Handbook of Industrial Lighting

Stanley L. Lyons, FCIBS

Butterworths
London Boston Sydney Wellington Durban Toronto

First published 1981

British Library Cataloguing in Publication Data
Lyons, Stanley L.
Handbook of industrial lighting.
1. Industrial buildings — Great Britain — Lighting
2. Electric lighting — Great Britain
I. Title
621.32'2 TK4399.F2

ISBN 0-408-00525-4

Typeset by Tunbridge Wells Typesetting Services
Printed and bound in England

Handbook of Industrial Lighting

Foreword

This is a practical handbook to aid the reader who seeks to achieve good industrial lighting. It is intended for engineers and technologists such as lighting engineers, building services engineers, electrical designers and installers, works engineers and architects. It will also provide important back-up reading for students of these professions.

Designed as a work of reference rather than a textbook, it contains much information not available elsewhere except as articles, pamphlets and papers read before institutions. The information is fully up-to-date, and incorporates many practical ideas developed by the author during his long career in illuminating engineering.

The contents of the *Handbook* are relevant to all applications of lighting for industrial premises, including general lighting, task lighting, lighting for many specific engineering and manufacturing processes, lighting for inspection etc. It deals with the practical steps to be taken to design lighting suited to the environments met in various industries, including food manufacture, papermaking, leather and shoe industry, metal manufacturing trades, foundries and drop-forges, printing, brewing, distilling and soft drinks manufacture etc, dealing with the lighting needed to satisfy the visual tasks in each. It also guides the reader on suiting the lighting equipment to hostile conditions such as damp and steam; flammable dusts, vapours and gases; conductive dusts, corrosive atmospheres; vibration of the structure; soiled and smokey atmospheres, etc.

Information is included on the needs for daylighting industrial buildings, relating this to problems of heat-gain and heat-conservation. It deals with the heat-gain from lighting installations and sets out the elements of integrated environmental design for factories, including controlling heat-flow by structural and architectural design relating to the lighting.

Throughout the text there are many references to good safety practices and the role that factory lighting should play in reducing the frequency of industrial accidents. Emphasis is also placed on quality assurance, and an extensive survey of modern inspection techniques is provided. The contents are presented in short numbered paragraphs, extensively cross-referred for convenience in studying any topic, and a full index to the contents is provided.

Preface

The subject of lighting for factories and industrial plants appears to be simple, but many companies have lighting installations which are the least effective and the most neglected of their building services. Through lack of knowledge, opportunities are lost to light factories well, to make them more productive, more profitable, safer, and altogether more humane and pleasant workplaces. Much of the published information about lighting is of an educational or academic nature that does not suit the needs of the person who has to make important decisions about lighting immediately; further, as may be expected, the technical literature available from lighting manufacturers tends to put forward the types of equipment that it is their business to sell. Thus there is a need for this *Handbook,* which is offered as a source of guidance in the practical business of specifying, designing, ordering, installing, operating and maintaining lighting for all kinds of industrial premises.

I have long regretted the passing of the old *Lighting Service Bureau* (LSB) in Savoy Hill, London, which was operated by the former Electric Lamp Manufacturers' Association from pre-war days up to 1958. Also, the passing of its successor, the *British Lighting Council* which did a similar job of informing the public about lighting from 1958 to 1968. After 1968, The Electricity Council, in collaboration with organisations in the lighting industry, made excellent efforts to provide reliable information in the form of its many publications; but, sadly, its educational and information work has now been much curtailed. It was in harmony with the work of The Electricity Council that, in 1972, I produced the first edition of my book *Management Guide to Modern Industrial Lighting* of which this book may be regarded as the 'engineer's version'. An updated edition of that work will be published by Butterworths in 1982.

