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The Mathematization of Daylighting: a history of British architects' use of the daylight factor

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Abstract

British post-war planning guidance proposed that cities be rebuilt according to scientific principles. Mathematical tools were devised to determine built form; daylight levels within buildings were to be evaluated using a metric called the daylight factor. The daylight factor is still the principal metric used in daylighting guidance, despite recent calls to replace it with other metrics. This article explores whether the Modernist ambition, for buildings to be designed according to mathematically verifiable principles, was realised in relation to daylighting. Specifically, the article explores post-war architects' usage of the daylight factor in designing housing. The article draws on eleven semi-structured interviews with practising and retired architects, lighting consultants and a planning officer. Architects interviewed for the study reported that they did not routinely evaluate daylight factors at the design stage. Interviewees described the process as time-consuming, and often unnecessary as windows can be designed without undertaking a calculation or a photometric model study. Also, planning authorities rarely required architects to prove that proposed dwellings achieved specific daylight factors. However, those architects who were knowledgeable about daylight factors reported that this knowledge enhanced their understanding of the principles of daylighting. The daylight factor also helped to establish objective standards.

Keywords

Daylight factor; daylighting; standards; history

Introduction

British post-war planning guidance proposed that cities be rebuilt according to scientific principles. This is particularly evident in the series of Post-war Building Studies, commissioned by the Ministry of Works to prepare the UK building industry for post-war reconstruction.¹ The authors of the Study on *The Lighting of Buildings* were asked to 'review the scientific information... on the lighting of buildings' and to 'make recommendations for practice in post-war buildings'.² On its publication in 1944, one of the Study's key recommendations was that daylight levels in new buildings be evaluated using a metric called the daylight factor. Devised in 1895, the daylight factor is a measure of the illuminance within a room (usually on a horizontal plane), relative to the total amount of light that would be available under an unobstructed hemisphere with an overcast sky, expressed as a percentage. Incorporated into the British Standards in 1949,³ the daylight factor is still the principal metric used in guidance on daylighting.⁴

The perceived benefit of the daylight factor was that it permitted daylight levels within buildings to be 'assessed on a reasonably scientific basis', putting 'daylighting on a more rational basis than hitherto'.⁵ This ambition to use scientific knowledge to design buildings was not limited to daylighting, and reflected similar aspirations seen in the use of: scientifically generated building forms in the proposed redevelopment of Whitehall⁶; Newtonian mechanics to determine arterial-road layout in urban planning⁷; scientific management techniques to develop handbooks on ergonomics and efficient space planning.⁸

Some implications of the scientific method are revealed in the work of Edmund Husserl. In his final book entitled *The Crisis of European Sciences*, written between 1934 and 1937 and published posthumously,⁹ Husserl traced the emergence of rationalism and objectivity in European philosophy in order to demonstrate that the scientific attitude is a product of history.¹⁰ Husserl suggested that Galileo pioneered modern science by studying natural phenomena as if the world was written in a mathematical code that can be uncovered through scientific inquiry.¹¹ Husserl argued that following Galileo's work, mathematics became central to all scientific enquiry.¹²

While admiring of the achievements of science, Husserl was concerned that the world as experienced is very different from that described by mathematical formulae. To illustrate this problem, Husserl distinguished between morphological essences, for which there are exemplars (such as 'window') but which are not defined mathematically; and exact essences that are defined mathematically but which are ideals that can only be approximated in the real world (such as equilateral triangles).¹³ For aspects of the natural world to be subject to scientific enquiry, they must be described in exact terms, using statistics and precise measurements. This requires a process that Husserl called 'idealisation', in which the morphological is translated to the exact.¹⁴ Those aspects of the world that cannot be quantified are beyond the scope of scientific study.

We can see this process at work in attempts to describe daylight in quantifiable terms. Daylight levels within a room can be described in morphological terms (e.g. 'the room is well lit'), or in exact terms using metrics such as the daylight factor (e.g. 'the room has an average daylight factor of 2%'). The expression of daylight levels in exact terms is what distinguishes post-war guidance on daylighting from pre-war. The latter often centred on relationships between street widths and building heights, rather than quantifiable daylight levels within individual rooms. For example, British pre-war guidance on the preparation of planning schemes, issued to local authorities, specified that no new building should 'project above a line drawn from the centre of the street in front of the building at an angle of 56° from the horizontal'.¹⁵ Similarly, New York's 1916 Zoning Ordinance ensured that a building's bulk would be set back from the street as its height increased.¹⁶ Building-height-to-street-width measurements also underpinned Walter Gropius' influential analysis of housing density, in which he demonstrated that the angle of obstruction between well-spaced high-rise apartment blocks was significantly less than that for low rise residential buildings built to the same density.¹⁷

The introduction of daylight-factor-based standards represented a significant change in thinking on daylighting, but it is unclear what impact this had on architectural practice. This article explores whether the Modernist ambition, for buildings to be designed according to mathematically verifiable principles, was realised in relation to daylighting. Specifically, the article investigates how, since the introduction of the daylight factor, architects in England and Wales have assessed whether rooms in dwellings are likely to have adequate daylight, focusing on:

- Did architects think about daylighting in morphological or exact terms (to use Husserl's terminology)?
- What factors shaped architects' approach to daylight prediction?

