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PUBLIC SCHOOL LIGHTING

THESIS FOR DEGREE OF B. S.

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PUBLIC SCHOOL LIGHTING

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of Agriculture and Applied Science

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THESIS

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FOREWORD

In this thesis an attempt has been made to bind together all available data and statistics on public school lighting. At the present time there is no book published that covers the various phases of this subject. As far as possible, information concerning the many phases has been collected and used in this thesis, but still numerous points are left out due to lack of material pertaining to them. Due to the nature of this subject, a great deal of the contents of this thesis is not original, but consists of extracts taken from material obtained from numerous sources.

INTRODUCTION

The lighting in practically all of our school buildings is far below the standards set forth in the code of lighting for school buildings. This is indeed an unfortunate condition. The eye of the young child is in a formative state, and undue strain at such a period will surely manifest itself at a later date. Statistics indicate that a high percentage of absences and failures are due to defective eyesight. Conditions which tend to cause such effects should most certainly be remedied. The economics of the situation are apparent to any thinking individual.

Good lighting in the schools is not a commercial proposition. It is a duty!

Nearly five million of our school population of about twenty million have defective vision, 25% on account of poor lighting and 60% from other causes. Poor eyesight of school children costs the country \$130,000,000 a year, due to two million children that repeat a year on account of defective vision. This is on a basis of \$65.00 per child per year. Fifteen per cent of those having good vision up to the 9th grade, show defective vision in the 9, 10, 11, 12th grades.

In Biblical times a man named Esau sold his birthright for a mess of pottage -- traded a rich inheritance for a morsel of meat. It was a poor bargain, to say the least. Esau may have been hungry, but he surely had no conception of the relative value of things. He lived entirely for the present, and without the slightest thought for the future -- but before we criticize him too sharply, let us see if our own generation does not practice false economies that are almost as bad as Esau's unthinking blunder!

Take eyesight. We live in a visual world, and our sense of sight is a valuable birthright. Yet we abuse it severely. We call upon our eyes to function under lighting that we know is poor, and if the resulting eye-strain causes general fatigue, headaches, nervousness, indigestion, or even permanent impairment of vision, in a way it serves us right. We know better.

With our children the proposition is different. Their eyesight -- their priceless birthright -- is entrusted to our care, and it is clearly our responsibility to see that nothing impairs it unnecessarily. In general, we want our children to be equipped as well as possible for the competitive game of life. Education is a means to this end, but education at the expense of good vision tends to defeat its basic purpose, for vision is highly important in almost all kinds of work.

Aside from the enormous personal losses which result from imperfect vision, both during school life and afterwards, school lighting may be considered as one of those cost items which must be budgeted that maximum return will be obtained. Purely from this standpoint of the actual

dollars and cents cost of operating our educational system, if poor lighting and the resulting imperfect vision prevent annually only two per cent of our children from passing, the cost to the state of repeating the year's instruction for these children is as much as its total school lighting bill for the entire year! And where poor lighting has caused eye defects among school children, in later life their earning capacities are thereby reduced, which in the aggregate amounts to an immense economic loss to them and therefore to the nation. Clearly, the real cost of poor lighting is stupendous!



Chapter I.

LIGHT AND VISION

Light is the essential condition for vision -- Webster's Dictionary.

Since vision is extremely important to us in our daily activities, the influence of light on vision, is likewise important. Basic facts on light and vision, usually presented in highly scientific or mathematical form, are herein reduced to simple non-technical terms which show their practical applications in life.

In the Kela School of Lighting there is an exhibit showing a disc rotating at constant speed. Changing the amount of illumination on the disc apparently changes its speed of rotation. Under low illumination the disc appears to rotate rapidly; the geometrical patterns on its face are blurred and indistinct. When the illumination is increased there is apparently a pronounced slowing down of the disc, the patterns becoming distinct. The truth illustrated is fundamental: namely, that it takes less time to see under high illumination than under low -- that there is a time factor in the process of seeing, just as there is a time factor in taking a photograph.

Saving time, crowding extra seconds into every minute, is the common objective of efficiency effort. We do it by substituting machinery for hands and orderliness for lack of system, but wherever human eyes are used, if the light is inadequate, the hour is not long enough for the work

it should contain. The eye in its camera action is forced to take time exposures instead of snap shots. These exposures are taken thousands and thousands of times a day, and the extra fraction of a second for each exposure spells an accumulated loss of half an hour or so during the day.

Ample diffused illumination on the work saves this time; and with less, rather than more, effort on the part of the operator.

Good artificial illumination is a development of comparatively recent years, and although it is quite generally conceded to be desirable, there are few who entirely comprehend how the accompanying benefits are derived. The following curves present basic facts which provide a direct link between light and time -- between better illumination and the increased production and decreased accidents, which have invariably resulted.

Perception

Figure 1 shows the relation between the level of illumination and the simplest visual operation -- perception. This curve illustrates the outcome of a series of tests in which a black dot was exposed momentarily on a white field, and for each level of illumination the shortest exposure was found for which the subjects could detect the mere presence of the dot. The curve shows that at 2 or 3 foot-candles, which is a common value of artificial interior illumination, a relatively long time is required for perception. With an illumination of 10 to 20 foot-candles, which now represents very good practice, the time required for perception is much less, and it decreases steadily as the illumination is raised still further. This is to be expected, since the range of outdoor illumination to which the eye has become accustomed through centuries of evol-

Time and Light
required for
Perception

Relative Time

Foot-Candles of Illumination

Fig. 1.

120 110 100 90 80 70 60 50 40 30 20 10 0

ution is usually from 100 foot-candles, which corresponds to the waning illumination at sunset, to 10,000 foot-candles on a bright summer day.