In preparing the present *Handbook,* I have tried to keep it simple, and have glanced back to the publications that were available in past years, and have incorporated much of value that I found there. Certain basic principles do not change, and so I have adopted, adapted and improved on what was written in the past, bringing all the facts up to date and in line with modern technology; and I have peppered the pages with practical examples and helpful hints that have arisen from practical work in lighting design and consultancy. Apart from books on lighting, my researches included collecting together many leaflets, booklets and pamphlets from the LSB, the BLC and The Electricity Council, as well as from other sources—these papers together amounting to a pile nearly 600 mm high. As most of these are now out of print, I have not listed them as references. However, some readers will be glad to know that an even greater collection of historical references to lighting are held in the Science Museum, London, under the title of the *The A. D. S. Atkinson Memorial Collection of Lighting Papers* which I was instrumental in having adopted as a National Archive through the good offices of the Lighting Industry Federation and the Company of Lightmongers.

Although I list a considerable bibliography, it was not possible for me to assign individual books as sources of particular items of information, for so much of the data presented in these pages is coloured by my own experiences in lighting. The art and science of illumination does not stand still; up to the last day before despatching my manuscript to the publishers, I have added the latest information culled from lighting manufacturers, researchers and academics. As far as I could contrive it, the information is up-to-date, complete, and incorporates proven guidance on all salient aspects of the specification, design, purchasing, installation, operation and maintenance of good lighting for industry. Importantly, the guide-lines I give are not biassed by any commercial considerations of my own—for I have none—but are intended to give a balanced view of the equipments and methods to be employed to produce the right quantity of light, light of the right quality, and light which has the lowest cost-in-use, while making wise use of both capital and energy.

One of the important reasons for producing a book of this kind is to attempt to bridge the communication gap between lighting specialists and what C. Dykes Brown has dubbed the 'lighting providers', as well as to make the art and science of illumination a meaningful subject to the users. Lighting engineers use many specialist words which have little or no meaning to the layman. Richard Forster(6) has remarked that "while research has been active, the application (of new lighting techniques) has been almost non-existent . . . Has the lighting industry failed to understand its own jargon?" Throughout this book, I have attempted to give the reader a broad understanding of what good lighting is, and how to achieve it. It has not been my intention to attempt to supplant established references such as the *CIBS/IES Code*(5), the *Technical Reports* and *Guides* of the CIBS, and *Interior Lighting Design*(7), to all of which the reader is frequently referred, but to explain and simplify the ideas which underlie the art and science of illuminating engineering.

I acknowledge the assistance I have had from the publications of The Electricity Council and the Chartered Institution of Building Services, as well as the considerable help from Members of the Lighting Industry Federation who have kindly provided product data.

Stanley L. Lyons

Contents

Chapter 1

Benefits of good industrial lighting

One important theme of this book is that the process of vision is aided by the provision of good lighting, and that this will affect worker performance. Generally, improvements in lighting produce improvements in quantity or quality of output, or both (1.1). Within certain limits, this 'productivity effect' can be shown to be related to the quantity of illumination, as shown by tests and measurements made in factories (1.2). Many studies have shown that the frequency and severity of industrial accidents can be significantly reduced by the provision of good lighting—this being confirmed by the extensive experience of users of good lighting (1.3). As may be expected, these benefits tend to offset the cost of the lighting, and it is commonly found that the quantifiable benefits due to improved output or quality of work and the reduction in accidents is many times greater than the cost of the lighting (1.4) as well as contributing to the wellbeing of the staff which results in even greater savings due to reduction in absenteeism and other management problems.

1.1 Visual performance affected by lighting

1.1.1 When a person is working, at least 80 percent of the sensory data necessary for the performance of his task is obtained visually. The *visual performance* of the worker is affected by both the quantity and the quality of the illuminance that reveals the task and its surroundings (1.1.2). Visual performance is the achievement of the worker in the performance of his visual task, which may consist of observing small detail (e.g., reading, using instruments, gauges etc), as well as monitoring his immediate environment (e.g., observing for danger, movement of persons, spatial relationships). In some tasks he will require to judge speeds and distances. The performance of a *visual task* (which is usually taken to mean seeing the details of an object quickly and accurately, so that it can be comprehended) will depend in part on the standard of his vision, and on the available illumination which enables his eyes to attain the necessary level of *visual acuity.*
1.1.2 Visual task acuity[(1)] is the capacity of the eye for discriminating between details or objects which are close together, or discriminating the size of a very small object. This capacity is expressed as:

$$\frac{1}{S} = \text{Acuity}$$

where S is the angle of separation in minutes of arc between two lines or points which are just separable by the eye (3.1.2).