The article draws on semi-structured interviews with practising and retired architects, lighting consultants, and a senior planning officer (Table 1). Some interviewees were contacted directly by the researcher, particularly where they were known to have undertaken daylighting research in addition to working in architectural practice. Other participants responded to adverts circulated by the RIBA via social media. Participating architects were asked to describe the approach they took to daylight prediction, how this approach changed over time, and what factors shaped their approach. The lighting consultants and planning officer were asked about the development of daylighting standards over time, the enforcement of such standards through regulation and planning controls, and the uptake of daylighting principles by architects.

Interviews lasted 47-153 minutes. Digital audio recordings were made of each interview, which were then transcribed verbatim. Transcripts were analysed thematically, using N-Vivo software to store and retrieve data. Thematic analysis is a method for identifying and reporting patterns in data. Each theme is intended to capture an important aspect of the data in relation to the research question, but the analysis produced is not merely descriptive as development of themes involves interpretative work.¹⁸ In analysing the data, consideration was given to the problems

posed by the fallibility of memory. A longstanding concern with oral history methods is that interviewees' recollections might be inaccurate and subjective. John Gold, for example, observed such problems in interviewing architects in order to construct a history of modernism.¹⁹ In addressing such concerns, some historians have suggested that the value of oral history lies in exploring how individuals choose to remember the past.²⁰ Robert Proctor, in reflecting on the value of interviews in architectural history, describes how architects construct 'their histories through present desires, particularly the desire for esteem,' and suggests that, 'The significance of an oral history of architecture is in what it can tell us about the values and myths within a design culture.'²¹ In this article, interviews were used primarily to explore architects' attitudes towards daylight prediction, rather than to simply gather accounts of how architects practised. Consideration was given to internal consistency of interviewees' recollections, and secondary source material was used to substantiate interview data. Interviews focused on the design of housing, partly because some of the key secondary sources relate to housing.

Given the age-range of the interviewees, it was difficult to explore architects' use of the daylight factor prior to the late 1950s. Also, given the changes to architectural practice and to daylighting standards over time, it was decided to limit the scope of the study. The study's timeframe therefore runs from 1956, when the first of the interviewees entered practice, until 1992 when average daylight factor was introduced into the British Standards, replacing previous methods of daylight prediction. The article discusses how daylighting has shaped architectural discourse, and then summarises the daylighting standards that affected housing design during the period covered by the study. The study's findings are organised around the themes identified in the analysis of interview data.

This study's contribution to current debates

How buildings are evaluated can significantly affect urban form, as demonstrated in numerous studies.²² For example, Jules Lubbock has argued that post-war daylighting standards, in determining post-war buildings' forms, promoted Modernist high-rise architecture; the standards acted 'like a computer virus designed to destroy the 'programme' which had produced the traditional city'.²³ Addressing these issues in broader terms, Stephen Moore and Barbara Wilson have argued that technological standards 'have social and environmental consequences, as well as technological ones'.²⁴ Rob Imrie and Emma Street have argued that building-design standards are political interventions that are integral to the design process, challenging the view that architects are autonomous agents, free from the limitations of social settings.²⁵ They further suggest that, given the political dimension of building standards, architects have an 'ethic of responsibility' to engage with regulatory formation.²⁶

UK daylighting standards might soon change, with some writers calling for the daylight factor to be replaced with other metrics.²⁷ The daylight factor, which was developed in a pre-computer age, simplified the prediction of internal daylight levels by separating the contribution of diffuse sunlight from overcast skies from that of

direct sunlight, with the latter assessed through other methods. The daylight factor therefore takes no account of direct sunlight. Critics of the daylight factor suggest the metric's insensitivity to building orientation make it unsuitable for achieving balance between good daylight provision and effective solar control, vital given the importance now placed on buildings' energy performance. The adoption of new metrics came a step closer in 2013 when climate-based daylight modelling, rather than achievement of specific daylight factors, was made mandatory for buildings designed under the Priority Schools Building Programme.²⁸

These on-going changes to daylighting standards make it imperative that we understand the impact of such metrics on architectural practice. Previous studies have identified the key academic papers in the development of the daylight factor.²⁹ Surveys conducted in 1966³⁰ and 1994,³¹ indicated that architects rarely undertook full daylight-factor calculations or used model studies in housing design. However, there has been little consideration of why particular methods of daylight prediction were preferred over others, nor of the daylight factor as a cultural phenomenon rather than as a merely technical device. The effectiveness of design standards in promoting good daylighting is a crucial issue, particularly given developments in our understanding about the health benefits of daylight,³² which has prompted initiatives such as the RIBA's 'Space and Light' campaign.³³

