Original Communications.

THE PRINCIPLES OF ADEQUATE ARTIFICIAL ILLUMINATION.

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ILLUMINATION AND ITS RELATION TO VISION.
The Effect of Illumination on Visual Acuity.

Broadly speaking, visual acuity increases steadily, proportional to increasing illumination, up to standards of brightness far beyond those in ordinary use.

Under research conditions it was found that up to a brightness of about 12 foot-candles visual acuity is directly proportional to the logarithm of the illumination. Acuity still continues to improve up to, and beyond, 1,000 equivalent foot-candles, provided that the surrounds are adequately illuminated at the same time.

The effect of the brightness of surrounds in increasing visual acuity is important in practical design. Apart from its effect on actual acuity, undue contrast between the illumination on the work and that on the surroundings produces an unpleasant feeling of strain.

It is uncertain at what point visual acuity came to a maximum but as, for example, the lace workers in Geneva work in brilliant sunshine, so that the white material must have a brightness of many thousands of equivalent...
foot-candles, the reason for this choice would indicate an improved acuity even up to that illumination.

Industrial research has shown that output in certain fine work does not reach its maximum daylight value until an artificial illumination of the order of 20 foot-candles is attained, this illumination being provided by a well-planned installation designed to secure approximate uniformity over the whole area of work.

In the case referred to (typesetting by hand) an increase of average lighting from 1'30 to 20'0 foot-candles increased production by 24 per cent.

In wool knitting an increase from 5'0 to 50'0 foot-candles caused an increased production of 20 per cent., and in silk weaving raising the illumination from 50 to 100 foot-candles increased production by 21 per cent.

In these days of increasing Army mechanization illumination in many spheres of work will have to approximate to accepted modern standards of industrial lighting, and the same factors will have to be considered: Effect on output; effect on quality of work; effect on accident incidence, i.e. the proper lighting of dangerous machinery as a safety factor.

Defective lighting tends to affect detrimentally both the quality and quantity of the work turned out. The factors mentioned apply, of course, to-day to technical shops at present in being in barracks.

The reason why industrial lighting values have arisen so rapidly in recent years is that the employer finds it commercially economical to:
(a) Increase output by better lighting, rather than by an increased wage bill, (b) pay for more light rather than pay a higher accident compensation rate.

Daylight Illumination.

Normal daylight enables our eyes to function under the best possible conditions.

Its characteristics are also those which must be aimed at in the production of a good system of artificial lighting, except that its spectral composition does not appear to be necessary unless for special purposes.

It is adequate even when greatly obstructed, and adequacy is the first condition which any lighting installation should satisfy, to ensure that objects can be seen easily and quickly by persons of average visual capacity. It has an excellent distribution ensuring the avoidance of undue contrast, has good uniformity and even diffusion with the avoidance of shadow (apart from direct sunlight).

No artificial lighting system can replace ideal daylight conditions, but daylight illuminations (in addition to their colour and diffusion advantages) are of very high values. Direct summer sunlight on the south coast on a cloudless June day is in the order of 10,000 foot-candles, shaded sunlight 1,000, and indoor lighting near a window on a bright day 200 foot-candles.

Over the greater part of winter, late autumn and early spring, and on wet days in summer the sky brightness is such as to produce an illumina-
tion of about 500 foot-candles on a horizontal surface in the open. Such conditions are probably the worst which may still be regarded as providing reasonable daylight.

"Daylight" Electric Lamps.

Where artificial light is used to mix with daylight and so increase the total available illumination, especially for clerical or similar work, a more satisfactory mixture results from the use of "daylight blue" lamps in suitable fittings than is the case with ordinary pearl or opal gas-filled lamps.

Considerable experimental work has shown, however, that the evidence on this point, except in certain specific cases, is somewhat inconclusive, and it is probable that the nature of the lighting fitting and its distribution factor are much more important in the opinion of the average user than the colour of the light.

A very close imitation of the spectral composition of daylight does not appear to be necessary except for special work.

The ordinary commercial "daylight blue" bulb gives partial correction only, the minimum amount of red and yellow being cut out to produce a daylight effect.

Some workers dislike a high intensity of "daylight blue" illumination, owing to what is usually termed its "cold" effect.

From the point of view of efficiency a definite disadvantage to its use is that, owing to the absorption of the blue glass bulb, at least double the wattage of daylight lamps must be installed, according to the amount of colour correction given by the lamps.

Colour matching units which require that the artificial light used when making the match has, as far as possible, the same spectral distribution as daylight (assuming that a colour match by daylight is the end in view), are specialized forms of "daylight" illumination and will not be described here.