The visual acuity of a subject is not constant, but varies from instant to instant according to the available illuminance. For example, one cannot read small print by moonlight, simply because one cannot generate sufficient acuity for that task in that illuminance. Thus, to a greater or lesser degree, any visual task could be handicapped if the subject is not provided with sufficient illuminance to achieve the visual acuity required to resolve the details of that task. If the size of detail to be seen is large, then a lesser illuminance will be required, and conversely; here it must be remembered that when we speak of the 'size of detail', what is meant is the 'apparent size'—viz, the combination of physical dimension and distance from the eye—for it is the angle subtended at the eye by the smallest detail that determines the acuity demand.

1.1.3 Our definition of acuity (1.1.2) must be modified in practical cases to take account of the effect of contrast, e.g., the reflection factors of the parts of the task to be seen, and the contrast ratio between them and between the immediate background. If these reflectances are low, or if the contrast ratio is low, then a greater illuminance will be required to achieve a level of visual task performance compared with a task in which, though having the same 'apparent size' to be picked out, has higher reflectances and, particularly, higher contrast ratios. It will often be the duty of the lighting engineer to advise that the details of a visual task be modified to enhance the contrast ratio, e.g., by introducing colour contrasts, or by arranging that critical objects may be seen in silhouette, or seen against a darker or less well illuminated background (3.2.6).

1.1.4 The visual acuity of a subject not only varies with the incident illuminance (1.1.2) but declines throughout his life. Older subjects need greater illuminance than younger subjects to achieve comparable visual task performance. The recommendations for illuminances to be provided (Appendix II) take this age factor into account, and provide for illuminances which will satisfy the needs of persons of normal working age. However, it would be sound practice to specify a somewhat greater illuminance than the standard recommendation in areas which are largely occupied by persons over the age of 40.

1.1.5 Our eyes evolved over millions of years in light which came from the sun, and, biologically speaking, light which flows from a direction other than from above is an experience for which our instincts and reflexes may not always be prepared. Light which comes to the task from some unusual angle will throw shadows, creating modelling and highlights which may be unusual, resulting in mistakes of perception. For example, light from below may cause the illusion of depressed areas of a surface seeming to be raised, and vice versa (Figure 1.1).

1.1.6 For electric lighting to illuminate an object so that its colours are recognisable and reasonably faithful to actuality, the spectral power of the light in all parts of the spectrum needs to approximate to that in daylight. The subject will be discussed in greater detail in Chapter 4, and it will suffice here to say that if the spectrum of the incident light is discontinuous (e.g., it contains little or no spectral energy in some bands of the visible spectrum) there will be distortion, or even absence, of colour perception. For most industrial tasks, some deficiency in *colour-rendering* (4.2.3) of the lamps will

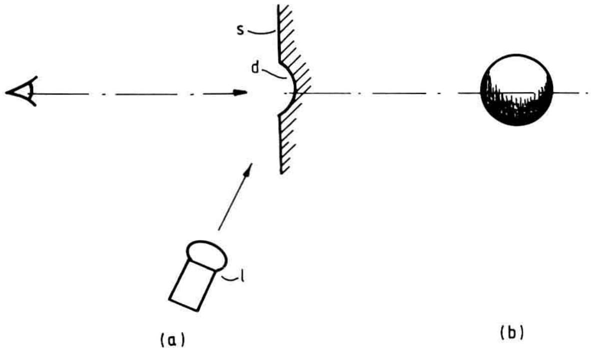

Figure 1.1 Effects of directional light. (a) Light coming from below eye-level to illuminate a light-coloured depression (d) in a flat plane (s) of lesser reflection factor, may create the illusion that the area (d) is raised rather than depressed. (b) The general appearance of the depression under these lighting conditions is similar to the familiar light pattern seen on a sphere illuminated from above.

not be a serious handicap to efficient work, but we shall also see that reasonable *colour-appearance* (4.2.2) of the lighting is of importance. Thus, lighting that is deficient in colour-rendering property, or is of an unfamiliar and unacceptable colour-appearance, may affect the visual performance of workers, and, directly or indirectly, their task performance (1.2).

