%
21	66.67%
27	70.83%
28	75.00%
29	79.17%
36	83.33%
43	87.50%
47	91.67%
49	95.83%
53	100.00%

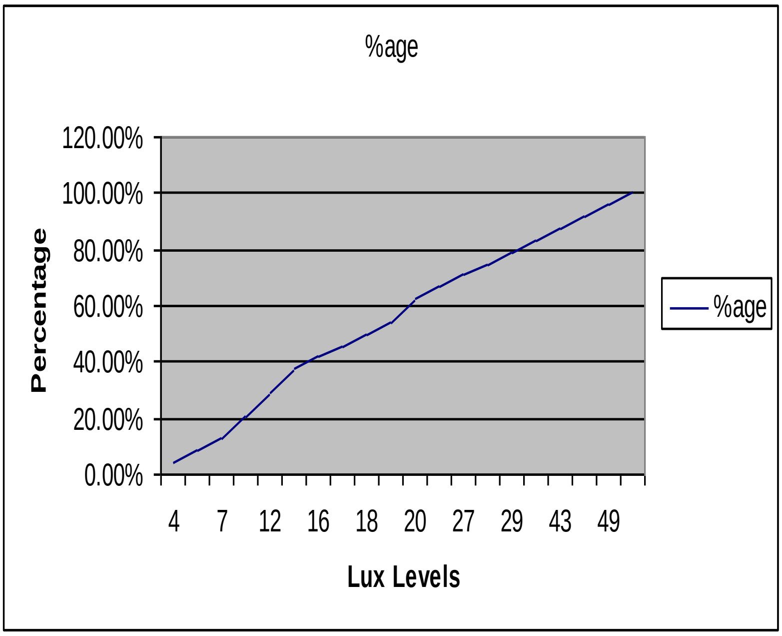


Table 7.02 and Chart 7.02 percentages of jury members comfortable at Lux Levels

On this basis, the jury results appear to be realistic as indicators of minimum acceptability. However, CIBSE/ BS is based upon the daylight factor, which includes internal reflectance and accounts for losses through the window, whereas the Waldram method relies upon the sky factor, which ignores internal reflectance and the whole of the window. It is necessary therefore to analyse the effect of these differences and this was the main purpose of experiment 2.

7.3 Experiment Two

The purpose of this experiment was to find some basis of comparison between actual and theoretical measures of daylight that would permit judgement of whether the Waldram method produces a valid result or whether one of the alternative methods is more accurate.

The Waldram diagram and the 'Rights to Light' software methods are a measure of absolute sky visibility producing a series of results based upon the percentage of sky visibility, adjusted by the formulae discussed in previous chapters, whereas the other measurements, on site, in the artificial sky dome and using the traditional and computerised methods for daylight analysis are measures of relative illuminance i.e. comparing the illuminance internally with that externally as a percentage.

The first stage of this analysis is to compare these latter methodologies on a like for like basis and the most straightforward way to accomplish this is to convert all of the readings to average daylight factors for the room using, where appropriate, those readings taken at 850 mm above floor level and with the window shut or glazing in place.

If these results bear a similarity to one another then the results using readings at 750 mm above floor level and/ or without window or glazing, may be used in further comparison as too can the artificial sky dome results with the internal surfaces blacked out.

The value with the surfaces blacked out i.e. no internal reflectance and no glazing or window open, would be approximately the equivalent of the values achieved using the Waldram diagram method in that they would only be measuring the illuminance entering the room from the sky dome. If this value differs from the actual values obtained using the Waldram method then the next stage would be to try to determine what method would achieve results that are nearer to being correct.

7.3.1 Century House Field Results

A Megatron BRS Daylight meter was used for this part of the experiment, as described in the previous chapter. The Megatron measures the external light value at the same time as the internal and provides a reading of the daylight factor as a percentage of external illuminance.

In order to obtain meaningful readings and to set up the equipment to ensure repeatability, it was necessary to place the internal sensor on a pedestal at the centre of each area defined by the twenty points used for the first sets of readings (see chapter 6). For example, the first square is defined by point 1 which is in the front corner of the room, point 2 which is to the right and adjacent the window, point 6 which is one metre back from point 2 and point 5 which is one metre to the left of point 6.

The initial sets of readings, using this method, were taken with the window open and the internal sensor at 850 mm above floor level. The daylight factor readings for each square are shown in the table below and once again the results immediately in front of the window, on this occasion in square 2,3,6,7 are noticeably higher than the others. The daylight factor can still be affected by various factors including the clothing of the person performing the readings and this necessitated a repeat of the experiment wearing neutral clothing and trying to eliminate any extraneous variables on each occasion.

Using this first set of readings, the average daylight factor for the room, with the window open, was calculated to be 3.79 over the whole room. Table 7.03 below sets out the results against the area of floor in which they were taken. The 'squares' at the rear of the room were not in fact squares, as can be seen on figure 7.01, and thus the value, when used to calculate the average, has to be weighted by the area.

The potential errors in reading the scale are discussed below, when taking readings using the same meter in the artificial sky dome.

Window open 850			
Square	**DF**	**Area m^2**	**DF/m^2**
1,2,5,6	6	1	6
2,3,6,7	15.5	1	15.5
3,4,7,8	3	1	3
5,6,9,10	3	1	3
6,7,10,11	4.1	1	4.1
7,8,11,12	4.1	1	4.1
9,10,13,14	1.05	1	1.05
10,11,14,15	2.05	1	2.05
11,12,15,16	2.55	1	2.55
13,14,17,18	1.5	.78	1.17
14,15,18,19	1.75	.78	1.36
15,16,19,20	2	.78	1.56
ADF for room			3.79%

Table 7.03 Readings using Megatron Giving ADF

The calculated average is not too dissimilar to the readings taken near to the centre of the room. Square 6,7,10,11 being 4.1% is only marginally higher than the ADF. It should be noted however that the window was open for this set of readings and that a reduction would be expected once the window is shut.

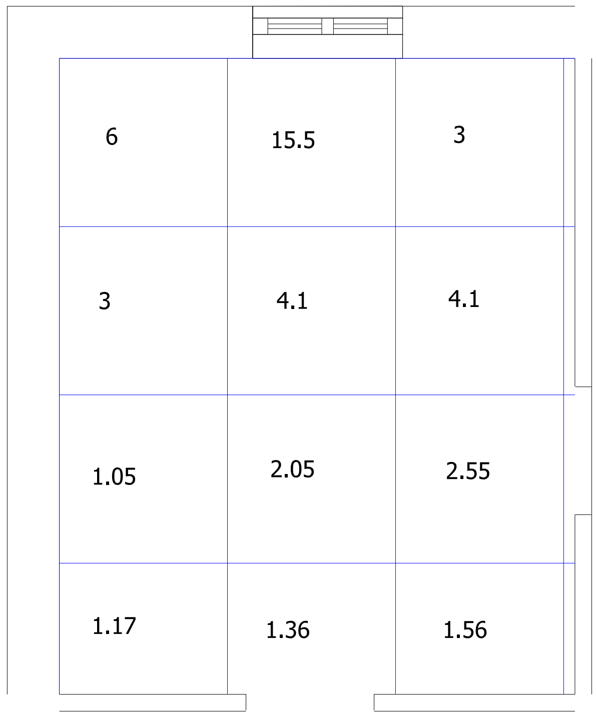


Figure 7.01 Floor Plan Showing Adjusted Daylight Factor Readings

The second set of readings were obtained on a typically overcast day and, on this occasion, one set of readings was taken with the window shut and the other open. There was a marked improvement in the daylight factor readings with the window open and, by eliminating the problem identified above, the readings nearer to the middle and rear of the room, with the window open, show an improvement.

The average daylight factor with the window shut was 2.9 and with it open 6.29 (Table 7.04) with the greatest benefit being to those areas at the rear of the room. This reveals approximately 54% reduction resulting from the window being shut and this reduction will be referred to later.

Here too the ADF results are not too dissimilar to the results for the squares nearest the centre of the room where the daylight factor with the window shut would be expected to be below 3.0.

Window shut 850			Window open 850		
Square	**DF**	**DF/m²**	**square**	**DF**	**DF/m²**
1,2,5,6	3.0	3.0	1,2,5,6	5	5
2,3,6,7	8.0	8.0	2,3,6,7	16	16
3,4,7,8	8.0	8.0	3,4,7,8	13.5	13.5
5,6,9,10	2.5	2.5	5,6,9,10	4.5	4.5
6,7,10,11	3.0	3.0	6,7,10,11	5	5
7,8,11,12	3.0	3.0	7,8,11,12	7.5	7.5
9,10,13,14	2.0	2.0	9,10,13,14	8	8
10,11,14,15	1.5	1.5	10,11,14,15	5	5
11,12,15,16	1.5	1.5	11,12,15,16	3	3.0
13,14,17,18	1	0.78	13,14,17,18	3.5	2.73
14,15,18,19	1	0.78	14,15,18,19	3.75	2.93
15,16,19,20	1	0.78	15,16,19,20	3	2.34
ADF		2.9%	**ADF**		6.29%

Table 7.04 Second Set of Readings Using Megatron, Giving ADF With Window Open and Closed

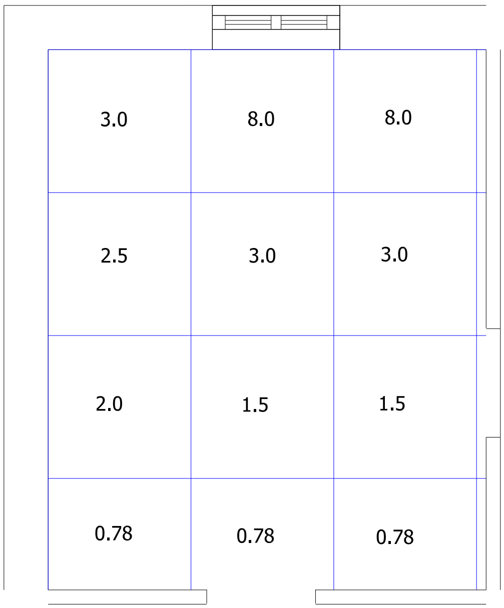


Figure 7.02 Adjusted Daylight Factor Readings with Window Shut

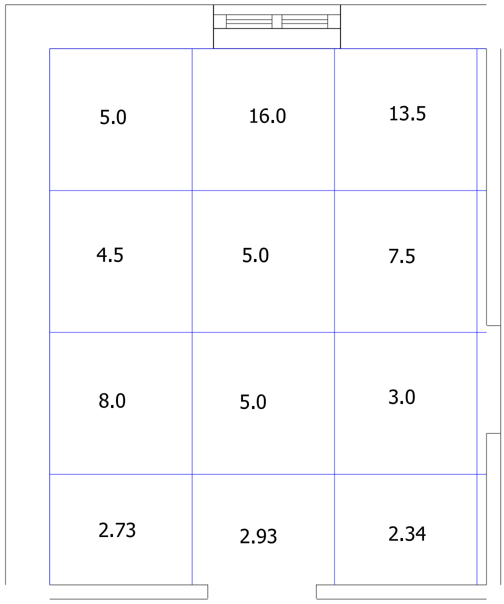


Figure 7.03 Adjusted Daylight Factor Readings with Window Open

7.3.1.1 Internal Reflectance

During the latter set of Megatron readings, the internal reflectance values were also read using the Hagner Meter. The value of R used most commonly for calculations based upon the BRE method is between 0.5 and 0.6. It can be seen from the results below that this would be an underestimate for this particular room.