Discrimination

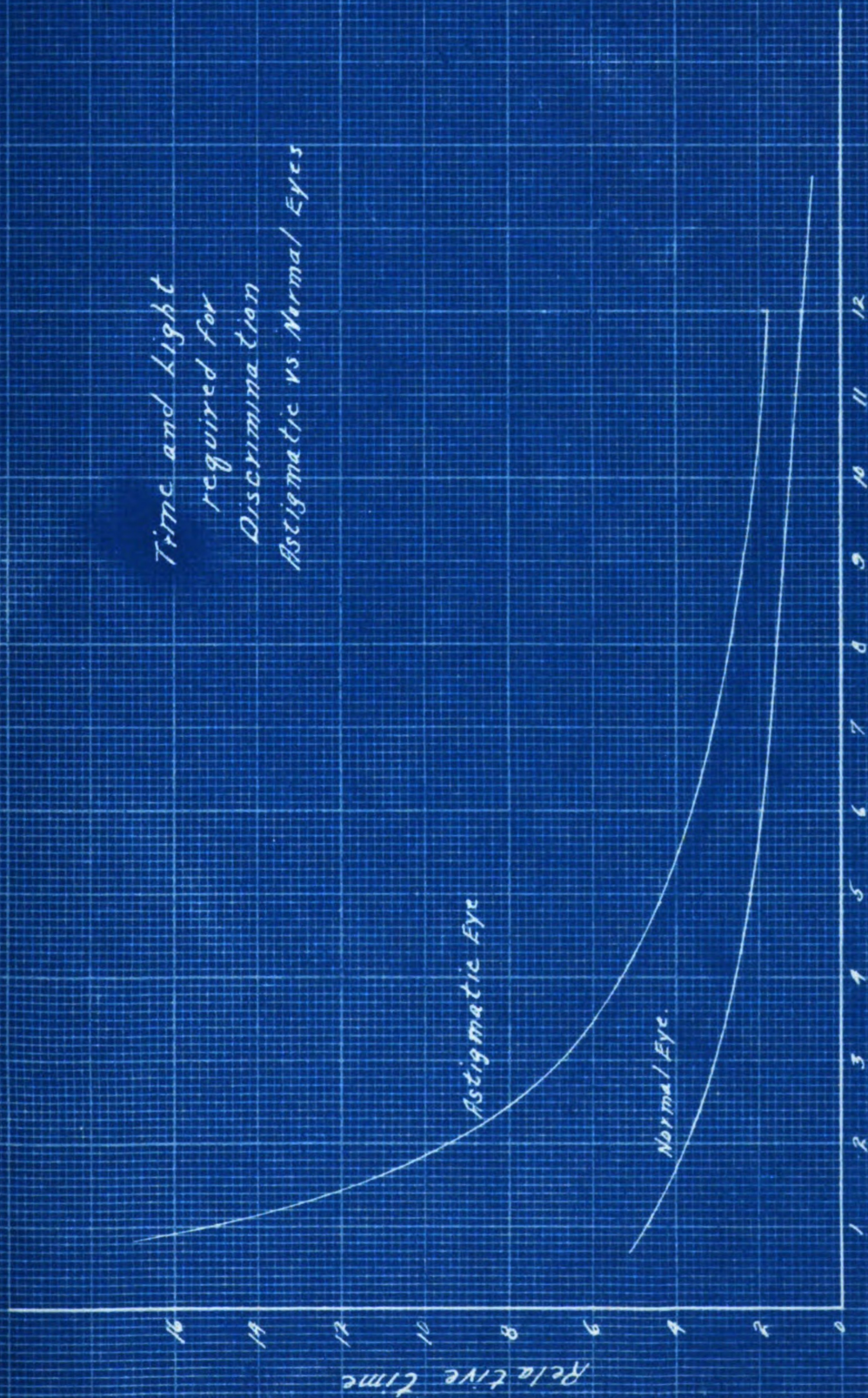
Good vision requires more than the mere perception of an object; it requires the discrimination of its fine details as well. The speed with which this discrimination can be accomplished -- or in other words, the speed of vision -- involves all factors of light and lighting which influence the ability of the eye to distinguish details by differences in brightness and color. Tests similar in character to the "perception" tests, have been conducted on the relation between the time required for discrimination and the amount of illumination. The results show the same general trend as that noted in the curve of Figure 1; the eye discriminates details more rapidly under the higher levels of illumination, although requiring more time than for mere perception.

In all these basic tests it should be remembered that if the contrast between the test objects and their backgrounds were less pronounced than black on white a much higher illumination would be required to give the same clearness and quickness of vision.

The Astigmatic Eye

Further tests have proved that an astigmatic eye always requires longer for discrimination -- for vision -- than does a normal eye under the same illumination. The curves in Figure 2, covering the more common intensities of artificial lighting, show this to be the case. They also show that an increase in illumination benefits the astigmatic eye to a relatively greater extent than the normal eye, or conversely, at the lower

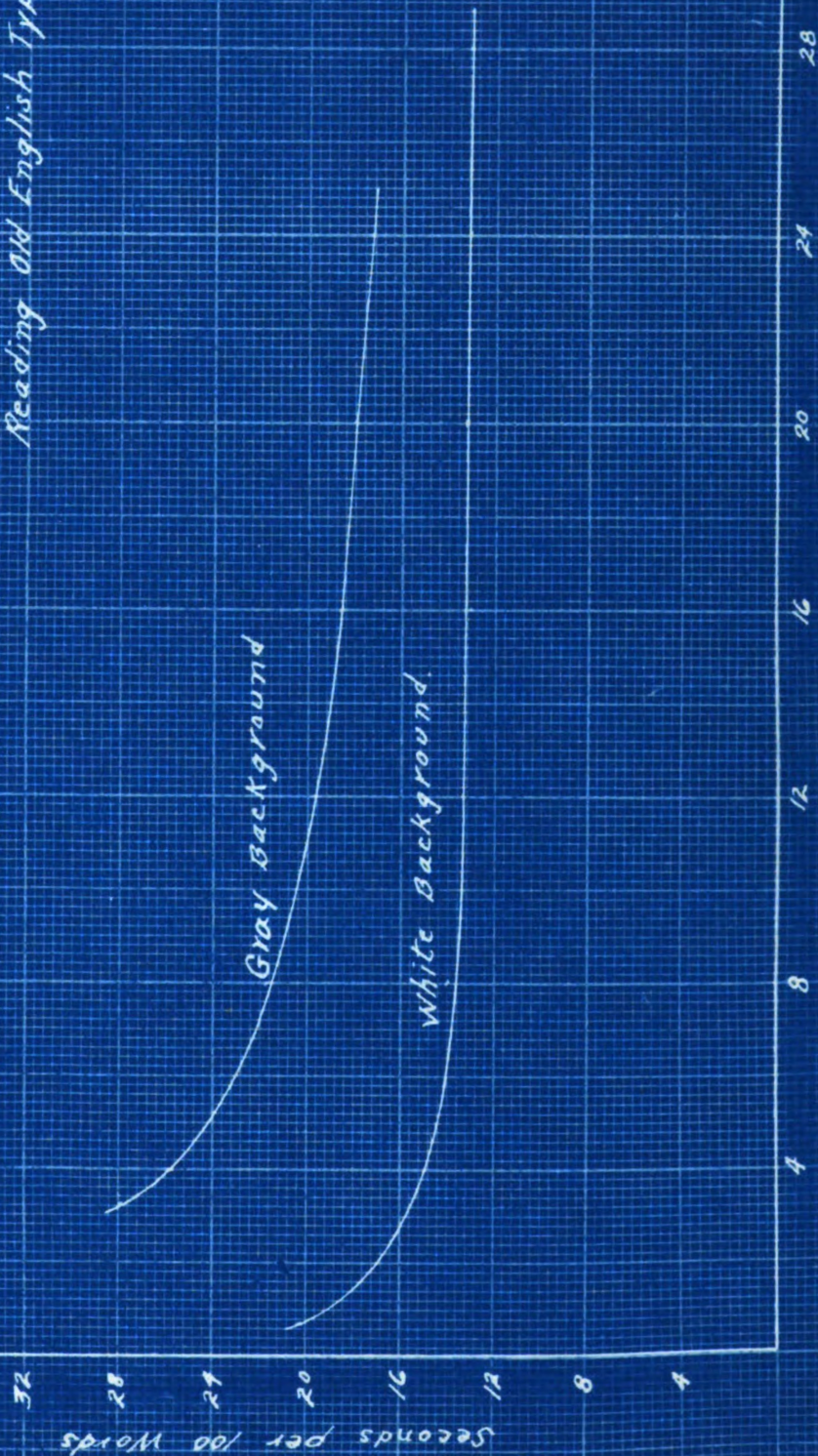
Time and Light
required for
Discrimination
Astigmatic vs. Normal Eyes



Foot-Candles of Illumination

Fig. 2.

Time and Light
required for
Reading Old English Type



Foot-Candles of Illumination

Fig. 3.

Light vs Immediate Fatigue
for
Astigmatic and Normal Eyes
Three minute sustained vision test.