Psychological Adequacy.

During daylight hours we are accustomed to fairly bright surroundings, and these influence our general outlook and sense of well-being.

The psychological effect of inadequate or unsuitable artificial lighting is not confined to the conscious irritation arising from difficulty in seeing. A code of lighting standards based solely on the amount of light sufficient to secure the requisite degree of visual capacity for the work in hand may be physiologically adequate yet psychologically inadequate. Even for rough work the level of illumination necessary to promote a high standard of personal efficiency may be considerably higher than the minimum that would suffice for the visual performance required. It is probable that an average level of illumination of three to four-foot candles is the lowest that is really consistent with true welfare.

Inadequate illumination produces unnecessary fatigue and headaches
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from eye strain, induced by overaction of the muscles of accommodation and convergence.

Apart from its effect on the eyes themselves, fatigue has the general effect of depressing the level of efficiency at which all the functions of the body and mind operate, and visual perception is a process which demands attention and apprehension as well as actual capacity to see. Yet it is just when we are most likely to be fatigued, towards the end of the day, that artificial light has to be used. The method of providing it should therefore be such as to stimulate rather than to depress our functional efficiency.

Psychological Effect of Poor Lighting.

The subjective aspect of inadequate or unsuitable lighting is far from negligible.

There can be no doubt that bad lighting conditions have a most depressing effect on those forced to live under them.

The psychological effect of adequate lighting has been amply exploited in civil life.

Few conditions have a mentally more irritating effect than those associated with bad lighting, whether the badness is due to inadequacy or to glare and shadow; and a worker continuously subjected to such conditions cannot be expected to work at his maximum efficiency. Indeed, if other conditions are also adverse, the nerve strain involved may be enough to precipitate a complete breakdown in health.

Good lighting is an aid to good discipline and decorum.

Suitability of Illumination.

It is probable that sufficient attention is not paid to the requisites of good lighting other than mere adequacy; for example, shading and the relative position of light sources and work. The light fittings in a room may be efficient as regards throwing light down on the plane of work, yet if the ceiling is left in too dense a shadow, the whole interior appears oppressive.

To take a concrete illustrative case, if we accept the requisites of good lighting as: (1) Adequacy. (2) Suitability—(a) Uniformity and constancy; (b) prevention of glare; (c) avoidance of shadow; and apply them to a "tailor's shop" in barracks, we might, if the lighting conditions were poor, find the following conditions:

In a small room several separate unshaded pearl bulbs are pulled down to the level of each man's forehead directly over his work. These bulbs may be of a higher wattage than that authorized.

In such a case the conditions as regards illumination would be: (1) Local adequacy on the point of work—general inadequacy in the room as a whole. (2) Suitability—unsuitable for the following reasons: (a) Lack of uniformity; (b) marked prevalence of direct glare; (c) sharp and dense shadows except directly on the local area of work. (A certain degree of
“shadow” is not undesirable in tailoring, as it aids perception of detail, but it should be soft and luminous shadow.)

Tailors working under the conditions mentioned would probably complain of eyestrain and headaches due to unsuitable lighting, and such complaints would be well founded.

The office workers in the Army, often on duty for long hours and sometimes working on documents pencilled on coloured paper, require, in my opinion, particularly carefully designed and adequate illumination.

**Glare.**

Glare may be one of two varieties: (1) Direct glare; (2) reflected glare (indirect glare).

*Direct glare* may be defined as the entry of light into the eye from sources other than the object looked at.

*Reflected glare* as the entry into the eye of too much concentrated light.

Both may be encountered simultaneously. For example, in driving a car towards the low evening sun, one is dazzled by the direct glare of the sun and at the same time by a specular (mirror) reflected glare from the polished road surface.

The effects of glare are probably due to the scattering of light within the eye.

It is common knowledge that gross glare gravely affects visual acuity, but with some of the smaller sources of high brightness, so sited as to act as glare sources, the effects are purely subjective and produce no measurable depreciation of performance.

Nevertheless, although a glare source may produce no lowering of visual acuity, the subject affected may shade his eyes with his hands, or take other steps to avoid it. He has the feeling that the conditions are unfavourable.

Even if a worker may never look directly at such light sources, yet he is troubled by their presence near to the object at which he is looking.

In workshops the temporarily dazzling effects of glare, and the consequent impairment of vision, makes for inefficiency of work and renders the worker more liable to accident, apart from the subjective irritation of the adverse lighting conditions and the eyestrain involved.