	Carpet	**Radiator**	**Ceiling**	**Wall**
L (Candela/ sqM)	80	90	100	150
E (Lux)	580	350	360	550
R	0.43	0.877	0.872	0.856

Table 7.05 Reflectance readings from Century House

These values are to be used in the manual and computerised calculations of the Average Daylight Factor below and the value of each has to be combined to produce an average reflectance value 'R'. (Table 7.06)

To convert the figures above to a value of R that is an average for the room, each value has to be compared to their area as a percentage of the whole. The radiator, for example was 1.4 metres wide and 450 mm deep making an area of 0.63 square metres. By multiplying each area by its reflectance then dividing the total of all areas into the totals of all reflectance values, the average reflectance is determined as being 0.78

	Length	Height/width	Area m^2	R	A*R
Radiator	1.40	0.45	0.63	0.88	0.55
Walls	13.69	2.70	36.91	0.86	31.59
Floor	3.78	3.07	11.59	0.43	4.99
Ceiling	3.78	3.07	11.59	0.87	10.11
Totals			60.72		47.24
Average Reflectance					0.78

Table 7.06 Average Reflectance of all surfaces in Century House

7.3.2 Century House Theoretical Results

The theoretical results obtained are those using manual and computerised methods based upon the original Waldram Diagram and the BRE Guidance. (Littlefair 1991)

7.3.2.1 Predicted Well Lit Area Using Manual Waldram Diagram and Computerised Methods

Figure 7.04 below shows the comparative results with the manual calculations based upon the areas counted on the Waldram Diagrams for each of the grid points identified in chapter 6. The location of the 0.2 contour is then estimated by ratio between the nearest adjacent values to the length of the line between the values and then a curve is drawn, using the operator's experience to link the locations to form a contour line. On this occasion the readings were performed at one metre centres and it would be common practice to then perform more measurements along the assumed contour line to improve the accuracy.

The computerised results, which were based upon a 100 mm grid, show the area below the 0.2 contour hatched and it can be seen that there is a degree of similarity between the two sets of contours. The figure also illustrates the relative levels of accuracy that can be expected of the different methodologies.

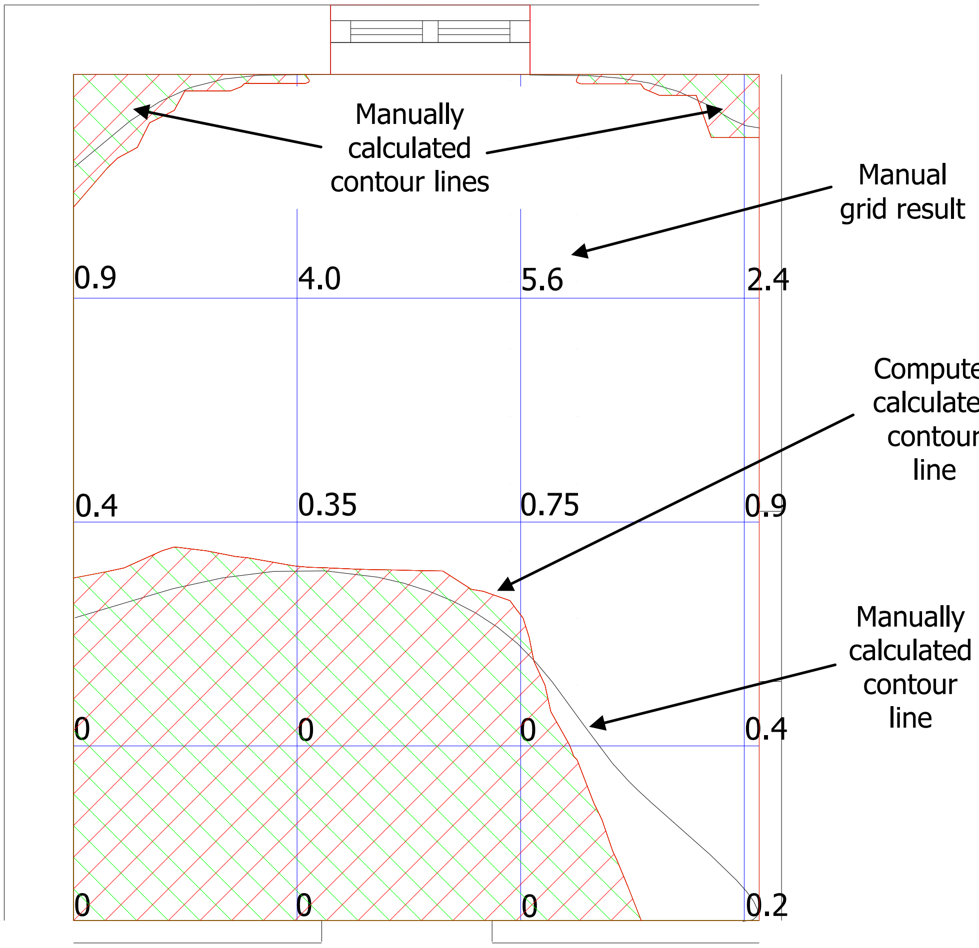


Figure 7.04 Manual and Computer Calculated Contours Using Waldram Method

The manual result of 7 square metres 'well lit' compares with the computerised result of 7.79 square metres when using the 100 mm centre grid. It is noticeable however that the computerised results for the 'one metre' grid are dissimilar at 8.91 square metres and this can be attributed, in the main, to practitioner experience using the manual method and judging where the contour line should be, whereas the computer method uses only predefined mathematical rules. This confirms the need, when using the computerised system, to use the smaller grid to ensure sufficient accuracy. The results from a one metre grid are, at best, only an indicator.

7.3.2.2 Predicted Vertical Sky Component (VSC) Using Computerised and Manual Methods

The computerised method assumes a maximum VSC of 40% and projects a series of rays from the centre point of the window towards and around the obstructions. It then counts the number and value of the rays, which pass around the obstructions, and reports the VSC as a percentage. In this case the answer was presented as 30.981%.

The manual method involves using the modified Waldram Diagram for calculating vertical sky component, which appears as figure B1 in the BRE guide to site layout planning for daylight and sunlight (Littlefair 1991).

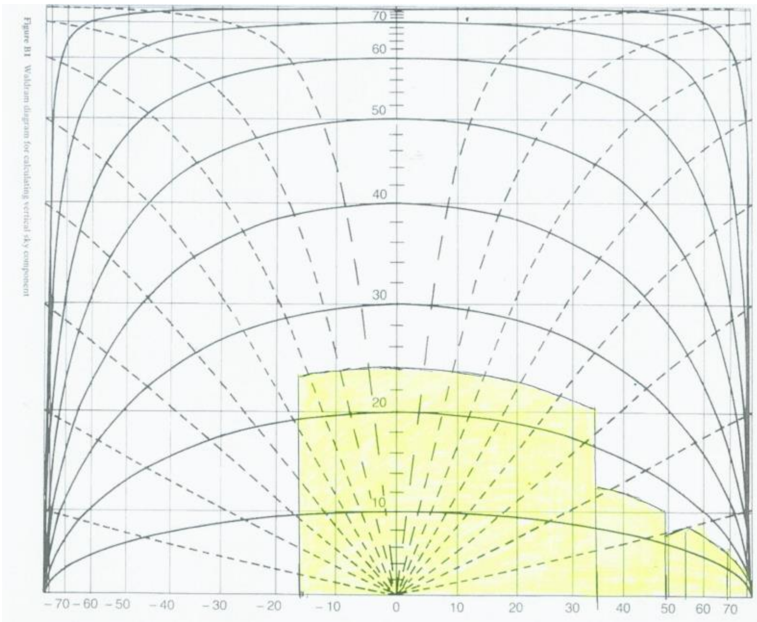


Figure 7.05 Modified Waldram Diagram for VSC showing obstructions

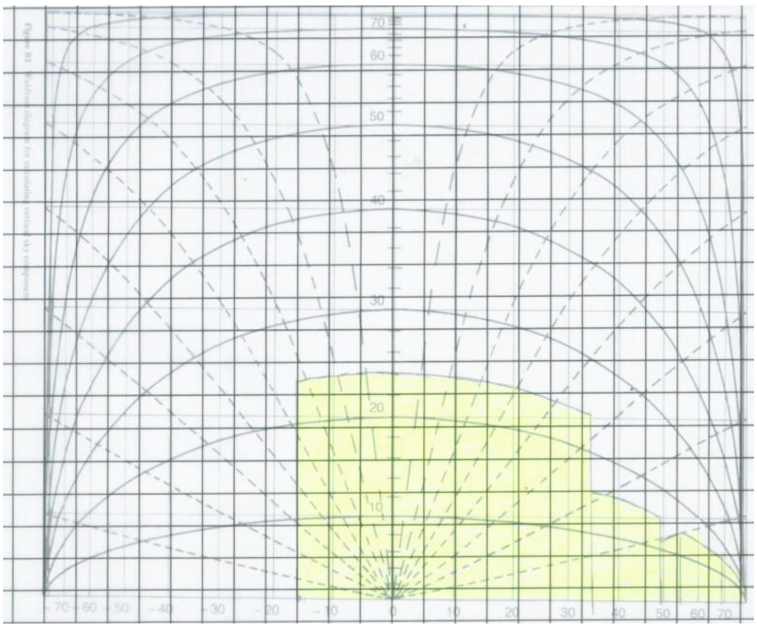


Figure 7.06 Modified Waldram Diagram for VSC showing obstructions with grid overlay

By plotting the outline of the obstruction buildings when viewed from the centre of the window (Figure 7.05), then overlaying the plot with a one centimetre grid (Figure 7.06), it is possible to count the number of squares obstructed against those, which are unobstructed. Each square represents 0.1% and the total chart is approximately 40% or 396 squares (22 x 18). The number of unobstructed squares for this reading was approximately 70.