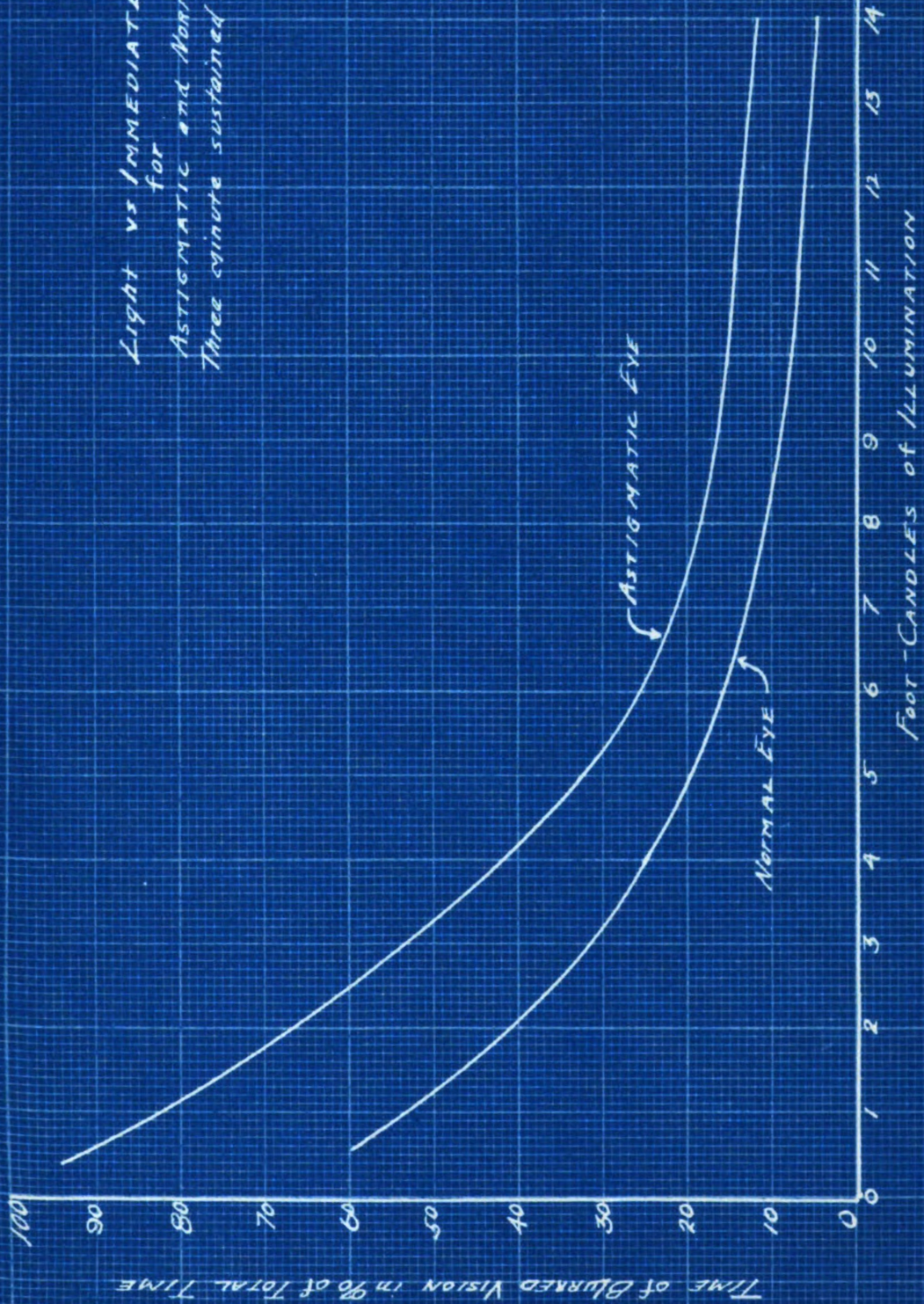


Fig 4.

levels of illumination the astigmatic eye is handicapped even more than the normal eye.. This fact is especially worthy of note, because more than half of the industrial workers of today have defective vision.

Reading Test

The practical value of these results have been verified by a test on the speed of reading, shown in Figure 3. As would be expected, the time required to read 100 words becomes appreciably less as the illumination is raised. It will also be noted that reading was faster with a sharp contrast between the type and its background. This latter fact is significant, since in the everyday uses of the eye, with the single exception of the printed page, brightness contrasts are seldom found as pronounced as black on white, which is the best condition for clear vision.

Eye Fatigue

It is a common experience that under a continuous gaze the eye becomes fatigued to such an extent that the details of the object viewed become blurred part of the time. Figure 4 shows the results of tests which have established the fact that under low illumination a fixed gaze fatigues the eye rapidly, whereas raising the illumination improves the clearness of sustained vision to a considerable extent. Here again the astigmatic eye is handicapped even more than the normal eye by insufficient illumination.

Glare and Vision

The foregoing tests have demonstrated rather conclusively that by increasing the quantity of light the speed and accuracy of vision are increased. This is only true, however, where the eyes are not subjected

to glare. It is generally known that the pupil -- the gateway of vision -- contracts very much when the eye is exposed to glaring light sources, but the practical effect of this contraction, which is Nature's safety valve, is usually overlooked.

When one looks at an object, an image of the object is formed within the eye, and nerves transmit the picture to the brain. The fundamental factor in vision is the brightness of this image, which is proportional to the area of the pupil and to the brightness of the object viewed. In the absence of glare the pupil automatically expands, which is equivalent to increasing the illumination on the object viewed.

To illustrate this point, suppose a workman has 10 foot-candles upon his work, but the lighting is so glaring that his pupils are contracted to a diameter of $1/8$ inch. A second workman also has 10 foot-candles upon his work, but the lighting units are of proper design and are hung well out of his direct line of vision, so that the absence of glare allows his pupils to expand to $3/16$ inch. The brightness of the image within the eye being proportional to the square of the diameter of the pupil, the images of the second workman will be about twice as bright as those of the first workman. Even though the intensity of illumination at the work is exactly the same in the two cases, the second workman is really enjoying the advantage of twice as much "seeing" light. His visual doorway is open a hundred per cent more than that of the first workman exposed to glare. There are other beneficial results arising from elimination of glare, such as greater comfort and safety, but the one just stated is directly measurable in terms of foot-candles.

Chapter II.

IMPORTANCE OF GOOD ARTIFICIAL SCHOOL LIGHTING

Correct School Lighting

What It Means:

Reduction in Eyestrain.

Better Progress in Studies.

More Cheerful Surroundings.

Greater Comfort, Safety, and Contentment.

Education in Good Lighting Through Experience.

How It Is Accomplished:

1. By Controlling Daylight:

Glass area of windows not less than $1/5$ of the floor area.

Desks arranged so that pupils do not face windows.

Width of room not more than twice the height of top of windows from the floor.

All windows equipped with proper shades to diffuse the light.

2. By Proper Artificial Light:

Approved standards of illumination intensities provided and maintained.

Lights shaded and proper distribution obtained by shades, reflectors, and enclosing glassware.

3. By Avoidance of Glaring Reflection:

Walls and ceilings finished with dull surface.

No glossy finish on desk tops or interior woodwork.

Dull blackboards.

Glossy paper avoided.

School Lighting As a Factor in Saving Sight

Eyesight conservation of school children is a problem of great national importance. Improper lighting is one of the direct causes of eyestrain which in turn produces such uncomfortable and harmful results as headache, unnatural weariness after study, bloodshot eyes, crusty lids, etc. Every effort should be made so to improve the lighting facilities of our schools that all children will enjoy equal advantages of normal physical and mental development. It is highly essential that the lighting of school buildings (both natural and artificial) be in accordance with approved standards. No child should be required to face the source of light, whether this be a window or a gas or electric light. Eyestrain will frequently result from such harmful practices, but it may be avoided by shading windows and by placing the lamps well above the direct line of vision and properly shading them.

Condition of School Lighting

Surveys of physical equipment of school systems made in different parts of the country show, almost invariably, that natural lighting facilities need improving and adequate artificial illumination is almost entirely lacking. The principal reason for this condition is that many school buildings were built years ago when the importance and value of proper lighting were not appreciated, and the science and art of lighting were very imperfect. This is particularly true in rural school districts, but exists to a surprising extent in many cities. Even some of our more modern school buildings have been planned without giving proper consideration to the arrangement of windows, the amount of window area, or the installation of adequate artificial lighting.