Reflected glare is probably mostly experienced by office staffs, in schools and by technical workers. For example light coloured cloth, shining metal or paper, may reflect light directly into the eyes of the worker. Such trying conditions can be avoided by proper positioning of the sources, and by suitable diffusion of, or increase in, the number of lights.

Particular care is required to avoid reflected glare in schools, and this should include avoidance of specular reflections from the blackboard.

As has been noted, illumination on a surface varies inversely as the square of its distance from the source of light.
If, in an endeavour to increase the local intensity of illumination, the light sources are fixed at low levels, the result is uneven light distribution; it may be to an excessive degree (local pools of light in areas of relative darkness) and direct glare from the lamps, if unshaded.

An open conical reflector having no angle of "cut-off" is, naturally, valueless as a shade. Some shallow conical reflectors were originally designed for small electric lamps. The modern large bulb extends far beyond the "shade," and produces dazzle when hung in the line of sight.

The following remarks regarding the angles of "cut-off" of shades are extracted from the "Second Report on Lighting in Factories and Workshops."

"Every light source (except one of low brightness) within a distance of 100 feet from any person employed should be so shaded that no part of the filament, mantle or flame is distinguishable through the shade, unless it be so placed that the angle between the line from the eye to an unshaded part of a source and a horizontal plane is not less than 20°, or in the case of any person employed at a distance of six feet or less from the source, not less than 30°."

With regard to the above it may be mentioned that practically every Army light source is a source of high brightness. Methods of producing sources of low surface brightness, such as diffusing globes, are used only in very exceptional circumstances.

By "low brightness" is meant an intrinsic brilliance of not more than five candles per square inch.

It should be remembered that the covering of a brilliant source by a very small shade, e.g. a small opal globe surrounding a high-power electric source, may give this globe a brightness three or four times as great as five candles per square inch, so that it may cause considerable glare, and should consequently be treated as a source of light in itself.

An ill-positioned office light, which is adjustable as to height, can be pulled down and fastened above an individual table by means of an arrangement of strings. By the same device it can afterwards be moved to various parts of the same office, and so used locally as work requires.

Such an arrangement violates all canons of good lighting.

In hospital lighting it is particularly important to avoid direct glare.

If wards, particularly small wards and bunks, are lit by centrally positioned sources of high surface brightness, it may be found that the natural line of sight of bed patients is almost directly at the light, producing an effect of intense direct glare.

Such glare conditions are very trying, especially to seriously ill or dangerously ill patients, who are unable to alter their position in bed so as to avoid the light. Centrally placed hospital ward lighting should be carefully positioned, of relatively low intensity, and of very low surface brightness, and this lighting should be combined with screened individual bedside illumination.
Remedy for Glare Conditions.

This is a matter of illumination design. Glare can be minimized by such methods as: (1) Adequate diffusion of sources of high surface brightness. (2) Proper positioning of light sources. (3) Increasing the height of sources (their power, or number, or both being increased at the same time, so that the illumination on the plane of work is not diminished). (4) Efficient shading of lights. (5) The use of adjustable screened sources and adjustable concentrators for work at low angles, e.g. medical examination work.

In workshops, and similar situations, a system of low-voltage screened local lighting (run through transformers) is often economical and suitable, and is free from direct glare.

Direct, Semi-indirect and Indirect Lighting.

In direct lighting the whole plane is illuminated directly by the lamp (appropriately screened or shaded). This type of lighting involves considerable shadow effects, and unless the installation is well designed the illumination on the working plane may be far from uniform. Unless well designed, too, glare effects are liable to be produced.

In semi-indirect lighting the light reaches the working plane partly through a diffusing bowl or similar fitting placed immediately below the lamp completely shielding the direct light from the eye, and partly by diffuse reflections from the ceiling and upper parts of the walls, which receive the direct light of the lamp and which provide a considerable fraction of the whole illumination.

In indirect lighting the whole of the light before reaching the working plane is thrown on to the ceiling and the upper parts of the walls, partly by the source directly, and partly from an opaque reflector placed beneath the source. This type of lighting is characterized by the almost complete absence of shadows and the uniformity of the illumination over the working plane, but the brightness of the ceiling and upper parts of the walls must of necessity be high.

The principal distinction therefore between these systems is that in the direct system the light emanates from points, and in the indirect from surfaces, whilst the semi-indirect system is in some sense a combination of both. In indirect lighting the illumination is more even and diffused, and resembles daylight when the sun is hidden in casting little or no shadow itself, and in neutralizing shadows cast by any other sources that may be in use.