How daylighting has shaped architectural discourse

Light is integral to architectural aesthetics, as encapsulated in Le Corbusier's statement:

Architecture is the masterly, correct and magnificent play of masses brought together in light.³⁴

However, in housing design from the late nineteenth century onwards, natural light has been regarded as particularly important for supporting occupants' health, connection to outside, and ability to see to undertake tasks. The belief that sunlight has health benefits can be traced to antiquity, but the modern belief in the curative effects of natural light are derived from miasma theories in which stagnant air was regarded as the cause of disease. Nineteenth-century housing reformers promoted access to natural light. This trend continued even after the 1860s, when the miasma theory was displaced by the discovery of bacteria by Pasteur and Lister,³⁵ not least because in 1877 Downes and Blunt demonstrated the bactericidal properties of light.³⁶ In the early twentieth century, the development of sanatoria that used sunlight to treat rickets and some forms of tuberculosis was very influential on early Modernist architects.³⁷ Modernist aspirations to improve occupants' health through increasing insolation in buildings coincided with some Modernists' rejection of the enclosed boxes that characterised pre-Modernist buildings, and a desire to open up buildings.³⁸ In the UK such arguments were used to support the use of freestanding tower and slab blocks, and underpinned planning policies and the development of standards such as the permissible height indicators³⁹ (described in further detail below).

While health benefits were believed to derive from direct sunlight, research on light-for-vision centred on diffuse light from overcast skies. Some initial work on measuring diffuse daylight levels was undertaken in the nineteenth century in an effort to find ways of resolving right-to-light cases, where new buildings caused a reduction in the light available to buildings that had been in existence for twenty years or more.⁴⁰ This technical work was crucial in facilitating the development of methods for measuring daylight in buildings. A key driver was building scientists' belief that, while science could not determine all aspects of building design, science could contribute to an understanding of what light levels are required by occupants to perform specific tasks.⁴¹

Development of the British Standards on daylighting

Alexander Trotter devised the daylight factor in 1895 as a means of quantifying daylight illuminance in a room. Noting that daylight illumination fluctuates according to the time of day, season and weather, Trotter observed that the ratio of indoor to outdoor illuminance remains constant for any given room. He therefore defined the daylight factor as the proportion of daylight in a room relative to that available under an unobstructed hemisphere. Trotter developed a photometer with daylight attachment, which was sufficiently accurate to allow readings to be taken inside and outside, in quick succession, to measure the daylight factor in internal spaces.⁴²

P. J. Waldram, who pioneered the science of measuring daylight, used Trotter's photometer,⁴³ before devising a graphical method of measuring daylight factor; the Waldram diagram (Figure 1). In a paper co-authored with his son in 1923, Waldram argued that for the purposes of measuring the daylight in a room, an overcast sky could be assumed to have a uniform illuminance. Following this assumption, the proportion of the sky's light that reaches any given surface is equal to the proportion of the hemisphere visible at that surface.⁴⁴ The Waldram diagram provided an accurate measure of the sky visible at a point, but required a drawing to be made for every measurement of daylight factor. In 1940 the Building Research Station (BRS) devised a series of celluloid protractors that allowed the approximate area of visible sky at a given point to be measured from plan and section drawings, simplifying the procedure (Figures 2 and 3).⁴⁵

Although Waldram diagrams and BRS protractors permitted calculation of daylight factor at a point, they were not useful for measuring the area over which a specified daylight factor was exceeded. The latter was considered essential to initial attempts to devise daylighting standards.⁴⁶ A formula devised in 1943 by the National Physical Laboratory enabled daylight-factor contours to be drawn in plan, indicating the boundary between those areas of a room that were above a specified daylight factor (Figure 4).⁴⁷ Daylight-factor contours, along with interviews with occupants, were used in a survey of sixty-two apartments,⁴⁸ which provided the evidence to support the recommendations made in *The Lighting of Buildings*.⁴⁹ The National Physical Laboratory's formula was also used to prepare tables,⁵⁰ which were incorporated into the first British Standards on daylighting, published in 1949.⁵¹ The tables were

intended to be easy for architects to use,⁵² and indicated the depth and area enclosed by specific daylight-factor contours for windows of given dimensions and angles of obstruction. Recommendations on sunlight were published in a separate British Standards document in 1945.⁵³