1.1.7 Light which comes to the eye, directly or reflected from objects, which embarrasses vision and handicaps the performance of the visual task is termed *glare.* It is convenient to discuss glare as *discomfort glare* (which does not, at least in the short term, affect the performance of visual tasks, but which tends to bring about an earlier onset of fatigue) and *disability glare* (which handicaps the subject, reducing what he can see—in an extreme case to just seeing the glare-source). Glare may be *direct* (e.g., from unshielded lamps) or *indirect* (e.g., from glossy surfaces or the surface of a liquid). Some surfaces which appear to be *matt,* behave in a *specular* (mirror-like) manner when the light strikes them at low incident angles. Unwanted reflections from the surface of paper, for example, will reduce the *contrast rendering factor* of the print against the paper, to the point where reading is more difficult or is impossible.

1.1.8 This section has reviewed some of the ways in which the quantity and quality of lighting may affect visual performance. We have seen that visual acuity (1.1.2) is affected by the incident illuminance, by the reflectances and luminance contrasts in the task zone (1.1.3), by the decline of acuity of the subject with age (1.1.4), by unusual directions of light flow (1.1.5), by the colour-rendering property of the light (1.1.6), and by the degree of glare experienced by the subject (1.1.7). These factors are probably the dominant ones, but the list is not exhaustive. Other factors may affect visual performance, such as (a) the time available for seeing, or the speed of movement of the object to be seen; (b) the effect of light which has an interrupted or flickering character; lighting of varying illuminance and its periodicity of variation (5.3); (c) the duration for which the subject is required to perform the task (where, for example, a task can be performed reasonably well for a short period in the given illuminance, but where continuance of the task in that illuminance would lead to early onset of fatigue and incidence of errors). A further factor (d) is the effect of the visual abilities of the subject; for example, a person of normal or corrected vision might perform well under given conditions, while a person suffering from the common eye defect of astigmatism would need a higher illuminance for equal performance, particularly if the task involved frequent and rapid re-focusing of the eyes at distances. More information on how visual performance is affected by lighting is available[1] but the objective of this section will have been reached if it is appreciated that visual performance is not constant and cannot be taken for granted. The art and science of illuminating engineering is directed to providing lighting that will produce a high standard of visual task performance, coupled with economy, safety and the effective use of energy and resources.

1.2 Lighting and productivity

1.2.1 Productivity is the beneficial result of applying resources (manpower, machines, materials, energy, capital, plant and buildings) to the achievement of an objective. The prime activity of management in organizations is (or should be) to maintain and improve the productivity of their organizations. But mere improvement in output may not be enough, for such an improvement must be qualified by stating that increased output at higher unit cost, or increased output at higher reject rate or at lower quality standard, would not be regarded as increases in productivity. Nor would increase in output which was achieved by the subjection of the workforce to greater discomforts or greater risks of injury or ill-health be acceptable. Leaving aside for the moment the humanitarian objections to the latter, and disregarding the objections which would be made by Trade Unions and other organizations should risks of injury or ill-health be imposed on a workforce in quest of greater productivity, it is clear that, although 'danger money' might be paid, it is simply not practicable to seek greater productivity at a cost of suffering to others. It is apparent that the simple definition of productivity with which this paragraph opens is not indicative of a policy to be pursued unless the objective of 'productivity' is qualified by constraints such as 'without uneconomic increase in unit cost', 'without an uneconomic increase in reject rate or an unacceptable lowering of quality', and 'without imposing greater risks or discomforts upon the workforce'. Productivity achieved within all these constraints would almost certainly lead to greater profits by the organization, or the reduction of losses, or the reduction of operating cost of service industries. The objective of this section will be to show that good industrial lighting can aid the achievement of such true productivity, while the next section (1.3) will examine the subject of worker welfare and safety in relation to lighting.