From this it is possible to calculate the vertical sky component as 396 – 70 = 326 or 32.6% VSC.

In this instance the manual method is providing an answer slightly greater than the computerised method. This is probably due to several factors including inaccuracy in plotting the obstructions and in counting the squares and part squares.

The BRE guide recognises that for a room with non-continuous obstructions, there is the potential for good daylighting provided that the VSC at the centre of the window is not less than the value for a continuous obstruction of altitude 25 degrees which is equal to a VSC of 27%. The guidance also suggests that if the VSC of 27% is achieved within 4 metres horizontally from any window then sufficient daylighting is still likely to be achieved.

On this basis, it appears that the room is likely to have a sufficient average daylight factor to be acceptable. What is not clear from this is whether the method predicts that a 5% average daylight factor will be achieved, which would be considered by the British Standard to be sufficient without artificial illumination or merely one of the minimum levels of acceptability, which assume the support of artificial light.

7.3.2.3 Predicted Average Daylight Factor (ADF) Using Computerised and Manual Methods

The computerised method uses the value reported for the VSC to calculate an equivalent angle of obstruction and this is inserted into the formula provided by the BRE in the guide to site layout planning for daylight and sunlight (Littlefair 1991). The ADF is the average illuminance internally, divided by the unobstructed illuminance externally and multiplied by 100% and it can be calculated as follows:

The diffusible visible transmittance of glazing multiplied by the net area of the window multiplied by the angle of visible sky measured at the face of the window (which is obtained using the VSC and checking the table in the guidance notes) divided by the total area of the rooms internal surfaces multiplied by one minus the average internal reflectance, squared and expressed as a percentage.

The formula is expressed as $Df = TA_w\theta/A(1-R^2)$ %.

Where,

T = the diffuse transmittance of the glass including corrections for dirt on glass and any blinds etc.

A_{w} = the net glazed area of window

θ = the angle of visible sky in degrees taken from table C1 in the guide

A = the surface are of the room, walls, floor, ceiling

R = the average reflectance

In this case, the result reported by the computer was 2.33%.

The manual method is identical to the computerised method but the VSC used was that calculated using the modified Waldram diagram.

The values used are as follows:

T = 0.8

A_{w} = 0.96

θ = 74 (taken from table C1 in the guide)

A = 60.12

R = 0.78

The resulting daylight factor when these values are imported into the formula

$Df = TA_w\theta/A(1-R^2)$ % is: 2.41%.

By any standards the results for the computerised and manual methods are very comparable and demonstrate the similarity of the calculation process. The results are also comparable to those obtained by practical measurement, although the figure of 2.9% is 20% to 25% higher than that obtained through the calculation process which suggests the possibility that there may have been some errors in the process which need to be checked in the artificial sky dome.

7.3.3 Century House Artificial Sky Dome Results

The final piece of this part of the experiment was to attempt to reproduce the daylight factor result in the artificial sky dome.

The model and obstructions used were built to a 1:40 scale, which was the largest that could be achieved and still fit within the artificial sky dome.

In each case, a series of readings was taken for each location, at the scale height of 850 mm above floor level and with no window glazing, and the average of these readings was calculated. A check reading was then taken to compare against this. Once these readings had been completed the experiment was repeated with glazing and for the various conditions mentioned above and, additionally, without the obstructions to assess the effect.

Despite using a smaller sized sensor within the model, it was nevertheless relatively large. For this reason only four readings were taken, one in each quadrant of the room and a fifth reading in the centre to compare later with the new mathematical model.

Using this methodology, the average for the room without glazing was 5.78 and the average with glazing was 2.69, a reduction of 53%, which is reasonably close to the reduction noted previously.

More importantly, the value of 2.69 falls between the values of 2.33 and 2.41, from the calculation process and the value of 2.9 obtained through the practical measurement on site. On enquiry with the BRE it appears that their methodology does produce a slight underestimate of the values in some circumstances. (Littlefair 2007)

At the time of undertaking the experiment it was anticipated that the readings, with the obstructions removed, could be used for comparative purposes but this has not been necessary and in any event, could not be replicated on site.

readings with obstruction (no glazing)						readings with glazing	blacked out no glazing
location	1st set	2nd set	3rd set	average	check readings	Average	Average
1	11.5	11.85	11	11.45	10.5	5.5	8.5
2	6.75	6.75	6.5	6.67	6.5	3.0	4.5
3	3	2.75	2.5	2.75	2.5	1.25	0.5
4	2.25	2.5	2	2.25	2.25	1.0	0.5
5	3.5	3.5	4.25	3.75	4	1.75	1.5
Average of Readings 1 to 4				5.78		2.69	3.5

Table 7.07 Readings in Artificial Sky Dome with Obstructions

readings without obstruction (unglazed)						readings with glazing	blacked out no glazing
location	1st set	2nd set	3rd set	average	check readings	Average	Average
1	12.25	12.5	11.5	12.1	12.0	6.0	10.5
2	9.0	10.0	9.25	9.4	9.5	4.5	8.5
3	3.25	3.75	3.5	3.5	3.5	1.5	3.5
4	3.25	3.5	3.5	3.4	3.5	1.5	3.5
5	6.75	6.25	6.25	6.7	6.5	3.0	6.0

Table 7.08 Readings in Artificial Sky Dome without Obstruction

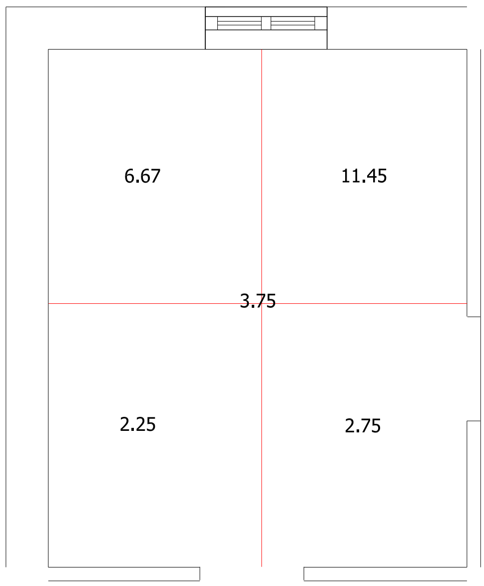


Figure 7.07 Average Readings in Artificial Sky Dome with Window Open

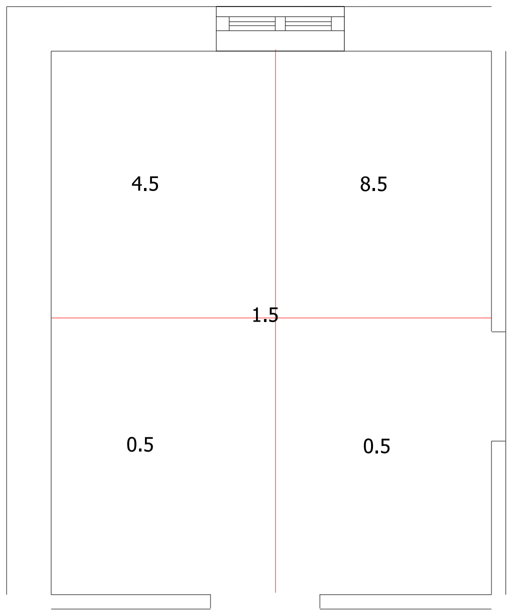


Figure 7.08 Average Readings in Artificial Sky Dome with Surfaces Blacked out

With the readings in the sky dome providing a reasonable comparison with those obtained in the field, i.e. the average readings unglazed being 5.78 and 6.29 respectively and with the window closed, 2.69 and 2.9 respectively, the further experiment involving blacking out of all the internal surfaces and removal of the glazing, to measure the sky factor, was expected to provide a reasonable comparison with the theoretical model produced by using the Waldram method.

Previously it has been demonstrated that the loss attributable to the window was around 53% to 54% in the sky dome and on site. By comparing the two sets of readings without glazing and on the one hand the internal surfaces replicating those on site and the other with the surfaces blacked out it is possible to determine the effect of internal reflection. However, to assess the benefit of internal reflectance it is not possible to use a comparison of the average percentage gain, through reflectance, for the room as this would produce a complex result with a range of increase from 135% at the front to 550% at the rear.

In this instance, by using the readings at the single point 5, at the centre of the room, it can be seen that the benefit of internal reflectance, without the glazing is to increase the illuminance in that location, from 1.5 to 3.75, an increase of 250%. If this factor is applied against the loss caused by the window/ glazing then the reading of 1.5, in the room without glazing and blacked out, would be expected to become 1.76 ((1.5 – 1.5*53%)*250%), with glazing and replicating the internal finishes of the original room. The actual reading was 1.75.

It is acknowledged that there is the possibility that the plastic film which was used in the modelled window did not exactly replicate the double glazing in the room, possibly not causing as much loss as the real window and that the internal reflectance, being higher than average might affect the results. There is, however, the possibility that, in an average room, the loss through the window might be balanced by the gain through internal reflectance and thus there is an indication that the principle of measuring the sky factor as opposed to the daylight factor might give a reasonable approximation of reality, provided that the measurement of the sky factor is based upon the same sky model as that in the sky dome.