A weakness with the early standards was the assumption that an overcast sky has a uniform brightness, which in practice is never true. This concern was addressed by a formula devised by Moon and Spencer in 1942, which expressed the distribution of light in an overcast sky,⁵⁴ and was used to create revised versions of the BRS protractors.⁵⁵ Another criticism of these early British Standards was that they provided a measure of light received directly from the sky only, even though daylight levels in a room are also affected by internally and externally reflected light. A formula, devised by the BRS in 1954, enabled internally reflected light to be quantified. To further simplify the process, the BRS produced nomograms, that is, diagrams describing the relation between the key variables. This allowed daylight factor at a point to be calculated accurately by adding the internally reflected component to the externally reflected and sky components. The amount of light received directly from the sky (the sky component) could be evaluated using one of the established techniques such as Waldram diagrams, or BRS protractors or Graded Sky Factor tables. The externally reflected component could be ascertained by measuring the visible obstructions at a point, in the same way that visible sky is assessed, and then dividing the resulting value by ten.⁵⁶

This three-stage process for evaluating daylight factor at a point was incorporated into the revised British Standards on daylighting in 1964, superseding the use of the National Physical Laboratory's tables.⁵⁷ Daylight prediction methods, which measured the extent of visible sky only, were now said to measure sky factor, as distinct from daylight factor, which included internally and externally reflected light. The 1964 British Standards also permitted the use of photometric methods to measure daylight factor, in existing buildings or models.⁵⁸ Such methods included the use of photometers, such as the BRS Daylight Factor Meter, or cosine-corrected photoelectric cells that could be connected via an electrical circuit to a metering instrument such as a microammeter.⁵⁹ The use of models was only really effective when used in conjunction with an artificial sky (Figure 5), as the brightness of natural skies constantly change making it difficult to obtain accurate readings.⁶⁰ The major advantage of photometric methods was that they enabled simultaneous measurement of direct and reflected light.

In a paper published in 1975, James Longmore suggested that the average daylight factor over the working plane might be a more suitable criterion by which to assess internal daylight levels than minimum daylight factor at a point.⁶¹ Joe Lynes took up this idea in a paper published in 1979, which described how a formula for calculating average daylight factor could be used to determine window size for a room where the average reflectance and vertical angle of visible sky were known. Lynes argued that using average daylight factor as a metric enabled daylighting to be considered early in the design process, whereas the 'point-by-point' method could be used only after the size, shape and position of windows had been decided.⁶² A draft version of

the revised British Standards on daylighting, published in 1982, provided recommendations on daylight levels in dwellings in terms of average daylight factors.⁶³ These recommendations were thought to be nearer to subjective requirements than previous standards,⁶⁴ but were not formally accepted as British Standards until 1992,⁶⁵ following refinement of the formula by the Building Research Establishment (BRE, formerly the BRS).⁶⁶ The current British Standards on daylighting are expressed in terms of average daylight factor.⁶⁷

Statutory controls on daylighting in housing

The Scottish Building Standards, introduced in 1963, required new-build dwellings to comply with minimum-daylight-factor standards.⁶⁸ However, no such statutory daylighting standards for dwellings were introduced in England and Wales. Standards controlling the space about buildings were incorporated into the Building Regulations introduced in England and Wales in 1965.⁶⁹ These Regulations specified the dimensions of open space required outside the windows of habitable rooms, including the height of external obstructions. The purpose of the Regulations, however, is unclear. Although obstructions to windows affect daylight levels in rooms, David Croghan and Dean Hawkes used model studies to demonstrate that compliance with the Regulations provided no guarantee that rooms would receive adequate daylight.⁷⁰ Later versions of the Building Regulations specified the dimensions of open space required outside windows for ventilation purposes only.⁷¹

Planning controls on daylighting in housing

No daylighting standards were specified in the 1947 Town and Country Planning Act. However, most post-war development plans indicated that daylighting would be considered in assessing applications to develop. Most local authorities evaluated daylighting in proposed development schemes using permissible height indicators (Figure 6).⁷² The Ministry of Town and Country Planning devised these indicators in preparing for post-war reconstruction, to enable local planning authorities to ensure there was adequate space between new buildings for them to receive sufficient daylight.⁷³ Permissible height indicators were initially intended for use in the design of office buildings,⁷⁴ although in 1952 a second set of indicators was issued for use in housing.⁷⁵ The indicators tested whether sufficient sky was visible at the external walls of a building for rooms within to comply with British Standards on daylighting, provided an adequate number of conventionally sized windows were used. Compliance with the indicators did not guarantee that a building's internal spaces would meet the British Standards. There were two types of indicators, the first intended to ensure a new building would not obstruct the windows of neighbouring buildings, and the second designed to check that buildings in a new development would not obstruct each other.⁷⁶ The Ministry of Housing and Local Government published revised indicators in 1964,⁷⁷ as did the Department of the Environment in 1971.⁷⁸ The latter document was superseded in 1991 by the BRE's *Site layout planning for daylight and sunlight*, which gave recommendations on obstruction angles in place of permissible height indicators.⁷⁹