In some cases, however, shadows are desirable; for example, in the perception of detail in certain classes of material where vision is aided by the contrast produced by miniature shadows on the surface, e.g. sewing on certain materials. In these cases direct lighting is more suitable than indirect.

The necessity for a high reflection factor of ceiling and walls, and the
comparatively low efficiency of indirect systems of lighting will probably militate against their use to any great extent in large-scale illumination systems, such as exist in the Army, where efficiency in relation to cost must be considered.

Under conditions which admit of the installation of an indirect or semi-indirect system of lighting, it will be found to give a particularly pleasant and restful general illumination which can be augmented locally as required by properly shaded movable sources of direct lighting.

**Lighting of Army Schools.**

School lighting provides a problem of its own.

The illumination may be either inadequate in intensity or ill-distributed in design.

It is necessary, in designing school lighting, that the following main points should be kept in mind:

1. Illumination on the plane of the work should be adequate and this should include a reasonable degree of uniformity.
2. Avoidance of objectionable shadows. The number and position of lights should be so chosen that objectionable shadows cast by the body, or by structural features of the room on the plane of the work, are avoided.
3. Avoidance of glare, especially the direct glare of unscreened or inefficiently screened lamps, and also of reflected glare.

Numbers (2) and (3) above are a matter of illumination design and layout.

As regards (1), an acceptable working basis of artificial lighting of schools is that contained in the Report of the Sub-committee appointed by the Technical Committee of the Illuminating Engineering Society published in *The Illuminating Engineer* in July, 1931.

The composition of this Sub-committee is given in the report which is headed “The Artificial Lighting of Schools.” Its main points as regards intensity of illumination are extracted here:

1. The recommended values are minima.
2. If the illumination is not comparatively uniform the minimum will have to be exceeded in certain parts of the room.
3. A high depreciation factor must be allowed for in planning an initial installation.

**Précis of Recommended Minimal Intensities of Illumination for Schools.**

Minimum on the plane of work—five foot-candles for ordinary reading and writing.

For special work (art classes, drawing, etc.) eight foot-candles. (This work is comparable to map reading in the Army.)

Blackboards to have 60 per cent in excess of above lighting, measured on the plane of the board.

No part of any school building to have an illumination of less than one
foot-candle. This to be measured, in the case of stairways, on the tread surface of the stairs.

Great importance is attached to the avoidance of direct and reflected glare, and of objectionable shadows, and details are given in the report regarding the positioning of light sources with a view to the elimination of such defects.

Lighting of Reading and Recreation Rooms.

It might be of interest to outline the principles of modern good lighting of a typical reading room in barracks.

The main requirements for adequate and suitable lighting are, as always:—

1. Sufficient illumination for the purpose in view—i.e. adequate intensity measured in foot-candles.
2. A reasonable degree of uniformity of illumination.
3. Avoidance of troublesome dazzle or glare arising either directly from inconveniently bright light sources (direct glare) or indirectly in the reflection of light in glazed or polished surfaces (reflected glare).
4. Avoidance of troublesome shadows cast on books or papers (especially head shadows).

The modern lighting system must be planned to produce specific results, not only in illumination values, but in complete suitability for the purpose in view. The correct spacing of fittings, the different characteristics of fittings, and the reflection factors of ceilings and walls, etc., are all factors of importance that materially affect the final result, and so have to be considered when designing a lighting scheme.

Dark colours for walls and ceilings which absorb much light should be avoided. (The reflection factor of white paint is about 84 per cent, of light buff paint 61 per cent, of deep buff 31 per cent, of light green 47 per cent, and of dark brown 12 per cent.)

Diffused reflection from light surfaces furnishes a valuable addition to the available illumination on shelves and tables, and even more important is the resultant softening of the shadows and the diminution in the contrast between the brightness of light sources and their surroundings.

Unfortunately the lighter the wall surface the more easily it shows dust and dirt.

Polished and glossy surfaces in which images of light sources are liable to be formed should be avoided. Walls and ceilings should have a matt finish. Furniture and woodwork, especially table-tops, should be unpolished.

Adequate general lighting is required, a minimum service illumination at table height being five foot-candles.

Care is necessary to avoid troublesome shadows being cast on books or periodicals by the heads and shoulders of readers. The spacing of lighting units and their height require consideration from this point of view, as also the use of diffusing glassware.
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No unshaded lamp should be visible at any angle to persons reading at tables, but when lighting units are visible at an angle of less than 30° from a horizontal line of sight the average brightness of the envelope used to surround the lamp should not exceed five candles per square inch.