In experiment three, the fundamental basis for the theoretical assessment of the sky factor is examined by comparing the present method assuming a uniform sky with the results obtained using a CIE sky model.

7.3.4 Other Century House Field Results

7.3.4.1 Lux Meter Readings

The initial purpose of these measurements was to determine the practicality of the process using a single Lux meter and to gain an indication of the likely levels involved and the impact of the external obstruction. Given the variations in weather patterns over the period, the external values varied over a wide range and thus the internal readings could not be accurately converted to a daylight factor. For this reason it was deemed preferable to use the Megatron. There were, however, three useful purposes to the data obtained; firstly to assess the reduction caused by the window (for comparison with other measurements taken), secondly to assess the change in illuminance levels when the datum is 750 mm above floor level as opposed to 850 mm above floor level and thirdly to verify the pattern of illumination within the room.

The loss through the window can be demonstrated by the difference between two sets of readings taken at 850 mm above floor level with the window open then shut.

location	850 window shut (Lux)	750 window shut (Lux)	850 window open (Lux)	750 window open (Lux)	% Decrease with window shut	% Decrease with window shut
					850	750
1	20	11	39	22	48.72%	50.00%
2	40	14	68	26	41.18%	46.15%
3	324	11	402	22	19.40%	50.00%
4	15	10	28	20	46.43%	50.00%
5	49	43	98	72	50.00%	40.28%
6	150	99	320	139	53.13%	28.78%
7	84	157	127	250	33.86%	37.20%
8	39	36	76	104	48.68%	65.38%
9	42	31	91	70	53.85%	55.71%
10	27	40	54	131	50.00%	69.47%
11	35	56	103	142	66.02%	60.56%
12	28	41	49	130	42.86%	68.46%
13	20	18	48	43	58.33%	58.14%
14	24	17	50	57	52.00%	70.18%
15	22	19	45	53	51.11%	64.15%
16	18	24	40	61	55.00%	60.66%
17	10	15	21	30	52.38%	50.00%
18	12	16	21	31	42.86%	48.39%
19	13	18	24	34	45.83%	47.06%
20	14	20	25	35	44.00%	42.86%
Average					47.78%	53.17%

Table 7.09 Reduction Caused by Window

Using this set of readings the average reduction of 47.78% is not too dissimilar to the reduction measured in the artificial sky dome and on site using the Megatron. Bearing in mind the variable sky conditions during the measurement process, this is a reasonable indicator although it is acknowledged that there is a variance across the series.

It is worth noting that the same set of measurements at 750 mm above floor level produce an average reduction of 53.17%. Given the inherent inaccuracy of this method of measurement, it is not possible to be definitive but the indication is that by reducing the height of the datum, in this room, there is a 10% increase in the loss resulting from the window being closed. The most significant increase in loss is close to the window where the reading at the front wall falls below cill level.

It is possible to check this by using the average of the readings taken over the whole period with the window open or shut and at each datum level.

Location	Averages 850 Window Open (Lux)	Averages 750 Window Open (Lux)	Averages 850 Window Shut (Lux)	Averages 750 Window Shut (Lux)
1	58	69	60	35.5
2	253	88.5	91.33	42
3	811.75	69.5	778	35.5
4	97	62	44.67	35
5	194	255.5	135.67	131.5
6	368.25	308.5	236.67	169.5
7	376.5	448	282	228.5
8	169.75	219	138	103
9	158.5	177	125.67	85.5
10	178.25	213	126.33	110
11	227.75	256.5	171	113
12	152.75	296.5	103.33	110.5
13	87.25	130	88	59
14	104.75	180	97.67	68.5
15	112.25	215	99	79.5
16	103.5	217.5	66	52
17	67.5	118.5	64.67	52.5
18	79	150.5	67	13
19	79	157.5	58	44
20	76.5	142.5	57.67	40
Average	187.76	188.73	144.53	80.4

Table 7.10 Comparisons of Average Readings at each Datum Level

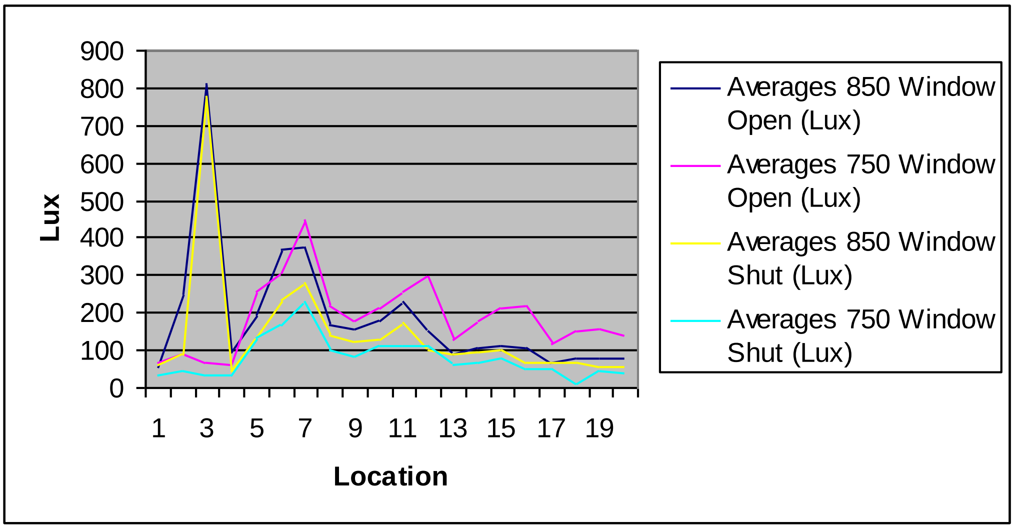


Chart 7.03 Comparisons of Average Readings at each Datum Level

Analysed in this way, it is suggested that in fact the difference in measurement between the two datum levels, with the window open, is minimal but with the window closed, there is a significant reduction again most noticeable at the front of the room under the window cill. If this set of readings is eliminated, as can be seen in chart 7.03 above, the remainder of the readings are relatively consistent with an average of around 27% reduction between 850 mm and 750 mm with the window shut.

It is important to recognise that these values are an indication only and would only apply in this room but that, when measuring a real room in a real case, using the correct datum level for assessing illuminance may be significant.

7.3.4.2 Check of CIE Overcast Sky Model

The CIE sky is a set of theoretical sky models. The version that is used most commonly for daylight calculations is the standard overcast sky referred to in previous chapters. During the site readings taken at the BRE, there was an opportunity to take one set of readings of sky illuminance in an open field on a relatively overcast day, for two bearings; east and south east. The readings were taken in the early afternoon and thus may have been affected by sun to the south as will be seen by the readings. Despite this, it can be seen that the readings to the east, away from the sun, do bear a similarity to the predicted results in table 7.11 below. It was not possible to take readings to the north or west owing to physical obstructions and there was insufficient time or resources to investigate the CIE sky further. For this reason, reliance has been placed on others in using the CIE model as part of experiment three.

Altitude in degrees	East (Cd)	South East (Cd)	Predicted based on CIE (Cd)
90	2.9	9.1	2.0
80	1.8	5.7	1.98
70	1.35	3.9	1.92
60	1.25	3.1	1.82
50	1.1	2.75	1.69
40	1.1	2.95	1.52
30	1.15	3.0	1.33
20	1.05	2.6	1.12
10	0.6	1.6	0.90
0	0.3	0.8	0.67

Table 7.11 External light values checking CIE

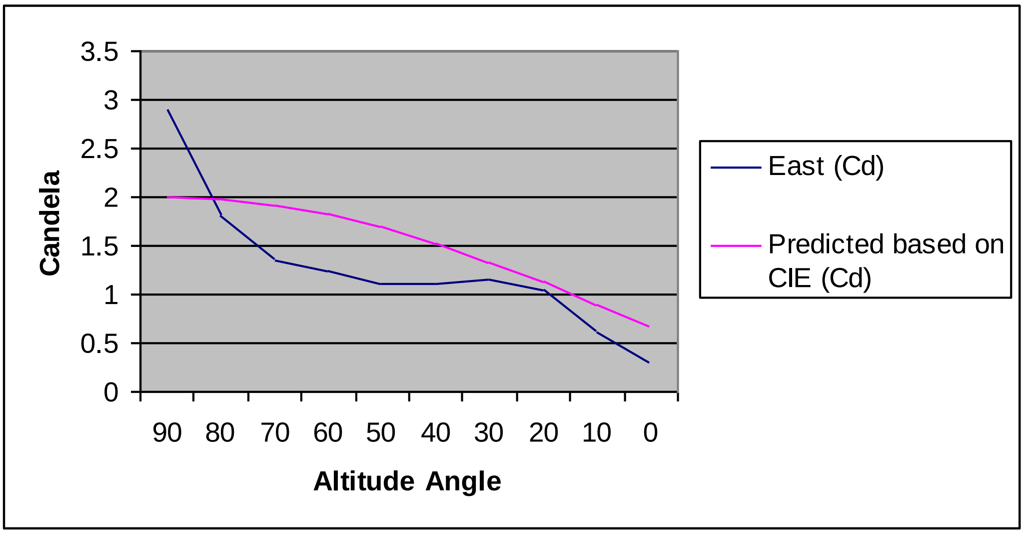


Chart 7.04 Comparison of CIE Sky predictions with readings taken towards East

It is assumed that, for the most part, readings to the north will be slightly lower than those to the west or east and significantly lower than those to the south. This is supported, in part, by the research by Littlefair, which is described in chapter four.

7.4 Experiment Three

Using the formula derived from the CIE sky and Lambert's Cosine Rule, a modified Waldram Diagram can be created, which can then be used to compare the results, which are obtained with a uniform sky against those obtained with an overcast CIE sky, which represents a more realistic situation.

It is important, when creating the diagram, to insert the equivalent angle into the formula established in chapter 6 and not to just multiply the two formulae together.