Daylighting in architectural education

Architects interviewed for this study who completed their formal education in the late 1950s or early 1960s reported that they learned little or nothing about daylighting science during their studies.⁸⁰ An exception was a Cambridge University graduate who was introduced to the daylight factor and BRS protractors as a student, but was 'not sure we ever used them' in the design studio.⁸¹ By contrast, those architects who completed their formal education in the late 1960s and 1970s reported that they were taught something about daylighting science.⁸² One was taught to use BRS protractors,⁸³ while another was taught about daylight factors and Waldram diagrams 'in a very rudimentary way' via a lecture course, but did not use this knowledge in the design studio.⁸⁴ One participant studied at Manchester University in the 1970s where Joe Lynes delivered lectures on daylighting. Lynes taught students to use gnomonic projections in preference to BRS protractors, having developed the technique.⁸⁵ The participant recalled that those who delivered the building science lectures were rarely involved in teaching design studio, although they would give advice on studio projects if asked. It was therefore unusual for students to use building science techniques, such as gnomonic projections, in the design studio, although the participant did do this himself.⁸⁶

The participants' experience probably reflects the changes in architectural education that followed the Oxford Conference in 1958. The conference aimed to review architectural education, and concluded that architecture should 'take its proper place in the university'.⁸⁷ This required schools of architecture to undertake research, which in turn would inform teaching. One consequence was the growth in building science in British universities from the early 1960s. An RIBA-funded study, conducted by Lyall Addleson in 1967-68, revealed that by the late 1960s daylighting science was widely taught in schools of architecture,⁸⁸ but primarily through lecture courses as timetabling constraints often made it difficult to integrate daylighting into design teaching.⁸⁹ Addleson also noted that building scientists working in schools of architecture often lacked design expertise.⁹⁰ Some schools, however, ran practical exercises covering the use of BRS Simplified Tables, and BRS Protractors. However, Addleson noted that the use of formulae was rarely encouraged and in some cases students were not expected to calculate internally reflected components, for which the use of formulae or nomograms would be necessary. Some schools reportedly encouraged the use of model studies, although Addleson observed that this required 'considerable time and an artificial sky', and consequently many of these studies were limited to visual appraisals.⁹¹ Addleson suggested that while there was a scientific basis to the teaching, the content of lighting courses in schools of architecture could be best characterised as 'sophisticated empiricism'.⁹²

The expansion of the building sciences would explain why architects interviewed for the present study, who graduated in the late 1960s, were taught the basics of daylight science while older participants were not. Some participants acquired daylighting expertise later in their careers, either through undertaking courses in town planning⁹³ or through undertaking research on daylighting.⁹⁴

Daylighting in architectural practice

When asked about their time in architectural practice, all architects interviewed for this study, including those with significant expertise in daylighting, reported that they rarely undertook daylight factor calculations when designing windows.⁹⁵ As one explained:

In the practice I don't think we ever used a daylight factor protractor [unless we] were to do something beyond the kind of limits of what [we] would typically have done.⁹⁶

Participants observed that in most situations they would determine window size through personal judgement,⁹⁷ experience,⁹⁸ or through using rule-of-thumb techniques.⁹⁹ Experience was accrued through observation of existing buildings,¹⁰⁰ and particularly through developing knowledge of 'customary practice'.¹⁰¹ Experience was also acquired through undertaking successive design projects, including from the rare occasions when daylight factors were calculated, either by the architects themselves¹⁰² or by external consultants.¹⁰³ Participants reported using rules of thumb such as ensuring the area of glazing was proportional to the room's floor area,¹⁰⁴ and positioning windows such that external obstructions were below 25° in elevation above the horizon as measured from the window's centre.¹⁰⁵

Interviewees' observations echo the findings of previous studies. For example, a survey conducted in 1966 revealed that 33% (27 of 82) of architects surveyed sometimes used BRS protractors to predict daylight levels in rooms at the design stage, but only one respondent reported calculating the internally reflected component. This strongly suggests that undertaking full daylight factor calculations was rare at this time. By contrast, 73.5% (60 of 82) of architects surveyed used experience or rule-of-thumb techniques in considering interior daylighting.¹⁰⁶ 25% (21 of 82) reported that they used models to assess daylighting in buildings under development, but these were probably primarily subjective visual appraisals as the photometric equipment necessary to measure daylight factors was not widely available at the time of the survey.¹⁰⁷ In a similar survey conducted in 1994, 42% (14 of 33) of the architects surveyed claimed to use BRS protractors, but no respondents mentioned calculation of the internally reflected component, while only 9% (3 of 33) used the simpler average daylight factor formula. 42% (14 of 33) claimed to never make interior daylight predictions. In this particular survey, only two respondents mentioned the use of 'intuition' or 'empirical assessment' in daylighting, but the study's authors suggested that this apparently small number might simply reflect the survey's design.¹⁰⁸