1.2.2 Studies of work performance have shown that where work is performed in adverse lighting conditions, output and quality of work are lower than may be achieved by the same workforce in optimum lighting conditions. It is well known that the disadvantage of adverse lighting conditions can be partially or temporarily overcome by dint of especial effort by the workers, but that this cannot be long maintained because of stress and the early onset of fatigue. The practice of granting short rest periods has been used as a substitute for improving the lighting, and this has led to bargains in which management agreed to pay the operatives 'relaxation allowances', eg sums of money in lieu of the rest periods. Thus, in some factories, there is the paradoxical situation where the management pays operatives extra wages to work in a poor light! Nothing can be said in favour of this, for the total payments to the workers far exceed what improvement of the lighting would cost (in terms of capital expenditure and running cost), while, even though extra money is paid for the operatives to tolerate the poor lighting, output and quality, and hence profitability, must inevitably suffer.

1.2.3 Taking an opposite view to those managers who pay their workers 'relaxation allowances' to work in poor lighting (1.2.2), more enlightened managements provide better lighting in the justified expectation that the value of extra goods produced, or the enhanced added-value due to better quality of work, will be greater than the additional cost of providing lighting of optimum standard (18.1). While it must be stressed that the optimum standard of lighting means lighting of good quality as well as of sufficient quantity, the pay-back for this investment and management care may provide increased output, decreased rejects and improvement in safety standards, as indicated in Table 1.

Table 1 Effect on performance, rejects and accidents due to improvement in illumination in workplaces[2] (See 1.2.3)

Company or type of work	*Illuminance* Old (lux)	New (lux)	*Performance increase* (%)	*Rejects decrease* (%)	*Accidents decrease* (%)
Adox Camera Works	370	1000	7.4		
Mosbach, Gruber & Co Leather punching	350	1000	7.6		
Pearl sorting	100	1000	6.0		
Crocheting	100	1000	8.0	22	
Classroom test (observation, logical thinking, speedy and accurate calculation)	90	500	7.7 (ave.)		
Composing room (print)	100	1000	30	18	
Screw sorting	100	1000	10	22	
Linde Machine Factory	200	550			43
Telephone receiver assy	150	250	36	57	
Mfr of bearings	60	250	13		
Tile making	50	200	4		
Frawley Corp (Paper Mate Pens)	500	1500	28		
Metwood Mfg Co	300	2000	16	29	52 reduction in lost time
Erickson Tool Co	500	1600 2500	10	20	50 of minor accidents
Douglas Aircraft (minute parts assy)	500 general 1000 local	4000 general		90	
Cotton-spinning mill, (loom efficiency)	170	750	10.5 loom efficiency	39.6	

1.2.4 An important function of lighting in factories is to contribute to creating a pleasant environment for the support of morale and for the general wellbeing of those who work there. The lightmeter does not tell the whole story, for while the illuminance on the working plane may be adequate for seeing, the measurement of illuminance does not give any appreciation of how *bright* the room may seem. A room lighted mainly by 'downlighters' for example, especially if the decor were dark, could present a very gloomy and depressing appearance, even if the horizontal illuminance was a 1000 lux or so. The brightness of the room as perceived by the occupants will be due to a combination of the room reflectances and the way the light is distributed from the luminaires and interreflected between the room surfaces (2.2.3).