Thus the formula established in chapter 2 for the equivalent angle,

ATAN(TAN(α*PI()/180)*COS(β*PI()/180)), provides the equivalent angle 'θ' below in the CIE Lambert formula:

p=(-1/2 cos^2(θ)+1/2 sin(θ) -1/6sin(3θ)+1/2).

The table of results appears at appendix 5, which were created in a Microsoft Excel Spreadsheet. Figure 7.09 below is the chart which results from this data and this can be compared directly with the original Waldram Diagram prepared using the same methodology in Figure 7.10. (Manescalchi 2007)

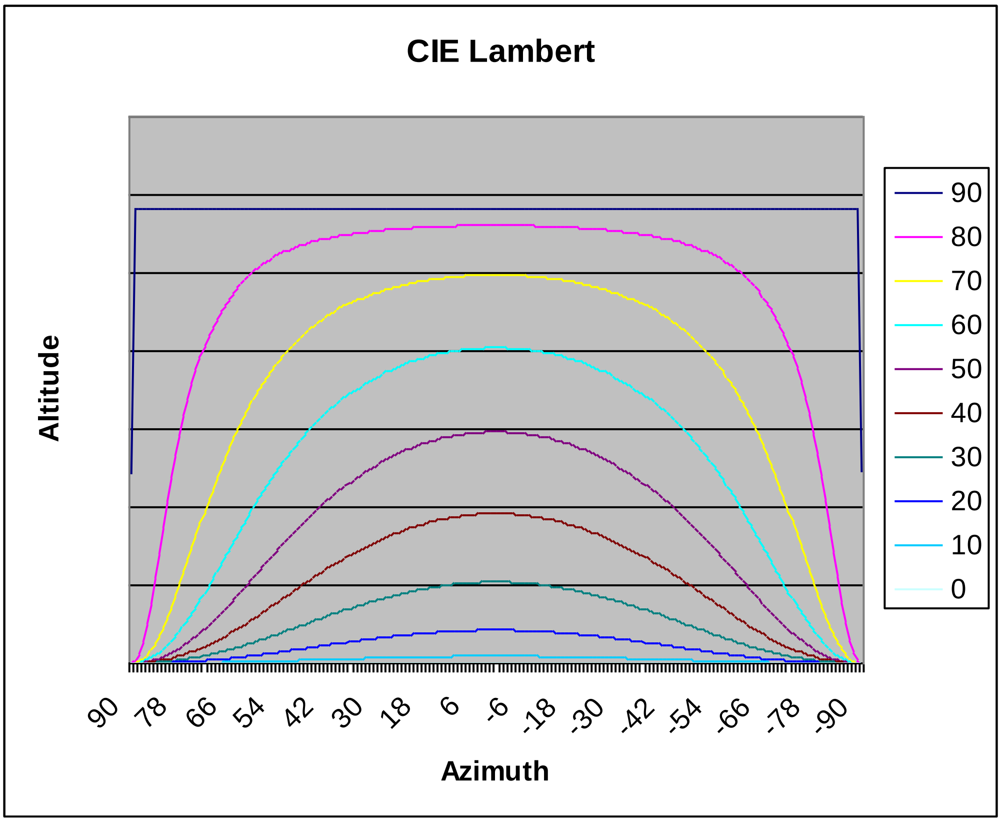


Figure 7.09 Modified Waldram Diagram Using CIE and Lambert Factors (CIEL)

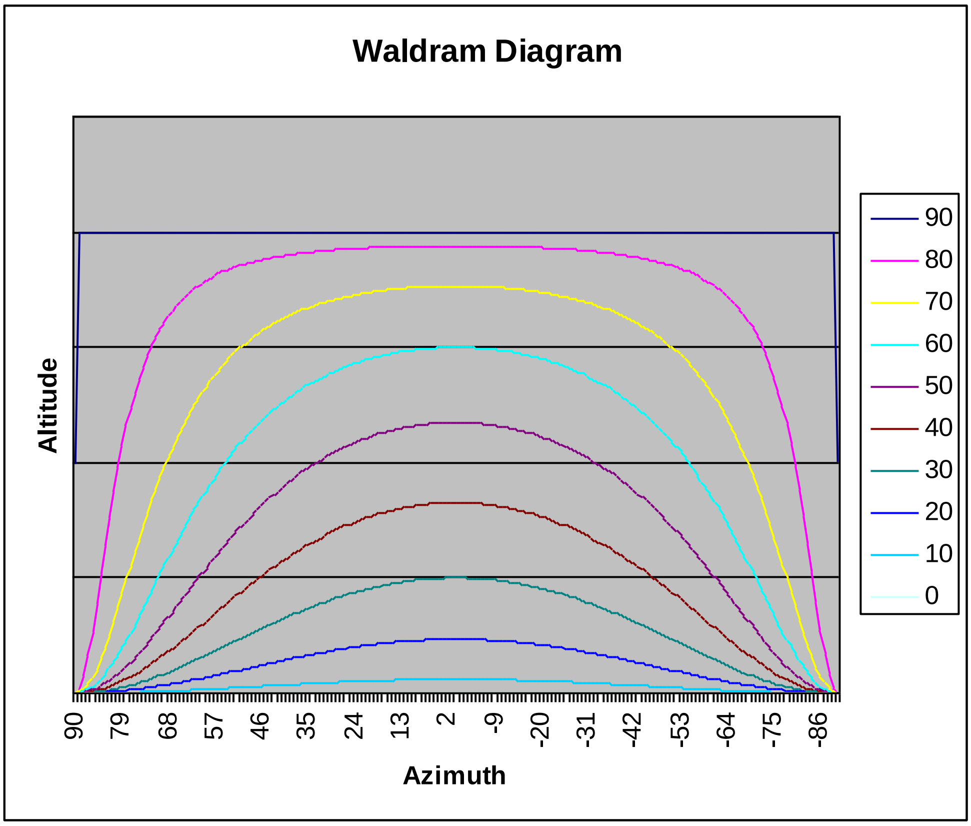


Figure 7.10 Original Waldram Diagram

The modified (CIEL) diagram still shows the reduction in space between lines of altitude close to zero and close to 90 degrees altitude but the diagram is no longer symmetrical around 45 degrees with a general bias towards light from the higher altitudes.

The significance of this is that the light from lower altitudes, which normally penetrates furthest into a room, will have a lower value than that predicted by Waldram. This might have an impact on decisions made where the 'well lit' area is close to the borderline, 50% of the room, which is used by surveyors when advising clients. It would probably not affect the relative results to any great extent. Thus a loss of light to 1 square metre of floor area, as a result of a development, using the Waldram method would probably still be 1 square metre using this alternative method since all other factors will remain constant. That is to say, the same diagram will be used for both before and after and thus the relative areas of window and obstruction will remain in direct proportion to each other.

7.5 Triangulation

The purpose of triangulation in this context is to determine whether the actual physical measurements taken on site and in the artificial sky dome bear any relationship to the predicted results using the Waldram method or the BRE/ BS methods and how this may be predicted on a theoretical basis.

Each of the average daylight factors from the above experiments can be related to a 5,000 Lux sky in that they each represent the ratio of internal to external illuminance and from this it can be seen, in table 7.12 that the physical measurements are consistent and higher than the theoretical measurement using the BRE/ BS method.

Comparison of ADF Results with glazing in (%)		**Equivalent Average Lux±**
ADF Site	2.9 ± 0.25	145 ± 12.5
ADF Sky Dome	2.69 ± 0.25	134.5 ± 12.5
ADF Computer	2.33	117
ADF Manual	2.41	121

Table 7.12 Comparison of theoretical and practical ADF

On site the average Lux Meter readings, with the window open, were very similar for both heights of measurement. The results were noticeably lower with the window shut and more so when measured at only 750 mm above floor level as illustrated in table 7.10.

Parameters	**Lux**
850 Window Open	188
850 Window Closed	145
750 Window Open	189
750 Window Closed	80

Table 7.13 Average Site Lux Meter Readings

The readings at 850 mm with the window closed are very close to the ADF for the site in table 7.12 above but this is most likely coincidence since the measurements were subject to vagaries of the weather, i.e. there is no adjustment for external illuminance, and they should therefore be regarded as an indicator and no more.

The importance of the measurements taken in the sky dome are that the physical site measurements can be verified and that the model could be changed to ascertain what varying conditions would produce as a result.

The results for both glazed and unglazed conditions (table 7.14) and matching the internal and external conditions with the site are close enough to be considered reliable. On this basis the measurements for the situation when the internal surfaces were blacked out and the window unglazed can be considered to be reliable and it is these results which, if Waldram were correct, would be the same as those obtained by using the Waldram methodology.

Table 7.14 also shows the increase in illuminance that would occur with the removal of external obstructions.

Sky Dome Readings at Point 5 (% DF)		**Equivalent Average Lux±**
unglazed	3.75 ± 0.25	188 ± 12.5
glazed	1.75 ± 0.25	87.5 ± 12.5
black unglazed	1.5 ± 0.25	75 ± 12.5
Without obstructions		
unglazed	6.7 ± 0.25	335 ± 12.5
glazed	3.0 ± 0.25	150 ± 12.5
black unglazed	6.0 ± 0.25	300 ± 12.5

Table 7.14 Readings Taken in Artificial Sky Dome at Point 5

From this, it would be expected that, using the Waldram method, the room would have an Illuminance, at the centre of the room, of 75 Lux or 1.5% of the sky dome.

The 0.2% contour line, using the Waldram method above, enclosed an area of approximately 4 square metres out of the room total of 11.8 square metres thus the average for the room will be above 0.2% and the room would be expected to be well lit and this is borne out by the various measurements taken and by the researchers subjective appreciation.

However, from figure 7.11 which was produced using the Waldram method, it can be seen that the 1% and 1.5% contour lines enclose somewhat less than half the area of the room and that both contours occur in front of the central point in the room. Thus the Waldram method actually produces a lower result than the practical experiment would suggest.