Compliance with daylighting standards

One interviewee suggested that while architectural design is primarily intuitive, the quantification of daylight is required to satisfy 'the building inspector' and 'the planner'.¹⁰⁹ However, in the post-war period architects were rarely required to demonstrate that a building complied with specific internal daylighting standards. As

described above, while the Scottish Building Standards required new dwellings to achieve specified internal-daylight levels, there were no statutory controls on daylighting in England and Wales. However, interviewees reported that compliance with permissible height indicators was often required to obtain planning consent¹¹⁰ or funding, to cover the capital costs of construction, from bodies such as the Ministry of Housing and Local Government.¹¹¹

This situation is exemplified by London development plans, where the strictest daylighting standards were enforced.¹¹² The 1951 County of London Development Plan stipulated that permissible height indicators would be used to assess proposed residential developments,¹¹³ as did the 1976 Greater London Development Plan¹¹⁴ and local plans prepared by London Boroughs.¹¹⁵ Specifically, the 1976 Development Plan referred to the Department of Environment's *Sunlight and Daylight: Planning Criteria and Design of Buildings*. This stated that while local planning authorities would be concerned with the space between buildings,

The architect and developer, however, are just as much concerned with another part of the process of planning and design, namely the design of individual buildings. To ensure that enough sunlight and daylight can be had inside rooms they must rely on other criteria such as those of the Code of Practice of the British Standards Institution.¹¹⁶

The implication was that daylight levels within buildings were primarily the architect's responsibility, while local planning authorities were responsible for checking that there was adequate space between buildings. It was also suggested, however, that an architect be asked to demonstrate that individual rooms within a building would receive adequate daylight, as defined by the British Standards, if the proposed development did not comply with the permissible height indicators.¹¹⁷ An earlier document entitled *Planning for Daylight and Sunlight*, published by the Ministry of Housing and Local Government in 1964 and which was superseded by *Sunlight and Daylight*, made a similar distinction between the architect's and local planning authority's responsibilities:

The main concern of the planning authority is to ensure that any new building is sited in such a way that it does not interfere with the reasonable daylighting needs of adjoining land; a new building must be a good neighbour and give others a chance to see the sky.¹¹⁸

By contrast, it was for the architect to 'ensure that good daylighting conditions are provided within rooms that need them'.¹¹⁹

A former senior planning officer, interviewed for this study, echoed these views when describing his time working for the Corporation of London in the early 1960s. He explained that the Corporation's priority was to ensure that any new development 'didn't do harm to the neighbours.' Planning applications were therefore checked using the permissible height indicators. The planners also expected architects to observe the British Standards on daylighting. However,

interior daylight levels were not routinely checked as these were regarded as the responsibility of 'the architect and the architect's client'. The planners' view was that if the architect and developer wanted 'to create crummy conditions [inside the building] that's over to them'. Architects and developers were expected to take responsibility for internal daylighting even where the Corporation owned the freehold on land, such as in the Barbican development. From mid-1960s the interviewee worked for a London Borough, where a similar attitude prevailed, although he observed a decline in use of the permissible height indicators through the 1970s, as described below.¹²⁰

Architects interviewed for this study described a similar pattern, where planning consent was dependent on the space about buildings, but not on internal daylight levels.¹²¹ One architect who was involved in 'a number of daylighting cases' in London recalled the priority given to maintaining specific 'vertical daylight factors... on the face of the building', rather than needing to prove that there would be adequate daylight within buildings.¹²² One consequence of local planning authorities' approach was that architects did not need to undertake detailed evaluations of internal daylight factors for most housing projects. Where buildings were designed in a conventional manner, it was sufficient to use 'rule of thumb' to judge whether individual rooms would receive sufficient daylight.¹²³ Detailed evaluations were required only where proposed developments failed to comply with permissible height indicators.¹²⁴ One architect provided an example from early in his career, when he worked for Leslie Martin. In the late 1950s, Martin was exploring the feasibility of high-density low-rise housing, in place of the high-rise apartment blocks that were commonly built at the time. The interviewee recalled how 'we... had a hard fight with... the client and the planners' to prove that the proposed dwellings would receive adequate daylight. Ultimately model studies were used 'to show the doubters that it worked'.¹²⁵ However, the onus was on architects and lighting consultants to demonstrate that adequate daylight levels could be achieved in internal spaces, and it is not clear that many local planning authorities had staff with sufficient skills to check these evaluations.¹²⁶ One architect remarked, 'Whether the chap in the town hall could... check it anyway is another matter'.¹²⁷ Another commented, 'I don't remember anybody ever checking' that buildings complied with the relevant daylighting standards.¹²⁸ A lighting consultant observed that:

I've had planners on the phone to me saying I've got this report and I have no idea what it means, can you help me?¹²⁹