1.3 Lighting and industrial safety

1.3.1 Of the various factory services which may contribute to the welfare and safety of occupants of workplaces, lighting is of high importance. A report of a five-year study by the Accident Prevention Advisory Unit of the Health and Safety Executive (UK) says that the most safety-conscious companies are those which tend to be commercially successful(3). The report also says that the management characteristics needed to achieve a high standard of health and safety for employees are the same as those required for efficient production. One of the reasons for the failure of some companies to take effective measures for safety is the lack of appreciation and the lack of involvement on the part of senior executives. Decisions about health and safety should rank equal in importance with others regarding the operation of the business. It may well be that many managers do not realise that there is a close link between the standard of lighting provided and the standard of safety to be achieved in industrial premises; thus the responsibility for lighting is often placed with an executive of limited budgetary and decision powers within the organization(4). The director or manager responsible for lighting should acquire a suitable appreciation of the function of lighting in respect of welfare and accident prevention, and should also realise that investment in good lighting is usually self-financing (1.4, 18.2).
1.3.2 The provision of lighting, 'sufficient and suitable' for the environment and the tasks in the workplace, and in places to which visitors or the public may be admitted, is a legal requirement (see Appendix I). An appreciation of the technical aspects of lighting to enhance safety is given in Chapter 5.

1.4 Cost-benefit of good industrial lighting

1.4.1 Not all the benefits of good lighting can be assessed in financial terms, though there is little doubt that in the majority of cases improvements from poor or mediocre standards to modern standards of lighting will bring measurable returns which can be convincingly demonstrated by calculation. Some of the benefits are due to the improvement of the working environment, and are demonstrated by the modified behaviour of the occupants. For example, improvements in lighting which result in a more pleasant workplace may be accompanied by improvements in *sickness absence rate* (1.4.2), *labour turnover rate* (1.4.3), and *'failed-to-start syndrome' rate* (1.4.4); similarly, losses due to *'invisible absenteeism'* (1.4.5) and *minor accident rate* (1.4.6) are checked. The more tangible benefits, such as reduced errors and faults, greater output, better quality and less accidental damage to goods etc are readily calculated (18.1), as will be the cash savings due to using more efficient luminaires and more efficacious lamps (18.2).

1.4.2 It has to be recognized that there is widespread abuse of the custom of requiring an employee to produce a doctor's certificate only when a period of absence from work exceeds two days. Keeping a record of the annual lost days due to uncertificated sickness, department by department, or by functions of employees, will prove to be a most interesting indicator of staff satisfaction with the total working environment. Often, when the working environment is significantly improved (e.g. by redecorating, reducing noise-levels or improving the lighting) the loss of productivity and profit due to uncertificated sick-absence will be found to be greatly reduced, and permanently so.

1.4.3 Labour turnover is, of course, related to wages and other conditions; but, the effect of lighting on the morale of the workforce is usually sufficiently marked for it to be noted that the labour turnover (e.g. rate of replacement of staff per annum due to resignations other than retirement) is lower in better-lighted premises. The difference may show up between departments, or between parallel establishments of the same organization, or between organizations. In companies that provide really good environmental conditions, there may actually be a waiting list of persons who want to join the company—many of whom are relatives, friends or neighbours of existing staff who have heard how good the conditions are. Even in times of mass unemployment, there is always a shortage nationally and locally of really desirable employees; and the provision of good working conditions, including good lighting, is a relatively inexpensive aid to attracting the right people.

1.4.4 The 'failed to start syndrome' is the situation where a person is hired, but does not turn up for work on the agreed day. It has been noted that if the prospective employee is shown the workplace at the time of the interview and the appearance of the workplace is unpleasant, dingey and poorly lit, then there is a greater probability of the new person not starting work. If the candidates are selected and engaged, but are not shown the workplace at the time of interview, and if the workplace is of unsatisfactory appearance and lighting, then a high proportion of starters resign after a short period of employment.

1.4.5 'Invisible absenteeism' is the condition where an employee is on the premises during working hours, but is absent from his workplace for significantly long periods of the day, or is at his workplace but not actually working. In many factories it has been found that a large proportion of female operatives doing repetitive and rather boring jobs may be 'invisibly absent' for as much as 20 minutes in each hour. Improving the lighting may reduce the strain on employees, and make the workplace more bearable, so that improvements of as much as an extra ten minutes in the hour have been noted, ie, output hours raised from 0.66 of norm to 0.83, an improvement of 17% for the relatively insignificant cost of improving the lighting. This effect