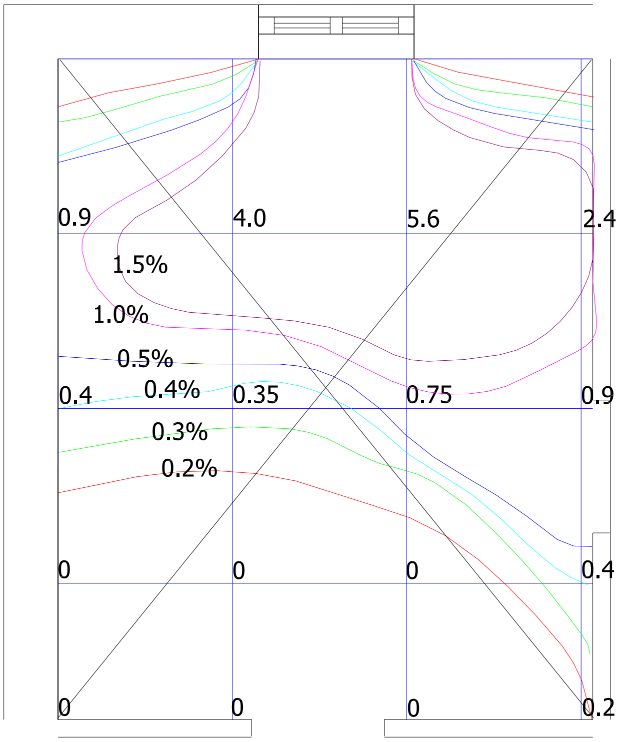


Figure 7.11 Plan Showing Contours Using Waldram Method

If, instead of using the Waldram Diagram, the CIE Lambert Diagram is used, the results might increase and possibly replicate the results of the physical experiments. The Plan at figure 7.12 below uses the chart at figure 7.09 to reproduce the results for each grid point. The approximate contour lines are shown for 0.2%, 0.3%, 0.4%, 0.5%, 1.0% and 1.5% and, from this, is can be seen that the 1.5% contour passes very close to the physical centre of the room.

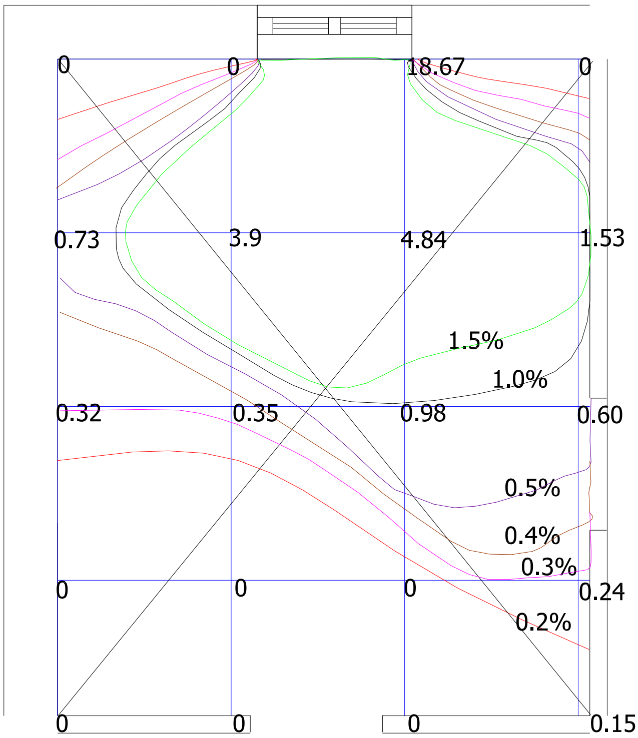


Figure 7.12 Contour Lines Produced Using CIE Lambert Method

It should be noted that the 0.2% contour is not significantly different to the Waldram method in terms of floor area enclosed, although the shape of the contour differs, but that the central value of 1.5% is closer to replicating the result from the artificial sky dome and thus demonstrates that the new chart is probably a valid representation of the situation where the internal reflectance and window are ignored.

The jury result showed that a value of 30 Lux was considered to be the minimum acceptable level of illuminance for a satisfaction rate of 80%. This compared with the CIBSE/ BS minimum levels for living rooms and kitchens of 25 Lux and 30 Lux respectively (using a 5,000 Lux sky). These values would lie in the contour range of 0.5% to 0.6% in Figure 7.12 which would approximate to 50% lying in front of the contour and 50% behind which, in this instance, would not be dissimilar to the result using the Waldram method.

On face value this would appear to justify Waldram, albeit with a slightly amended formula. It should be noted however that the resultant illuminance is dependant upon the internal reflectance and the transmission through the window. Less reflectant internal finishes and/or poorer transmission through the glazing would produce commensurately lower results.

If the design of the measuring process should be such that it operates irrespective of the conditions within the room then the minimum acceptable illuminance should be evaluated on the basis that there is no internal reflectance and simply use the sky factor. If transmission losses, through the glazing, were to be considered then this would have the affect of reducing the illuminance but, just as internal reflectance is variable, different glazing or dirty glass would introduce variables (British Standards Institution 1992) that would make the calculation process unmanageable. In fact the purpose of the calculation is one of comparison i.e. between a predicted value before an obstruction is constructed and afterwards. Thus if these values are constant between the two measurements, they become irrelevant.

The results in experiment 2 suggest that there is a real possibility that the value of internal reflectance compensates for the losses through the window sufficiently closely that a reasonable approximation can be obtained by ignoring both.

It is also pertinent to consider whether it is sufficient that the illuminance value, of 25 to 30 Lux, should represent the value in the centre of the room, the average value or the minimum value.

The case law referred to in Chapter One, whilst not absolutely clear, appears to be leading towards the assumption that only half the room needs to be sufficiently lit i.e. benefiting from an illuminance greater than or equal to the minimum acceptable level. This simplifies matters considerably in that there is no requirement to calculate the average illuminance in the room, which could vary considerably as is explained below:

If it were assumed that 50% of the room benefited from 0.2% or more and that the minimum value would, nearly always, be zero then a maximum value of 0.4% might be argued, theoretically, to produce the average required. However this is never the case. The 'no sky' line is almost never at the back of the room and thus an area of the room will have zero sky factor, rather than just a line on the back wall, and the highest values may well exceed 0.4% by several factors making the average for the room indeterminate.

For example, in the room used in experiment 2 and using the traditional Waldram method, 50% of the room receives approximately 0.5% or more sky factor but the average for the room is 1.94% $\pm$ 0.5 and this a room of simple shape with a single window. The same room using the CIEL sky model produces an average sky factor of 2.12% $\pm$ 0.5.

If it were decided that the required level of illuminance should be the average for the room then any calculation process would have to assess the whole of the room in much the same way as the Average Daylight Factor calculation is produced and this would lead to difficulties in assessing the value of the loss. Should it be, for example, a percentage of the floor area based upon the percentage reduction in sky factor?

It should be noted that, in the examples given above, a room where 50% of the floor area receives 0.5% sky factor and has an average sky factor of around 2%, could have significant obstructions placed in front of the window before the average for the room comes down to 0.5%. On this basis it can be said that using the derived value as an average for acceptability will almost certainly result in a worse lit room than where the derived value is the minimum for at least 50% of the room.

Whilst the results, for the room examined, appear close between the Waldram method and the proposed CIEL method, it must be appreciated that, in a different, more complex room, there may be more significant differences and, as has been mentioned previously, where the result of the difference would be to move the contour line beyond the acceptable limit, that this could be significant to the client or to the court considering the case. For this reason, the proposed CIEL diagram should be used as it more closely represents the sky conditions and the effect of Lambert's cosine rule.

The difference in values resulting from a change of datum level only become significant where, as in the room studied, the readings fall below window cill level but here too, the most accurate representation of reality is to measure at work surface level and not the generally accepted 850 mm above floor level as is currently the case.

7.6 Summary

The result of experiment one, when taken into context with the standards applied by CIBSE/BS, demonstrates that 1 foot-candle (10 Lux) is not considered to be acceptable for ordinary use and that the level is more likely to be around 2.5 – 3 foot-candles (25 – 30 Lux).

Experiment 2 provides an indication that it may be valid to ignore windows and internal reflectance in that these introduce compensating gains and losses of illuminance, which may, in some rooms, be close to unity.

Finally, experiment three demonstrated that it is possible to produce a diagram using the CIE overcast sky model which generates a result which is close to that obtained in the artificial sky dome.

In the subject room, at least 50% of the room receives light from 0.5% of the skydome represented by the CIE Lambert Diagram and thus the room in figure 7.12 would be considered to be adequately lit.

In the next part these results are drawn into the conclusion and recommendations for further research.

Part D
Conclusions and Recommendations

Conclusions and Recommendations

An entitlement to 'sufficient light' for the comfortable use and occupation of a dwelling house, or for the beneficial use and occupation of business premises, 'according the ordinary notions of mankind'

Lord Lindley, *Colls v Home & Colonial Stores* [1904] AC 179, HL

8.1 Introduction

In earlier chapters the historical and legal bases of the methodology for calculating availability of daylight in 'Rights to Light' cases has been examined and the hypothesis put forward that this methodology is not valid and requires reassessment. The conclusion of this research is that this is the case and, within this chapter, these conclusions are set out with an explanation of the limitations of the research to this point and recommendations for further research.

It has however been established that any substitute methodology would need to be able to produce results which are capable of being used in both negotiation of compensation and advice to the court. It is proposed, therefore, that the daylight calculation should be undertaken, in future, using a CIE overcast sky model, accounting for Lambert's formula and that the readings should be taken at work surface level (approximately 762 mm in most cases) rather than the current level of 850 mm. 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.

8.2 The Present Position

It is accepted by most 'Rights to Light' practitioners that the procedure devised by Waldram during the early twentieth century was the first convenient way to measure the relative value of the light from the sky, for use in 'Rights to Light' cases and 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. (Chynoweth 2005) (Pitts 2000)

The concern amongst many practitioners is that the method of calculation of daylight in 'Rights to Light' cases is no longer valid (Chynoweth 2004). 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.

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 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 a uniform sky and that the value of the light received from the skydome is 500 foot-candles and that therefore 1 foot-candle of light is provided by 0.2% of the skydome and that, provided 1 foot-candle 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 is upon this basis that practitioners advise the Court or negotiate compensation, but analysis of available case law suggests that the Judges frequently prefer their own or alternative assessments.