Demand for Good Artificial School Lighting

Artificial lighting should be provided for all schools. Although most of the school work is done in daylight hours, yet on cloudy or stormy days supplementary lighting is necessary. Artificial lighting must receive special consideration, for a satisfactory combination of natural and artificial lighting is one of the most exacting problems.

Moreover, during the last few years the schools have become overcrowded, making night sessions a common practice and good lighting is certainly required then. The method of securing this additional light should be given careful consideration.

To quote Dr. Wm. M. Howe, of the New York State Department of Education: "I believe that in time any school service that does not prevent most of these ocular defects, with which we are meeting so often, will be considered inefficient and derelict in its duty to school children. There is something intrinsically wrong in any educational system that permits from eight to fifteen per cent of our children to acquire defective vision within the few years of their school lives. Few children, as you may know, are born with defective eyes."

The fact that eye troubles are more prevalent among children in the advanced grades would indicate that this strain is increasing rather than decreasing. In most cases, the individual child receives his first exacting eye work when he goes to school, where from necessity a large quantity of printed and written matter has to be dealt with.

It can therefore be easily understood how a child, born with normal vision, but forced to do detailed work, oftentimes under poor illumination, develops poor eyesight. Indeed, one finds it difficult to appreciate the benefits of compulsory education when as a result of it many people are crippled in eyesight. It is essential to provide good illumination in the school in order that those pupils with normal eyes may see properly. In addition to this, it has been found that with adequate illumination pupils with defective vision are able to do much better work. Numerous cases have been reported where pupils were supposed to be mentally backward, where defective vision was later found to be the real difficulty.

In the majority of schools, the arrangements for daylight are generally satisfactory, but the artificial lighting may be very inadequate. Even today systems are in use which consist only of bare incandescent lamps and where reflectors are used, they are frequently inadequate or may be hung in such positions as to produce eyestrain. Again, the system may be otherwise properly designed, but the intensity of illumination be far too low.

Proper lighting of the school house should be considered not an expense but an economy. If, because of defective vision, a pupil is forced to spend one extra year at school, the cost of teaching this one student for a longer period than normally will much more than offset any of the expenditures necessary for proper lighting. Statistics reveal that these cases are legion.

The Development of the Art of Lighting

There are two distinct kinds of lighting in regular use by all civilized people. The first and most important is the light which comes to us from the sun. This is spoken of as natural lighting. The other is that devised by man to supplement the light of the sun and is called artificial lighting. Formerly people depended almost entirely upon the light from the sun. All work that required good light was done in the daytime. Lamps have been used for ages, but the older forms gave forth very little light. In fact while lighting is one of the oldest arts it has been one of the slowest to develop. There has been a greater development in artificial lighting in the last fifty years than there was in all the ages before, since the time when a flaming fire was the only source of light other than the sun. Within recent years there have been constantly increasing demands for artificial light that will take the place of sunlight. It would be difficult to conceive of not having light at night as well as during the day in our homes, our schools, public buildings, stores, and factories. Even though daylight is the most perfect form of light and artificial light has been wonderfully improved, care must be taken in the use of either, for eyestrain may be caused by faulty use of daylight just as it may be from wrong application of artificial light.

Elements of Lighting

Before discussing natural and artificial lighting separately, there are some principles applying to both which should be understood. Eyestrain may be caused by either daylight or artificial light. Either may be too bright or improperly directed, thus causing glare, or the illumination produced may be insufficient. The three important elements of lighting are referred to as:

1. Intensity.
2. Diffusion of light.
3. Distribution of light.

Intensity

It is self-evident that the proper amount of light must be supplied for any kind of work. The correct intensity is necessary in order that everything which is to be seen may be seen clearly and without fatigue. No matter what system is used, unless enough light actually reaches the desks, the lighting system is inadequate. It is not necessary to go into technical detail when we say that the unit of intensity of illumination is the foot-candle (defined as the illumination on a surface normal to a one-candle-power source at a distance of one foot). In an installation, we measure this value with a Foot-candle Meter or other portable photometer. The following table indicates the average intensity of illumination it is desirable to provide in the school house, the higher values representing the better practice.

Classrooms, study rooms.....	8-10 foot-candles on desks
Office.....	7-10 foot-candles on desks
Cloak room.....	1- 3 foot-candles on floor
Corridors and stairways.....	1- 3 foot-candles on floor
Laboratory.....	8-10 foot-candles on tables
Auditoriums and assembly rooms.....	3- 6 foot-candles on floor
Auditoriums and assembly rooms, if used for class or study purposes.....	8-10 foot-candles on work
Drawing, sewing.....	10-15 foot-candles on tables
Manual training, workshops.....	6-10 foot-candles on work

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Gymnasiums, swimming pools.....4-6 foot-candles on the space.

Even though we can supply adequate light for any process, it is inadvisable to allow the young child to do fine needlework under artificial illumination. The periods can be so planned that this may be carried on by daylight.

While such values as given above will produce satisfactory results, the higher, rather than the lower intensities are recommended. With the higher intensities, an increased degree of perception is obtained. If increased production in industrial plants and offices can be profitably brought about by high level lighting, why should not increased speed and accuracy of accomplishment on the part of pupils likewise be worth while?

As an unfortunate result of our economic system, students are usually compelled to work under less light than is provided in industry for similar operations. In reality, more light is needed, because the pupil in the process of learning has to give closer visual attention than a workman to whom a process becomes more or less automatic.

With the modern, very efficient Mazda C lamp, it is now possible to provide high level lighting and thus avoid eyestrain, at no greater cost than would have been incurred to secure a very low intensity, slightly over a decade ago.

To predetermine the results obtained from a given lighting system is a comparatively simple matter and several methods are outlined in Bulletin Index 13, entitled, "The Calculation of the Lighting Installation."

Diffusion

The harmful effects of glare can not be over-emphasized. The likelihood of glare from light sources is becoming greater and greater with the development of more efficient lamps with their increased intrinsic brightness. Practically all commercial light sources are far too brilliant to be in the field of view without producing a blinding effect and reducing the ability to see. When bright light sources are placed high above the head, the eyebrows protect the eyes, as will be noted out of doors under the noonday sun, but, from the construction of our buildings, illuminants must be hung rather low and come within the field of view. We therefore always reduce the brilliancy of the light by means of diffusing globes, shades, or reflectors, which either effectively enlarge the light sources or actually hide them from view.

Diffusion also softens the shadows so that severe contrasts are less likely to occur. It is not desirable, however, to go to such an extreme diffusion that we entirely eliminate shadows, for they are very essential to show the contour or shape of objects. Over-diffusion or flat illumination is trying to the eyes and unpleasant.

Not only must we take care of the light sources themselves in providing diffusion, but the walls and other objects must be given attention. Dull rather than polished surfaces are desirable here, and even a depolished or waxed finish is more desirable than varnished or highly polished surfaces on the desk and other furniture, as the latter produce mirrorlike effects in reflecting the light sources.

In this connection, attention should also be given to the desira-

bility of matt rather than glossy finished paper, for paper with a glossy finish likewise reflects light in an annoying manner.

When we think of diffusion, its antithesis, glare, also comes to mind and, as pointed out, intrinsic brightness is one of the greatest sources of glare, although it is not the only cause. A large area of low intensity may be very annoying. Everyone has experienced the glare from a cloudy sky. Excessive contrast may produce glare. This can be illustrated as follows: A bright incandescent lamp in a dark room is most annoying, whereas the same lamp viewed in an open window against the sky is not at all noticeable. This has a practical bearing in the school room where blackboards are adjacent to white walls of a high brightness.

Distribution of Light

Under this heading we have two extremes; one known as local lighting and the other as general illumination. In local lighting we provide relatively low candle-power light sources, located rather close to the work, furnishing a high intensity of illumination over a small area.