It should not be possible for any reader normally to occupy such a position that the illumination on the back of his work or paper exceeds that on the reading surface.

If feasible, instead of general diffuse lighting as above, supplementary local lighting by reading lamps may be employed. In this case the minimum value of the general illumination measured at table height throughout the room should not be less than 1 foot-candle additional to illumination furnished by reading lamps. The combination of general and supplementary local lighting on the tables should not be less than 5 foot-candles.

If reading lamps are used the bulb, which should be of the diffusing type, should not protrude below the level of the lower rim, and their shades, if not opaque, should be of a surface brightness not exceeding one candle per square inch.

Reading lamps should be so designed as to give a wide field of adequate light intensity without glare. Such lamps are available.

The position of bookshelves should be such that objectionable shadows are not cast on the backs of the books with the reader in any normal position.

The minimum illumination on the backs of the books should be 2 foot-candles.

The values of illumination mentioned above are minimum service values. A suitable depreciation factor varying from 25 to 35 per cent according to circumstances may therefore be applied.

The above notes, although written from the point of view of outlining the principles of good lighting of reading and recreation rooms, apply equally to many other places, for example the larger general offices.

Ophthalmological Aspects.

The irritation and ill-effects of inadequacy, unsuitability, lack of uniformity, glare and shadow play their part in the production of eye-strain and headaches which, especially in the case of the office worker, are so often attributed to insufficient light. Such complaints are often well founded. They are certainly very frequent.

It has been said that no specific cases of eye disease have been traced as being due to bad lighting.

I am not convinced that this statement is correct.

Perception of detail in vision depends on the size of the image cast on the retina of the eye. For this reason it is important that the illumination provided should be sufficient to make all necessary detail not merely
visible, but easily visible; otherwise the only resource available is to increase the size of the retinal image by keeping the eye close to the object, with the result that continuous strain is imposed to a greater or less extent on the muscles of accommodation and convergence, and when the object is fixed, an unnatural position has sometimes to be assumed. Headache is often due to these causes. Myopia may be so caused.

It is by this means of increasing the size of the retinal image that the young man with a full range of accommodation is enabled to do fine work (such as map reading) under indifferent conditions of lighting. He is able to sustain the effort for the short periods required. Complaints of eye-strain from young soldiers attending school are, however, common.

The conditions are very different in the case of the "permanent" office worker. He has to sustain such effort for years, working often long hours each day.

I have for many years noted that a certain number of cases of myopia occur in soldiers whose vision was a normal 6/6 on enlistment and who some years afterwards were found to be myopic, probably to the extent of reducing their distant acuity to 6/120. Such cases almost always seem to occur in young men employed in clerical duties, usually in otherwise healthy looking subjects.

Myopia beginning and advancing in adult life is otherwise not common. I have been, and still am, uncertain whether their disease is due to prolonged strain under difficult visual conditions.

The idea is certainly very suggestive.

The possible relationship of myopia in childhood to the effects of doing school home work under indifferent lighting conditions must also be borne in mind.

**Importance of Design in Improving Inadequate and Unsuitable Illumination.**

It is impossible to over-emphasize what is considered to be the most essential point to be borne in mind with regard to improving lighting installations which have proved to be unsuitable, namely that improved illumination must be the result of improved design and not a mere increase in intensity of existing sources.

In some cases indeed, such a procedure might make conditions even more trying to the worker than they had previously been.

It may be found necessary in certain cases, as an emergency measure, to increase intensity of illumination by increasing the wattage of existing sources, even at the expense of intensifying unsuitability (lack of uniformity, prevalence of glare and of shadows).

Really satisfactory lighting, however, is essentially a matter for collaboration between illuminating engineers and architects with due regard to the conflicting interests of suitability and cost. Such problems have to be
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dealt with on a wide basis, and with a consideration of all the factors involved.

When complaints are made that an electric light installation is of too high a power and "trying to the eyes," investigation will almost always reveal that the fault lies in bad design and unsuitability of lighting, and not to excessive intensity.

Summary.

The principles of adequate and suitable artificial illumination are described and discussed including:

1. Apparatus for and methods of measuring illumination.
2. Standards of illumination for various tasks.
3. The effects of illumination on visual acuity and its relation to certain forms of Army work.
4. The psychological effects of inadequacy or unsuitability of illumination.
5. The effects of and prevention of glare, direct and indirect.
6. The lighting of Army Schools.
7. "Daylight" lamps.
8. The lighting of reading and recreation rooms.
9. Medical and ophthalmological aspects of inadequate illumination.
10. The importance of good design as a factor in adequate and suitable lighting.