8.3 Review of Existing Methodology

The Waldram method is a theoretical rather than an exact representation of the illuminance provided by the sky. In using the diagram there are numerous possibilities for error through the manual process, which means that the results are only ever an indication of what the illuminance in a room might be. There is therefore the possibility of an injustice occurring if the illuminance level is set too low and/ or the error margin might make the loss either actionable or not actionable.

Whilst most computerised methods for performing the calculation do not use the Waldram diagram, they still measure the value of the area of skydome visible at each point, based upon this methodology, and this thesis has examined the following assumptions used in the Waldram methodology:

- that the total amount of light provided by the Sky Dome should be assumed to result in an illuminance of 500 foot-candles (5,000 Lux) to an unobstructed point on the horizontal plane,
- a Uniform Sky can be assumed for the purposes of these calculations,
- Lambert's 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 foot-candle (10 Lux) of illuminance over 50% of the room is adequate,
- it is appropriate to ignore window frames and glazing, and
- internal reflectance should be ignored

8.3.1 The Appropriateness of Assuming an Illuminance from the Sky Dome of 500 Foot-Candles (5,000 Lux)

There are many examples of publications where Waldram, and others, have referred to the value of illuminance from the sky being assumed, for the purposes of 'Rights to Light' calculations, to be 500 foot-candles (Anstey 1963), (Paterson 1928), (Waldram 1928). There is also considerable evidence available from respected commentators, over the years, which confirm the doubts that this assumption is correct. (Chynoweth 2004 and 2005), (Pitts 2000).

Waldram (1925;p14) 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.

According to his tables, the diffuse illuminance value of 500 foot-candles, or approximately 5,000 Lux was exceeded over 83.5% of the year at Bracknell and 84.1% of the year at Kew.

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, confirmed that the outdoor illumination from the whole sky, at that time, varied between a value of less than 500 foot-candles in December to about 3,750 foot-candles in June or July). This appears to confirm the use of 500 foot-candles as a reasonable minimum level of availability.

Hunt (1979) 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) and which showed the diffuse illuminance value of 5 Kilolux being achieved for in excess of 85% of the year.

Littlefair (1984; pp 44-45) 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 foot-candles. 500 foot-candles was achieved for 85.7 percent of the time.

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 foot-candles standard would appear to be justified although it is in fact neither a minimum nor an average.

8.3.2 The Validity of the Use of the Uniform Sky Model

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

Waldram (1925; p5) had already 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 argued 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 but his diagram appears to give more value to the light at about 45 degrees altitude.

He justified his use of the uniform sky in the section of the paper entitled 'Principles of Measuring Daylight', (Waldram 1925), where it is stated 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. This seems to be an expression of the limitations of the measuring equipment available at the time rather than a factor, which might affect the evaluation of sufficiency.

Anstey (1963) assessed the value of light from the sky and concluded that the value of sky brightness varied by angle of altitude in a manner not dissimilar to the CIE sky, which predicts that the luminance at the zenith will be three times that at the horizon. 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 illuminance and that this might be significant. (Defoe 2007b)

Littlefair (1991) concluded that the sky luminance is more stable under heavily overcast conditions and that as a consequence the CIE model of the overcast sky should be used for daylight calculations as it gives a good approximation of a uniformly and heavily overcast sky.

Whilst there is no direct evidence, it does appear that the uniform sky was adopted by Waldram and others as a mathematical simplification that may be no longer justified on the basis that the CIE sky represents a more realistic situation than the uniform sky and also that computers can be used to model even the most complex of skies.

8.3.3 The Adjustment to Account for Lambert's Formula and the Sky Dome

Waldram (1925; p5) acknowledged that in towns the zenith sky is nearly always brighter than sky nearer to the horizon, but his recommendation of an adjustment to the value of the light from the sky at various angles of altitude does not appear to have considered this. Instead the adjustment, which he used, is stated to have been based on the reduction in area of the sky dome with altitude and on Lambert's formula, which recognises that diffuse reflection redirects light equally in all directions but giving higher values with increasing altitude of the source.

There is doubt that the Waldram adjustment does actually use Lambert's formula which is usually stated as **E = p E0cos(θ)**, whereas the Waldram adjustment is usually given as **1-cos2 θ** and this is the formula also derived by Walsh (1961) with his 'Unit Sphere Principle' which makes no reference to Lambert's formula.

According to both Walsh and Waldram, the contraction at the bottom of the chart 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, (Lambert's Formula) 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.

The rationale behind the adjustment to the upper altitudes on the chart is that the representation is on a flat piece of paper as a rectangle. If it is desirable to represent the diagram as a single rectangle with all areas of equal value then it would be wrong to just 'stretch the points apart. To maintain the equality of area, the height of each part has to be reduced. 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.

In experiment three the use of the CIE (Overcast Sky) model, rather than the Waldram (Uniform Sky Model), in combination with Lambert's Formula, has produced an alternative diagram for the calculation of the 'sky factor'. This new diagram, when used on the Century House model, produces a different, although similar, assessment of the 0.2% sky factor contour to that produced using the Waldram diagram.

By comparing the daylight factor measured in the room on site, in experiment two, with that measured in the artificial sky dome, to ensure that the model is a true representation of reality and then changing the internal finish of the model in the artificial sky dome to eliminate the internal reflectance, it was possible to measure only the illuminance attributable to the sky factor and to compare this with the predicted contour using the CIE Lambert diagram. The reading at the centre of the model was 1.5%, which closely matched the value of the contour line passing through the centre of the room. The readings taken in each of the quadrants 1,2,3 and 4 are also similar to the contour values for those areas although this is harder to prove with the limited number of grid points used for the manual analysis but nevertheless it is suggested that the CIE Lambert diagram, when used on this room, produces a reasonable approximation of reality.

8.3.4 The Adjustment of the Chart to 20 Units in Height and 25 Units in Width

Waldram's original chart did not address 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.

The original diagram always appeared to be twice as wide as it was high representing 180 degrees wide and 90 degrees high. The later version was originally drawn as 25 inches wide and 20 inches high, which, at 500 square inches could be overlaid with a one-inch grid.

When a window or obstruction is plotted onto the Waldram diagram it occupies an area proportional to the area of the chart. 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 rather than using the ratio of window to chart area. (Defoe 2007b)

8.3.5 The Height of Work Surface Assumed To Be 850 mm

Littlefair (1993) quoted the accepted practice of measuring the daylight factor and stated that the working plane should be at 850 mm above floor level for houses and factories and at 700 mm for offices whilst in 'Rights to Light' cases the level is always assumed to be 850 mm.

Most office desks, kitchen worktops and tables are generally at approximately 762 mm, in height; In addition, when using computers or reading, the surface being viewed is often nearer to the vertical than the horizontal.

There appears to be little justification for using a datum level of 850 mm and if one refers to the original research by Waldram and others for the Illumination Research Council, there is mention of their reading a copy of the Times and of working at a desk in offices that are now part of the Ministry of Defence (Waldram 1923), (Taylor 1931). If as appears 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 could not be applied in the same way.

Experiment two demonstrated that the height of the window cill had a significant affect on some of the results when measurements were taken at 750 mm above floor level, as this was below the cill level. In relative terms, this would be insignificant if the same levels were used for both the existing and proposed conditions but in absolute terms there might be a significant disadvantage to the occupant where the illuminance levels will be different, and possibly lower overall than those at 850 mm above floor level. In practical terms the contour lines might change slightly and the 'well lit' area could move back into the room.

It is perhaps more relevant, when using Lambert's formula, to look at the affect that light falling on a surface has on the overall ambience of a room and in this sense it would still seem more appropriate to apply the formula to normal desk/ worktop height rather than 850 mm as this would more accurately represent the dispersal of light, from different altitudes, within a room. (Defoe 2007b)

8.3.6 Is the Illumination of One Foot-Candle (10 Lux) Over 50% of the Room Adequate for Normal Purposes?

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 and Lighting Engineers. Various bodies, including CIBSE and British Standards, have established what they believe to be adequate levels for lighting for various purposes but the results differ from those proposed by Waldram and, whilst psychologists all agree that daylight is necessary and opticians will advise that adequate lighting is necessary and that some of that lighting should be daylight, neither have stated how much is sufficient or required for ordinary use.

CIBSE and British Standards (CIBSE 1999) suggest a minimum daylight factor of 0.5% for Living Rooms with an average of 1.5% for the room, which, for a 5,000 Lux sky would translate as 25 Lux and 75 Lux respectively. This compares with Waldram's use, and the Court's interpretation, of one foot-candle, or approximately 10 Lux over half the area of the room as being sufficient.

Experiment one, in this thesis, was of limited scope but nevertheless indicated that that the lowest level of illuminance that is acceptable to a significant majority of the jury members was around 30 Lux. The number who felt that 10 Lux was sufficient for ordinary purposes was less than 20%.

It would be necessary to repeat this experiment with a larger population and under more controlled circumstances, with the involvement of specialists in ophthalmology and psychology, to achieve a definition of adequacy that would justify replacement of the current standard but there is sufficient evidence from this experiment to warrant a reassessment.

8.3.7 Window Frames and Glazing Should Be Ignored

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 upon the servient owner (the one wishing to cause a reduction in available daylight) 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. These factors will have affected the results of the original jury research but there is no direct evidence that any account was taken of this in the setting of the standard by Waldram.

In calculations of daylight for planning purposes, it is a requirement that the window frames and translucency of the glass be taken into account. Various computerised models use a 15% reduction for frames and 20% for glazing, as default values. The readings at Century House (table 7.04) and in the artificial sky dome (table 7.07) suggest that this is in fact an underestimate and that the loss should be closer to 53%. This would have a significant effect on the values being reported in 'Rights to Light' calculations, if it is assumed that there is no internal reflectance, but it would have no impact on relative reductions as each of these factors would be a constant.

In absolute terms there remains the issue that, where Waldram predicts an illuminance of 1 foot-candle, without considering internal reflectance, this would not be achieved due to the presence of the windows.