There is a tendency to use local lighting in drafting rooms, machine shops and sewing rooms. The lamp is often under the control of the pupil. He knows very little about the proper use of lamps and often works in his shadow. Good general lighting would, therefore, be much better. Local lights very often cause annoying glare to pupils at adjacent tables. The system is always unsightly, and the drop cords are often tied back, which is strictly against the rules for good wiring and a dangerous practice.

In general illumination much larger lamps are used, hung as high as possible, providing almost uniform lighting throughout the room; in fact, there is a much more uniform intensity across a room than is possible with natural lighting from windows as ordinarily placed. It simulates daylight, makes the room appear much brighter than local lighting; is, in general, independent of the arrangement of furniture and, without question, is the system best suited for schoolroom lighting. The wiring cost is much lower, there is less likelihood of glare, and no danger of breakage of lamps or reflectors.

The color of walls and ceilings has a very direct influence on the distribution and actual quantity of light delivered on the desks.

The Classroom

General Considerations:

It is natural to direct the light on the object to be seen and not to the eye; therefore, since it is necessary to hang lamps high and out of the line of vision, we equip them with reflectors or other devices to direct the light to the desks, or to the ceiling to be reflected downward. It is always desirable to shield or diffuse the light at angles near the horizontal and as even an intensity of illumination as possible should be provided throughout the room. While a certain variation in intensity of artificial illumination to the minimum intensity of artificial illumination, measured in foot-candles, and taken at the desk tops should be less than four. A symmetrical spacing of outlets is therefore essential.

More outlets are required for direct lighting than for the indirect systems, in order that multi-directional light may be provided.

It is always desirable to hang units as high as possible to keep them out of the field of view. No lighting units should come below a line extended from the eye of a student in the rear seat to a point two feet above the blackboard.

The wiring should be so arranged that the switches are readily accessible. It is often desirable to subdivide the circuit as follows: Have one circuit which controls the lamps near the teacher's desk so that he or she can work after hours without all of the room lighted; the remaining lights on a separate switch.

The fixture in the ordinary classroom serves a purely utilitarian purpose -- that of supporting the glassware and lamp. It should therefore be simple in character. The means of suspension of any type of lighting unit should be such that there is absolutely no danger of the glassware falling, and especially in the case of indirect units it is desirable to have some convenient means of cleaning.

Blackboards:

There is a likelihood of glaring reflections from blackboards and they should, therefore, always have matt rather than polished surfaces. It is sometimes possible to get rid of reflection by tilting the boards slightly. Blackboards which will be written on with colored chalks, and those that are more than twenty feet away from the pupil, should be especially lighted to an intensity approximately 50 per cent higher than the intensity in the rest of the room. This can be accomplished by the use of properly screened and judiciously placed local units similar to the systems commonly used on outdoor signs and billboards. For clear vision, black-

boards should not be located between windows.

Comparison of Various Lighting Systems:

Direct, semi-direct, and totally indirect systems are all employed for school lighting. Each has certain advantages and disadvantages which are outlined below. A number of factors must be taken into consideration which may be briefly stated as below:

Quality of illumination produced.

Convenience of maintenance.

Appearance of the installation.

Efficiency of the system.

Ability to provide the desired intensity.

Cost of installation.

Certain systems may appear to be most desirable from theoretical considerations, but may not work out well in practice. Obviously, the type of lighting unit to select is the one which will give a desirable quality of illumination in as efficient a manner as possible, over a long period. The proper maintenance of a lighting system in any class of service is of such importance that it has been deemed advisable to treat this subject in considerable detail in a separate bulletin, Index 14. Even greater emphasis must be laid on this question in the school, for supervision is at best meager and periods between cleaning of considerable length. These conditions should not exist, but nevertheless we must recognize that such is the case and take this into consideration when planning the lighting.

Total indirect lighting produces a very high quality of illumination, but requires a relatively large wattage for a given intensity. With such a system, there is little possibility of glare and the light is very soft and comfortable to work under. Glaring reflections are at a minimum. The inverted bowls, however, tend to accumulate considerable dirt and unless they are cleaned frequently the light output is materially reduced. A well supervised system of maintenance is absolutely essential where totally indirect lighting is installed. As pointed out, the results are excellent and one must expect to spend more money for obtaining the highest grade of a given commodity.

Semi-indirect lighting is an intermediate practice, most of the light from the lamps being directed to the ceiling, with a slight amount transmitted through the glassware. It is slightly more efficient than totally indirect lighting; the resultant illumination is well diffused and such shadows as are produced are very soft and do not cause annoyance. The best forms of semi-indirect units for school work employ dense glass or some other means of reducing the brightness of the lighting unit. A light density, semi-indirect unit, unless of very large size, becomes very bright and the system loses many of its advantages, because of the fact that a number of fairly bright objects are in the field of view. An open type semi-indirect unit is open to the same objections as a totally indirect fixture as to the accumulation of foreign material and depreciation of light output.

There has recently appeared on the market a number of totally enclosing, semi-indirect units which are relatively easy to clean and therefore offer special advantages.

In many of the older installations, open bottom, direct lighting units are used. Such a system is obviously efficient from the standpoint of light utilization, but the diffusion is not of the highest quality, shadows and contrasts are likely to be rather severe, and direct and reflected glare becomes serious, particularly if clear bulb lamps are employed. The use of this form of lighting is advisable only where costs must be kept at a minimum and where secondary consideration is given to the quality of illumination.

Where direct lighting is deemed advisable, dense opal or etched prismatic reflectors should be used. These transmit but a small portion of the light, and they, therefore, are not very bright. The diffusing bulb or bowl enameled Mazda C lamp should always be employed in preference to the clear lamp, as these finishes produce better diffusion, reduce reflected glare, and soften shadows.

The flat type reflectors should never be used in a schoolroom, for it is almost impossible to conceal the filament from view when using this style of shade. Opaque reflectors are, of course, generally unsuited, as the ceiling would be very dark when these are used.

In view of the above analysis, the enclosing, diffusing, direct lighting luminaire seems to be, at the present state of the art, the most generally applicable equipment for classroom lighting. If the proper type is chosen, a well diffused illumination, quite free from direct or reflected glare, is produced. Although the major portion of the light is directed downward, a considerable amount is transmitted upward, thus giving a cheerful appearance to the room and a character of illumination closely akin to

that produced by semi-indirect units. It is apparent that such equipment does not depreciate as rapidly with the accumulation of dirt as do other fixtures producing the same general quality of illumination. This should not be taken to mean that cleaning can be neglected, for it is always of prime importance.

The question has often been raised whether it is necessary to provide ventilation for a totally enclosing unit. Carefully conducted tests have indicated that, with sufficient radiating surface, in other words, an adequate size of fixture, ventilation is unnecessary when Mazda C lamps are used. Practically all types of fixtures on the market, of this nature, are sufficiently large to provide the necessary radiation. From a maintenance standpoint, ventilation is undesirable, for with it a current of air is passed through the fixture, and dust is naturally deposited on the glassware and lamp. With the fixture tightly closed, this action is negligible.

A number of factors must be taken into consideration when making a choice between commercial types of equipment of any one class. Considering, therefore, the type under consideration, i. e., an enclosing diffusing unit, one important element is the intrinsic brightness of the glassware. This is a function of the character of diffusion produced and the size of the globe or glassware.

If the diffusion is inadequate, as for example, that produced by a sandblasted clear glass globe, there will be a bright spot opposite the lamp and the rest of the globe considerably less brilliant. The brighter spot, of course, is the determining element. Assuming, however, that the globe gives good diffusion, the brightness will then depend on

the diameter of the globe and the size of lamp used. A given globe might be entirely satisfactory with a 100-watt lamp, but very unsatisfactory with a 300-watt lamp. For the positions and heights ordinarily encountered in classroom lighting, a maximum brightness of two to four candle-power per square inch should not be exceeded.