Interviewees reported a decline in use of permissible height indicators through the 1970s.¹³⁰ Referring to his time spent working for a London Borough, a retired planning officer described how pressure from politicians to grant planning consent for public housing schemes meant that where such schemes failed to comply with permissible height indicators, planners often felt they could do no more than draw 'it to the architects' attention'. The interviewee justified these actions by saying, 'our task was not to rock the boat'.¹³¹ Another possible reason for the decline in the indicators' use was that some planners felt able to assess applications without needing to make precise measurements. This was partly because these planners had

learned to recognise which building layouts would comply with the indicators. Describing permissible height indicators, one interviewee said, 'They'd achieved their objective, they trained a new generation.'¹³² There was also a feeling that the assessment of applications should not be 'mechanistic', and that it was necessary for buildings to comply with permissible height indicators 'not in detail but as a concept'.¹³³ Compliance with the indicators was never meant to override all other considerations,¹³⁴ and over time other policy considerations were given a higher priority. It was also observed that permissible height indicators required time and particular skills to use, and both were increasingly rare in local authority planning departments.¹³⁵ By the late 1980s permissible height indicators were no longer in use,¹³⁶ and the system was replaced in 1991.¹³⁷

Pressure on architects' time

As described above, through the 1950s the drive to achieve greater accuracy in measuring daylight levels led to the development of a three-stage process for calculating daylight factor at a point, which required the externally reflected, internally reflected and sky components to be calculated separately. Evaluation of the externally reflected and sky components could be undertaken using tables, but usually necessitated the use of BRS protractors or Waldram diagrams. In describing the time and effort required to calculate these components alone, one retired architect said:

The Waldram diagram... my God it took time... [clients] couldn't understand where the time went, I said well you try [drawing] a Waldram Diagram!¹³⁸

Lack of time meant that even architects who were enthusiasts for scientific daylighting techniques during their student years found it difficult to use these techniques practice, as one interviewee described:

Once you got out there into practice [with] sort of real, real life demands... did I ever get out that, those charts and actually in practice start working on daylight factors? I think I probably did in the case of one, one major scheme.¹³⁹

One architect suggested that architects do not undertake calculations unless they have to, precisely because they have so many other demands competing for their time. He suggested that most architects manage their time by focusing on critical issues, such as fire escape.¹⁴⁰ One architect suggested that the problem of architects' lack of time was exacerbated by changes to fee scales from the 1970s onwards.¹⁴¹ One retired lighting consultant, who had extensive experience of teaching architecture students, said he was now 'ashamed' of the way he taught daylighting in the 1960s and '70s, commenting:

Nobody's going to count dots or mess about with protractors... Life's too short!¹⁴²

Calculations regarded as unnecessary

In exploring the possible reasons for architects' apparent reluctance to routinely use daylight factor calculations, a former lighting consultant suggested that the idea that such calculations were necessary lacked 'credibility'. He observed that it is possible to design a window without undertaking a calculation, citing the work of Georgian architects.¹⁴³ Another lighting consultant made similar observations, citing the work of Sir John Soane.¹⁴⁴ One retired architect suggested that it was more important for architects to understand the principles of daylighting while 'the numbers [are] almost immaterial'.¹⁴⁵ Several interviewees discussed the importance of 'informed intuition' to their work,¹⁴⁶ with one explaining that with experience:

You began to develop some kind of instinctive... knowledge of... what would give you what daylight factors.¹⁴⁷

Another suggested that with experience:

You understand the relationships and you kind of get it right within... plus or minus ten percent error.¹⁴⁸

Interviewees who were knowledgeable about daylight factors reported that this expertise enhanced their understanding of the principles of good daylighting.¹⁴⁹ One interviewee argued that architects who do not understand the mathematics of daylighting are unlikely to understand the principles of daylighting. However, he further suggested that an architect with a robust understanding of the mathematics of daylighting rarely needs to undertake a calculation as he or she will 'know roughly what the answer is anyway'.¹⁵⁰ Some interviewees argued that a key strength of the daylight factor is that it better reflects human response than other lighting metrics. Owing to the way the human visual system works, it can be difficult for people to judge absolute illuminance levels, but most people have a sense of how much light is available inside relative to that outside. Average daylight factor therefore provides a good indication of whether people will judge a room to be well lit.¹⁵¹ As one former lighting consultant explained:

If I asked you to estimate the illumination in here without looking at the lamp, you could well be fifty percent out... If I asked you the average daylight factor, assuming you're used to average daylight factors, you can be fairly close.¹⁵²