8.3.8 Internal Reflectance Should Be Ignored

Modern methods of calculating Daylight, as opposed to the methods used for 'Rights to Light' calculation, such as those that were set out in BRE Digests 309 and 310 in 1986 and then in BS 8206: Part 2 and The BRE digest by Littlefair (1998,) are used only for Planning and design purposes and are not considered to be valid in 'Rights to Light' cases. 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.

It is argued that the rationale for ignoring internal reflectance, in 'Rights to Light' cases, 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. (Defoe 2007b) Another possible viewpoint is that the measurement process should be valid whatever the internal finishes.

Whilst it is true that the calculations are intended to measure relative values and that thus the presence of constant factors such as glazing, frames and internal fixtures and fittings does not matter, the original research by Waldram suggests that he considered one foot-candle to be sufficient whatever the internal finishes or presence of window glazing and frame. On the basis of the results of experiment one, it is suggested that only by considering internal reflectance can the illuminance produced by 0.2% of the sky dome be sufficient for ordinary purposes. If internal reflectance is to be ignored then the required illuminance can only be achieved with approximately 0.5% of the sky dome being visible over half the room.

This is demonstrated in chapter seven where the value of internal reflectance at the centre of the room was to increase the illuminance by 250% and, on this basis, a 10 Lux (1 foot-candle) result using the Waldram method would, for this room, achieve an illuminance of 25 Lux, ignoring the effect of the window as mentioned above.

Thus, whilst 10 Lux might be insufficient in absolute terms, the illuminance within the subject room achieved with a sky factor of 0.2%, and no glazing, would not be far short of the level indicated by the jury as being acceptable. If, however, the internal reflectance values were not as good as those in the subject room then the illuminance would decrease in proportion to the reduction in reflectance. With glazing losses then there is no possibility that 0.2% will be adequate.

It should also be noted that the value of 30 Lux in the Jury experiment is also very similar to the minimum value recommended by CIBSE/ BS, for Living Rooms and Kitchens as noted above, i.e. 0.5% and 0.6% of 5,000 Lux or 25 Lux and 30 Lux respectively.

8.4 Summary

The illuminance provided by the Sky Dome is rarely as low as 500 foot-candles but this is a reasonable figure if it is intended to represent all but the most overcast of days. It also means that, for between 80% and 90% of the working year, the subject room will have an illuminance in excess of the minimum required. However, the sky providing the illuminance is far from uniform even on the days when it is overcast and the only justification for using a Uniform Sky appears to be mathematical.

The CIE overcast sky, whilst still only theoretical, provides a better model for assessment of available light from any given altitude. The limited experiment in chapter 7 shows that the range of values in the eastern sky are similar to those predicted by the CIE and whilst it is not possible to replicate the research undertaken by them it is acknowledged that the CIE model is widely used and is the basis for the design of artificial sky domes.

The use of Lambert's formula in the assessment of the value of light from the sky has a purpose in that it recognises the value of light from higher altitudes. The Waldram Diagram does not appear to recognise this and the value is modified by the use of a uniform sky, which overvalues the light at lower levels by comparison with the CIE overcast sky. For computerised systems, the value of the light at any altitude or orientation can be modelled much more accurately and requires no artificial adjustment factors but would be too complex if the model considered all possible variables. It is sensible therefore that a sky model such as the CIE overcast sky, be used.

Some concern has been raised that the Waldram Diagram was artificially adjusted and that this would affect the results. There appears to be no reason why, when using the Waldram Diagram, 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. It is logical therefore to use a diagram, which facilitates easy calculation. If the sky were deemed to have a value of 5,000 Lux then half the sky as represented on the diagram would have a value of 2,500 Lux and therefore the diagram could be covered by a grid of 2,500 equal squares, which might make for greater accuracy in the counting process, if the manual approach is to be used.

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 normal desktop or table height of about 762 mm then it would be legitimate to use Lambert's Formula to adjust the illuminance from the sky relative to its effectiveness at desk top level on the basis that the work surface or materials placed upon it would act as a reflector of light adding to the daylight factor within the room and this will affect the overall result.

Nowhere is there any justification in support of 1 foot-candle (10 Lux) being adequate for normal purposes. Even those commentators of the time, who may have been familiar with working by candlelight, disputed the adequacy of such a low level 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 when considering whether the lighting is sufficient although it makes no difference when considering relative reductions.

8.5 Recommendations

The client and the court are entitled to the best advice possible on the basis of current knowledge. This research has demonstrated the weaknesses in the existing methodology and, regardless of whether the calculations are undertaken manually or by computer, it is recommended that the daylight calculation should be undertaken using a CIE overcast sky model, accounting for Lambert's theorem, and taken at an average desk top height desktop height rather than the current level of 850 mm. It is further recommended 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 currently accepted 1 foot-candle (10 Lux or 0.2% Sky Factor). The implication of this latter measure is that many more properties will be identified as suffering an actionable loss than has presently been the case.

It is not possible to overstate the importance of adopting the new model for assessment. A number of court decisions over the years and discussed in chapter one have shown that the present methodology does not always find favour, when decisions are being reached by other means, which suggests that the courts do not rely upon the results of the calculation.

Even without accepting that the sky factor should be increased to 0.5%, the new diagram would result in a relocation of the 0.2% contour, which might not affect the measure of loss but may change the situation from one where the loss was not considered to be actionable, under the present system, to one that would now.

The change to a new standard of 0.5% over half the room area would be much more significant in legal terms and might necessitate a re-evaluation of advice given in recent times. For this reason alone there may be difficulty in gaining wide acceptance amongst practitioners and ultimately the courts. Recent discussions, in Structural Survey, (Pitts 2000; Chynoweth 2004; Chynoweth 2005; Defoe 2007b) have raised the profile of the issue and this must continue with open discussion by the experts. Ultimately, acceptance can only occur when a case reaches the court and a decision is made based upon the new methodology.

8.6 Limitations and Further Research

8.6.1 Limitations

It is important to appreciate the limitations of this study. The research undertaken of the primary literature resources was as thorough as possible but inevitably there may be resources which were not discovered and which might have provided another perspective. Nevertheless the volume of information retrieved and examined in chapters 1 and 2 has proven sufficient to justify the purpose of this research.

The jury approach, in experiment one, to assess sufficiency of illumination, should not be considered to be sufficiently controlled to provide the statistical certainty which would be necessary to convince the courts that a new standard ought to be adopted, despite the fact that it was more controlled than the original experiment reported in Technical Paper No.7 by Paterson (1928).

Whilst great care was taken in the measurement of the daylight factor in the artificial sky dome and on site, the need to move the sensor between each reading and to check the calibration of the Megatron meter on each occasion could have resulted in inaccuracy. There are other ways in which the measurement process could be improved and these are explored in the recommendations below.

The readings were taken in a single room having a simple floor plan, single window and relatively easily modelled obstructions. Further research would need to ensure that the results obtained are consistent when these factors are changed.

The CIE Lambert diagram resulting from experiment 3 was tested by comparing the theoretical results from using this diagram against the measured results in the artificial sky dome. The theoretical results are subject to the same inaccuracies as those identified in chapter three and the practical measurement in the artificial sky dome was limited by the small scale that was necessary to fit within the sky dome. In addition, it is only one example of a room and obstructions. It would be necessary to use the diagram to analyse further examples of rooms and to compare the results with real measurements to fully validate the methodology.

8.6.2 Further Research

From the limitations on the research identified above, it is possible to identify ways in which this research may be continued as well as some immediate changes that might be implemented by practitioners.

The experiments performed at Century House and in the artificial sky dome whilst valid, might not be transferable and it is important therefore to repeat the process with alternative rooms and models. In addition, the following are recommendations on the ways in which the measurement process can be improved:

8.6.2.1 Standard of Illuminance Required

To be able to justify what is potentially a higher standard of illuminance, it is essential that further research should be undertaken to confirm the amount of light that is necessary for ordinary use. The jury approach provides a subjective evaluation only and whilst the experiment is considered to be more valid than that performed almost a century ago, it can still be questioned on the basis that it did not represent the population as a whole and that the jury members may not have understood what was being asked of them. This research can only be performed satisfactorily by specialists in ophthalmology and psychology whereby the effects of low light values on a normal lifestyle can be monitored and evaluated.

8.6.2.2 On Site

Taking measurements at one-metre centres does not provide a sufficiently refined set of readings from which accurate daylight factor contours can be produced. A single reading at the centre of the room is as likely to produce a result, which compares with the Average Daylight Factor of the room as a whole, as taking an average of the individual readings. In addition, the need to check the calibration of the Megatron meter between each reading made the process cumbersome. If a track system could be devised it might be possible to take a continuous reading from one side of the room to the other, locating the points through the room where each 0.1% daylight factor was recorded. This track could then be moved laterally and the process repeated until the contours were defined numerically.

The readings within the room should all be taken at work surface level rather than 850 mm above floor level to ensure that the effect of Lambert's formula is properly represented.

A room in which the internal reflectance could be eliminated and the window removed would obviate the need to repeat the test in an artificial sky dome and increase the accuracy of the results.

8.6.2.3 In the Artificial Sky Dome

If an artificial sky dome is required to perform the research then it should be remembered that whilst small-scale models provide a useful function, in that factors can easily be changed to assess their impact, difficulties arises, as in experiment two, that there is insufficient space to replicate the readings taken on site.

It is important for 'Rights to Light' purposes that the obstructions are modelled accurately to scale and distance and this is difficult to achieve within a small artificial sky dome. A larger dome is required with sufficient space for the obstructions to be correctly placed and the room modelled at a scale of at least 1:20. In experiment 2, the size and distance of the obstructions meant that the largest scale of room that could be accommodated was 1:40.

Readings should be taken at the scale equivalent of work surface height. Therefore the cells need to be correctly sized. This should not be a problem if the model scale is large enough but would be at 1:40 where the cell depth is too great.

Here again, a mechanised process of measurement would be preferred and this would eliminate the need to open the model to move the sensor between each reading. The Megatron could be recalibrated at the end of each run.

The Beginning

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