The succeeding chapter is devoted to an outline of the "Code of Lighting School Buildings." This code was published in 1918 by the Illuminating Engineering Society.

Chapter III.

CODE OF LIGHTING SCHOOL BUILDINGS

Introduction

In 1918 the Illuminating Engineering Society prepared and issued a code of lighting school buildings. Shortly after the publication of the code, the New York State Department of Education adopted it as a guide in planning the artificial lighting of school buildings in that State. The Industrial Commission of Wisconsin used the code as a basis for the preparation of the Wisconsin School Lighting Code, effective 1921. A number of provisions of the code have been incorporated in building codes in several States and municipalities.

Improvements in lighting practice during the past five years have made necessary a revision of the code to conform with modern standards; moreover, there has been a demand for more definite and detailed specifications than those contained in the 1918 code.

The accompanying code aims to meet this demand and is intended to serve not only as a guide for legislators, State and municipal departments of instruction, and other regulatory bodies interested in the formulation of enactments, rules, and regulations for the day-lighting and artificial lighting of school buildings, but also as a guide to architects in planning the lighting of school buildings and to school superintendents and other school authorities in bettering lighting conditions. A popularized brief of the code, now in course of preparation, is intended to serve as an aid to teachers in instructing children in the proper use of

the eyes and in the underlying principles of correct lighting -- an important part of the course in school hygiene that has received as yet but scant attention.

The code was prepared by a sectional committee consisting of representatives of organizations, societies, and individuals identified with the school-lighting problem in one or another of its various phases. The sectional committee was organized by the Illuminating Engineering Society and the American Institute of Architects, joint sponsors for the code, under the rules of procedure of the American Engineering Standards Committee. The code has been approved by the sectional committee, the Illuminating Engineering Society, and the American Institute of Architects.

Although the rules and recommendations of the code are based upon what is considered the best practice of the present time, it is probable that in the future modifications may become desirable as the art develops and as experience is gained in the application of the code.

Explanation of Technical Terms

In the rules and discussion of the code it is necessary to use some technical terms referring to the measurement of light. All such measurements are now based on standard lamps kept in the national standardizing laboratories of the various countries. The candlepower of these standards is fixed by international agreement, and other lamps are measured by comparison with them. The unit of candlepower is substantially the average intensity of the old standard sperm candle.

Every practical source of light has different candlepowers or intensities in different directions, and consequently "candlepower" is not a direct indication of the total light given out. In order to avoid ambiguity it has become customary in this country to rate lamps in terms of their total light output. The unit used is the lumen. The lumen is the light falling upon an area of one square foot all points of which are one foot distant from a source having an intensity of one candle. Such a surface receives an illumination of one foot-candle; in other words, one lumen of light flux is enough to furnish one foot-candle of illumination on 1 square foot. The lumens needed on a working surface are the product of the number of square feet of area to be lighted by the number of foot-candles required on the surface. The light output of an illuminant, as well as the light received on a given area may be measured in lumens.

No lighting installation can throw upon the working surface all the light produced. The coefficient of utilization of an installation with reference to a given plane is the ratio of the light flux (lumens) received on that plane to the total flux from the lamps illuminating it.

The reflection-factor of a surface is the ratio of the light flux reflected from the surface to the flux falling on it. Reflection may be regular, diffuse, or a mixture of the two.

Brightness as used technically means exactly what it does in common speech; that is, the intensity per unit of projected, or apparent, area of the source. The brightness of a surface may be due either to the

light emitted by it or to the light reflected by it and may be measured in various units; but in this code brightness values are stated in candles per square inch.

A luminaire is a complete lighting unit consisting of a light-source, together with its direct appurtenances, such as globe, reflector, refractor, housing, and support. The term is used to designate completely equipped lighting fixtures, wall brackets, portable lamps, or so-called removable units.

Rule I. -- Rules

General Requirements:

When in use during daylight hours, rooms in school buildings in which pupils are required to study or do any work shall be provided with natural light in accordance with the following rules.

When in use during periods when natural lighting fails, rooms in school buildings in which pupils are required to study or do any work shall be provided with artificial light in accordance with the following rules.

When in use, other rooms in school buildings, also school grounds, shall be provided with natural or artificial light in accordance with the following rules.

Rule 1. Illumination required:

The illumination -- natural or artificial -- maintained shall be not less than the minimum values in Table I. Values recommended for ordinary conditions of artificial lighting are presented in the last

Column. Higher values are often desirable.

Table I. -- Minimum values of illumination required and values recommended for artificial lighting.

	Minimum required foot- candles	Recom- mended foot- candles.
<u>On the Space</u>		
Walks, drives, and other outdoor areas, if used at night.....	0.1	0.5
Playgrounds, outdoor, if used at night.....	.5	2
Playgrounds, outdoor, if used at night for base- ball, basketball, etc.....	5.	10.
Storage spaces, passages, not used by pupils.....	.25	2.
Boiler rooms, power plants, and similar auxiliary spaces.....	1.	3.
Stairways, landings, corridors, aisles, exits, elevator cars, washrooms, toilets, locker spaces, dressing-rooms.....	1.	3.
Recreation rooms, gymnasiums, swimming-pools.....	3.	7.
<u>On the Work</u>		
Auditoriums, assembly rooms.....	2.	3.
Auditoriums, assembly rooms, etc., if used for class or study purposes.....	5.	10.
Classrooms, study rooms (desk tops).....	5.	10.
Classrooms, study rooms (charts, blackboards)....	3.	6.
Libraries, (reading tables, catalogues).....	5.	10.
Libraries, (bookshelves, vertical plane).....	3.	6.
Laboratories (tables, apparatus).....	5.	10.
Manual training rooms, workshops, etc.....	5.	10.
Drafting rooms, sewing.....	8.	15.

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• *Journal of the American Medical Association*, 2000; 284: 1039-1044

* *Journal of Management Education* 30(10):1139-1150, 2006. © 2006 Sage Publications

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Rule 2. Avoidance of glare:

Lighting whether natural or artificial shall be such as to avoid harmful glare, objectionable shadows, and extreme contrasts.

Bare light sources, such as exposed lamp filaments, gas mantles, or bright sky areas located within the ordinary field of vision are presumptive evidence of harmful glare. Seating shall be so arranged that pupils are not compelled to face windows. For specifications of definite requirements under this rule refer to Part III.

Rule 3. Distribution of Artificial Light:

Lamps, reflectors, or other suitable accessories shall be of such light-distributing character and shall be so installed in regard to mounting height, location, and spacing as to avoid excessive variation in illumination upon workplaces. In a classroom at the desk tops the ratio of the maximum intensity of artificial illumination to the minimum intensity of artificial illumination, measured in foot-candles, shall be less than 4.

Rule 4. Color and Finish of Interior.

In rooms in which close visual application is necessary, walls shall have a reflection factor within the range from 30 to 50 per cent. Ceilings and friezes (the latter in the case of high ceilings) shall have a reflection factor of at least 65 per cent. Desk tops and other woodwork shall have a reflection factor not exceeding 25 per cent. In corridors and halls, ceilings and walls shall have a reflection factor of at least 50 per cent. Dadoes and blackboards are obvious exceptions. Glossy finishes shall be avoided wherever they are likely to cause glare. The

preferred colors for walls are light warm gray, light buff, dark cream, and grayish green; for ceilings and friezes, white and light cream.

The nosing of treads on all stairs used as exits should be such as to show the edge of each step by contrast when viewed as in descending.

Rule 5. Switching and Controlling Apparatus.

Switching and controlling apparatus shall be installed at each point of entrance to school buildings, also in classrooms, basements, hallways, and stairways, also wherever required in other parts of buildings. Rooms having several entrances require such equipment only at the principal entrances.