One consequence is that where conventional architectural designs are used, architects who are knowledgeable about daylight factors will have a good idea about probable daylight levels within a proposed building. Several interviewees reported that daylight factor calculations were useful only when checking innovative designs.¹⁵³ One interviewee observed in designing a window an architect must consider the amount of skylight and sunlight admitted, the need to prevent unwanted glare, the level of ventilation provided by the window, the ease with which windows can be opened and closed, and the need to ensure occupants have

good views out while maintaining privacy. He suggested that architectural design therefore differs from engineering in that it is often difficult to reduce design 'problems' to a small number of variables, making mathematical optimisation difficult to achieve.¹⁵⁴

Conclusion

It seems likely that, for a generation of architects who were educated during the boom years of building science, daylight-factor-based standards helped to define what was conventionally regarded as a well-day-lit room. This was, however, primarily in morphological rather than exact (i.e. mathematical) terms. The daylight factor measures the proportion of internal to external daylight, which remains constant for any given room. In consequence, for simple buildings (e.g. dwellings) daylight-factor-based standards can be translated into principles usable at the design stage, such as the approximate glazing-area required for a room of a given internal surface area. This process is the reverse of that described by Husserl, being a translation from the exact to the morphological, from a quantifiable light level to a conventional understanding of what constitutes a well-lit interior. This translation from numerical to experiential is more difficult to achieve with standards expressed in terms of absolute light levels, not least because illuminance from daylight fluctuates over time. The daylight factor therefore allows for compliance with numerical standards without the need for numerical assessment, provided that architects understand daylighting principles.

Interviewees for this study who were knowledgeable about daylight factors reported that this knowledge enhanced their understanding of the principles of daylighting. However, architects did not routinely calculate daylight factors, or use photometric model studies, in the design of housing, relying instead on experience and rule-of-thumb techniques. While local planning authorities and public funding bodies tacitly expected architects to meet the British Standards on daylighting in the design of housing, generally it was unnecessary for architects to demonstrate compliance with the Standards in order to receive planning consent or state funding. Detailed assessments of daylight levels were usually required only where a housing scheme was unconventional. Assessment of daylight factors was time-consuming, and widely regarded as unnecessary as it is possible to design a window without undertaking a calculation.

Numerical assessments of daylight factors were, however, integral to scientific research on daylighting. They were used in the development of new building types, such as where photometric model studies demonstrated that high-density low-rise dwellings received sufficient daylight.¹⁵⁵ The daylight factor was also central to daylighting studies that underpinned influential publications.¹⁵⁶ Such publications added to a body of technical literature and design standards, developed through the course of the twentieth century, that encompassed many aspects of building design such ergonomics¹⁵⁷ and thermal comfort.¹⁵⁸ Technical literature on daylighting informed ideas about what constituted a well-day-lit room. This technical literature perhaps also reinforced the commonly held perception that science and rationality

were integral to post-war modernist architecture. However, the evidence provided by this study, indicating that architects did not routinely assess daylight factors when designing housing, suggests that architectural design remained distinct from engineering in that the design process did not centre on mathematical optimisation. The findings suggest that, even where scientific principles informed design, built form was not generated through mathematical processes. Further research is required, however, as it is possible that full daylight factor calculations were undertaken for other building-types such as schools, which were subject to stricter regulations.¹⁵⁹ It is also possible that routine calculations were made for other aspects of architectural design such as ventilation; daylighting might be a special case, not least because of the ease with which daylight factors can be estimated using rule-of-thumb techniques or experience.

That architects were rarely asked to demonstrate compliance with daylighting standards indicates that the existence of standards alone does not guarantee improved building design. Quantifiable standards are meaningful only where compliance is demonstrated through measurement, or where architects know how to meet the standards without resorting to measurement. Therefore, in the development of future daylighting standards, consideration should be given to the ease with which such standards can be translated into simple principles; and architectural educators must ensure that such principles are widely understood.

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Tables

Table 1

Interviewee number	Profession	Year completed formal education/entered architectural practice	Retired at time of interview?	Undertook daylighting research?
A1	Architect	1972	Yes	No
A2	Architect	1962	Yes	Yes
A3	Architect	1960	Yes	No
A4	Architect	1969	Yes	No
A5	Architect	1962	Yes	Yes
A6	Architect	1976	No	No
A7	Architect 9	1959	Yes	Yes
PO	Senior planning officer (background in architecture)	1956 (as architect) – and qualified as town planner in 1961	Yes	No
LC1	Lighting consultant	-	Yes	Yes
LC2	Lighting consultant	-	No	Yes
LC3	Lighting consultant	-	No	No

Figures

Figure 1. Waldram diagram, showing how much sky is visible at a given window.

Figure 2. Measurement of visible sky using BRS protractors – vertical component. (British Standards Institution.)

Figure 3. Measurement of visible sky using BRS protractors – horizontal component. (British Standards Institution.)

Figure 4. Daylight factor contours. (HMSO.)

Figure 5. The artificial sky at the University of Cambridge, used with photometric equipment and architectural models to measure daylight factors. (David Croghan.)