Rule 6. Exit and Emergency Lighting.

Artificial lighting to be provided under rule 1 in all stairways and exits and in the passageways appurtenant thereto shall be supplied preferably from an independent source or from a connection extending back to the main service entrance for the building so that failure of room lighting from internal causes will not affect the exit and emergency lighting. In case of unusual danger which may exist on account of type of building, nature of the work, crowded conditions, or lack of suitable exit space, an independent service shall be insured by connecting to a separate source of supply without or within the building.

Classrooms and auditoriums during stereopticon and motion-picture exhibitions may be dimmed. After dark, if more than 50 persons are gathered in rooms having an illumination less than 0.1 foot-candle, the exits from rooms and all passages to the exits of the building shall

be indicated by adequately illuminated exit signs, so as to clearly indicate the paths of safe exit from the building in case of emergency.

Rule 7. Inspection and Maintenance:

All parts of the natural and artificial lighting systems, including windows, skylights, lamps, luminaires, walls and ceilings, shall be systematically inspected and properly maintained and cleaned so as to assure illumination levels indicated in rule 1.

Rule 8. Blackboards:

Blackboards shall be illuminated and located with respect to light sources so as to avoid glare. The surface of blackboards shall be made and kept as dull as possible. Blackboards shall not be located in the same wall with windows.

Chapter IV.

NATURAL LIGHTING

In the preceding chapter, certain rules concerning the natural lighting of school buildings are given in the "Code of Lighting School Buildings." In addition this chapter will be devoted to a discussion of natural lighting.

We are dependent upon the light from the sky for all our natural lighting, and since it is superior to any form of artificial light, every means should be provided whereby it may be utilized as much as possible. Windows and skylights are the direct means by which daylight is admitted to the classroom. The securing of an adequate amount, therefore, depends upon the design of the building. The architect who plans the building is responsible for this. He should design the school building so that each room will have windows of sufficient size and number. Furthermore, the windows should be properly located and the rooms should be of suitable proportions. It is also important to consider the location of the building with respect to other buildings. This is especially true in large cities where nearby buildings are high. Not only is the relative position and size of nearby buildings important, but also the kind and color of material in their walls. A dark wall of another building which is close to the windows, lessens the intensity of daylight coming into the room by reflection. Oftentimes nearby high buildings cut off the daylight almost entirely, and in this case artificial lighting is the only remedy and its development has been discussed in the preceding chapter.

Systems of Natural Lighting

The two most common arrangements of the windows for providing natural illumination in school rooms are unilateral and bilateral.

The former is secured when windows are located entirely on one side of a room, and the latter when windows are placed on two sides of a room.

In many of the older school buildings the rooms were so designed as to have windows on as many sides as possible. If it was possible to have windows on one side only, no particular attention was paid to the arrangement of the desks relative to the windows, but in the last few years, the design of school buildings has improved to a great extent.

One of the fundamental rules for proper lighting of desks from windows in the walls is to have the dominant light come from the left side. For typical conditions, authorities on daylighting advocate unilateral lighting from the left side. If the room be unusually wide, this type of lighting will be insufficient and windows should be placed at the left and rear of the room. Windows at the left and rear are preferable to windows on left and right sides, because of the disagreeable cross shadows created by light sources on opposite sides.

For rooms of unusual width such as auditoriums, daylighting may be provided from windows on opposite sides of the room. Cross shadows in an auditorium are not as disagreeable as in small classrooms. Natural lighting from overhead sources, such as skylights, has very little applica-

tion in ordinary classrooms. It is used however in assembly rooms, auditoriums, libraries, and rooms with relatively high ceilings. Whenever this overhead source of natural illumination is used, the light should come from a north skylight or saw-tooth roof construction, and should be so located as to avoid direct sunlight.

The architect of a school building should arrange the number and size of the classrooms to comply with the rules regarding required window area. The room should be so designed that no work space is more distant from the window than twice the height of the top of the window from the floor. Although there is a varied opinion as to the size of classrooms, the dimensions recommended in the Code are 28 to 32 feet long by 22 to 24 feet wide, with a ceiling 12 to 14 feet high. As stated in a previous paragraph, the arrangement of the desks in a classroom is a very important factor. The sky as seen through a window or skylight is a source of glare and for this reason the desks should be arranged so that no pupil is required to face the windows or skylights.

Windows

As the windows of a schoolroom are the medium through which daylight is admitted, their importance can not be overestimated. Tests of daylight in well lighted school buildings indicate that, in general, the window-glass area should not be less than 20 per cent of the floor area. As the upper part of the window is more effective in lighting the interior than the lower part, it is recommended that the top of the glass be at no greater distance than six inches below the ceiling. The sills of side windows should not be less than 3 feet or more than 4 feet above the floor. No direct light should reach the eyes of seated pupils from below the horizontal.



Fig. 5—Good daylighting of a school library.

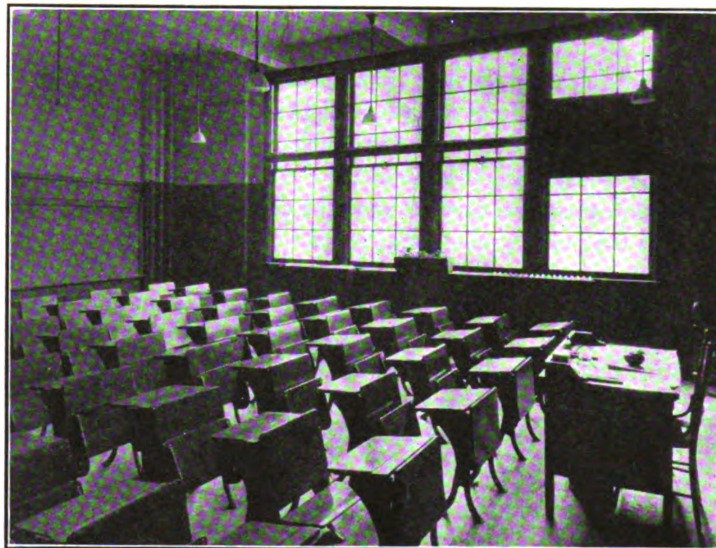


Fig. 6—Interior view of a classroom showing excellent arrangement of windows. Note the double shade rollers placed at middle of windows which permit either the upper or lower part of the window to be shaded independently.

The lighting value of a window at any given location in the room will depend primarily upon the brightness of the sky, the amount of sky visible through the window at the given location in the room, and secondarily upon the reflection factor of the surroundings and the dimensions of the room.

Observations in well lighted schoolrooms having a comparatively unobstructed horizon show that under normal conditions of daylight satisfactory illumination is usually obtained when the visible sky subtends a minimum vertical angle of 5° at any work-place of the room. It is recommended that a sky exposure for any pupil's desk in the room be at least 50 square degrees, preferably about 5 degrees vertically and 10 degrees horizontally. This should be borne in mind when selecting sites for new buildings as the proximity of adjacent buildings may seriously interfere with the natural lighting.

Window Shades

Although direct sunlight is desirable in interiors from a hygienic standpoint, it is often necessary to exclude or diffuse it by means of window shades. Shades should perform several functions such as the diffusion of direct sunlight; the control of illumination to secure reasonable uniformity; the elimination of glare from the visible sky or from bright areas outdoors, such as light courts, or adjoining buildings; and the elimination of glare from blackboards.

These requirements can be met by a number of arrangements, several of which have been found satisfactory and easy to maintain. For instance,

windows can be equipped with two shades operated on two rollers. These can be arranged with both rollers at the middle of the window, one operating upwards and the other downwards, or with one roller at the middle and one at the bottom, both operating upwards. Shades so placed may be operated independently, thereby facilitating the shading and diffusion of the light.

Instead of two shades a single shade can be used with a device that permits the roller to be placed at any position on the window. Such a shade can be so placed that the light will come in from the top of the window and will be shut out from the lower portion, or the middle portion. Another way of controlling the light is to use a translucent shade, which unrolls from the top down, and an opaque shade which unrolls from the bottom upward. Since it is the top portions of the windows which supply the illumination to the spaces in the room farthest from them, it is bad practice to cut out light by pulling down the shade from the top more than is absolutely necessary. Pulling down a shade from the top also interferes with ventilation when windows are lowered from the top.

The material of the shades should be sufficiently translucent to transmit a considerable percentage of the light and at the same time diffuse it. Their color should be such as to harmonize with the interior decorations of the room. A translucent shade transmits a considerable amount of light, hence care should be taken that this transmitted light not only harmonizes with the color of the room but meets visual requirements. A light tan or a light buff material will, in general, be satisfactory. With such shades it is possible to exclude all direct sunlight and at the same time to permit a considerable amount of light to reach the ceiling, which light in turn is diffused throughout the room.

Shades should be wide enough to cover the window and to extend over each side of the window frame so as to prevent direct light from passing its edges.

Chapter V.

TYPES OF ARTIFICIAL LIGHTING

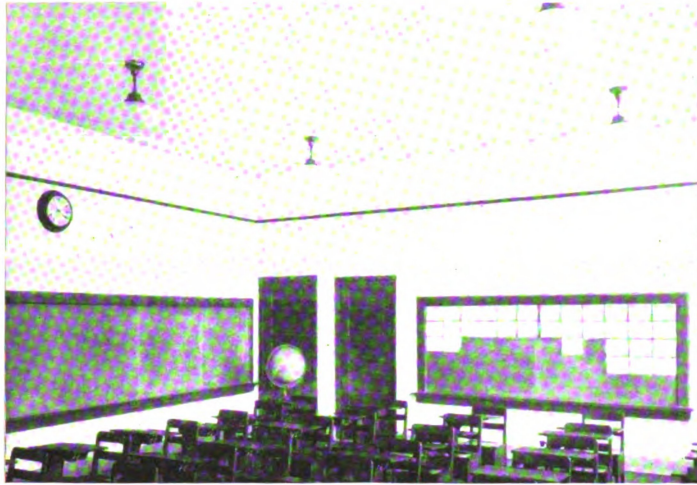
Requirements for Artificial Lighting

The design of an adequate and suitable artificial lighting system for school buildings requires the careful consideration of scientifically trained lighting experts, who have devoted years of study to the practical application of the principles of modern illumination. It is not possible in this brief sketch to discuss in detail the observations and calculations that must be made in order to design a system that is scientifically correct. On the other hand, it is possible to understand some of the more important principles which are recognized as fundamental requirements for good artificial lighting. These general requirements may be briefly stated as follows:

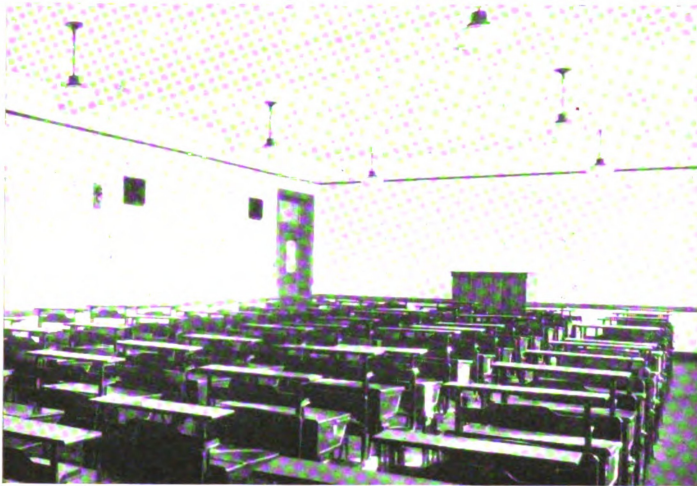
1. The required intensity of illumination should be provided for every work space, and every room according to the use to be made of it.

2. The lighting should be such as to avoid harmful glare, objectionable shadows and extreme contrasts.

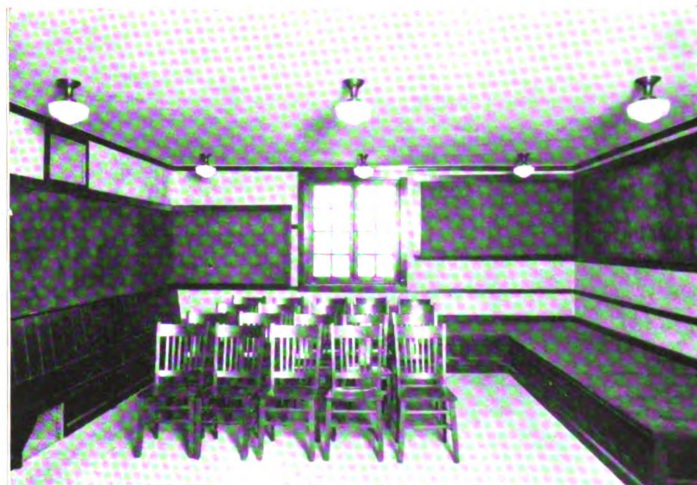
3. Lamps, reflectors, or other suitable accessories should be installed with regard to mounting height, location and spacing so as to secure an even distribution of artificial light over the work space.



Classroom; direct lighting units spaced about 11 feet apart; 200 watt lamp.



Study room; direct lighting units spaced about 12 feet apart; 300 watt lamp



Classroom; direct lighting units spaced about 9 feet apart; 150 watt lamps

4. The system should be operated from a source of supply that will insure continuity of service and steadiness of light.

5. Adequate maintenance of the entire system should be provided so that maximum efficiency is always secured. This includes cleaning and the replacement of burnt-out lamps or gas mantles.

Lighting Systems

In general there are three distinct systems of artificial lighting, namely; direct, semi-indirect, and indirect. These names are descriptive and designate broad classes of lighting, the boundary lines of which are indefinite.

The direct-lighting systems deliver at least half of the light below the horizontal so that the dominant light on the work places is received directly from the luminaires. Such systems may be divided into two groups; the direct-lighting system employing open-bottom luminaires and the direct-lighting system using inclosed and semi-inclosed luminaires.

An open-bottom luminaire direct-lighting system is one in which the dominant light reaches the work places directly from the luminaires which are open at the bottom and in which the light source may be seen from below. Such a lighting system may be further classified as local or general. In the former the luminaires are placed close to the work and illuminate a very limited area; in the latter they are installed overhead in such a way as to illuminate the whole room area as well as the limited area upon which the work is done. An inclosed luminaire is one in which the light source is completely surrounded by the globe and holder.

Some luminaires (sometimes termed semi-inclosing) having open or clear glass spaces in conjunction with diffusing glass, opaque reflecting surfaces, etc., may be considered from the standpoint of lighting to belong to the direct-lighting class.

A semi-indirect system is one in which an appreciable portion of the light reaches the work place directly from the luminaire, but in which more than half of the light is directed to the ceiling and upper walls and thence reflected to illuminate the work places. A semi-indirect luminaire usually consists of a lamp equipped with a diffusing bowl or inverted glass reflector. The relation between the relative amounts of light above and below the horizontal through the light center of such a unit depends largely upon the character of the transmission of the bowl. When the glass bowl or inverted reflector of the semi-indirect luminaire has a high transmission, the illumination approaches that of direct lighting, and when of low transmission the effect approaches that of indirect lighting.

A totally indirect-lighting system is one in which all of the light reaches the work indirectly after reflection from the ceilings and walls. The luminaire usually consists of a light source equipped with an opaque bowl or inverted reflector.

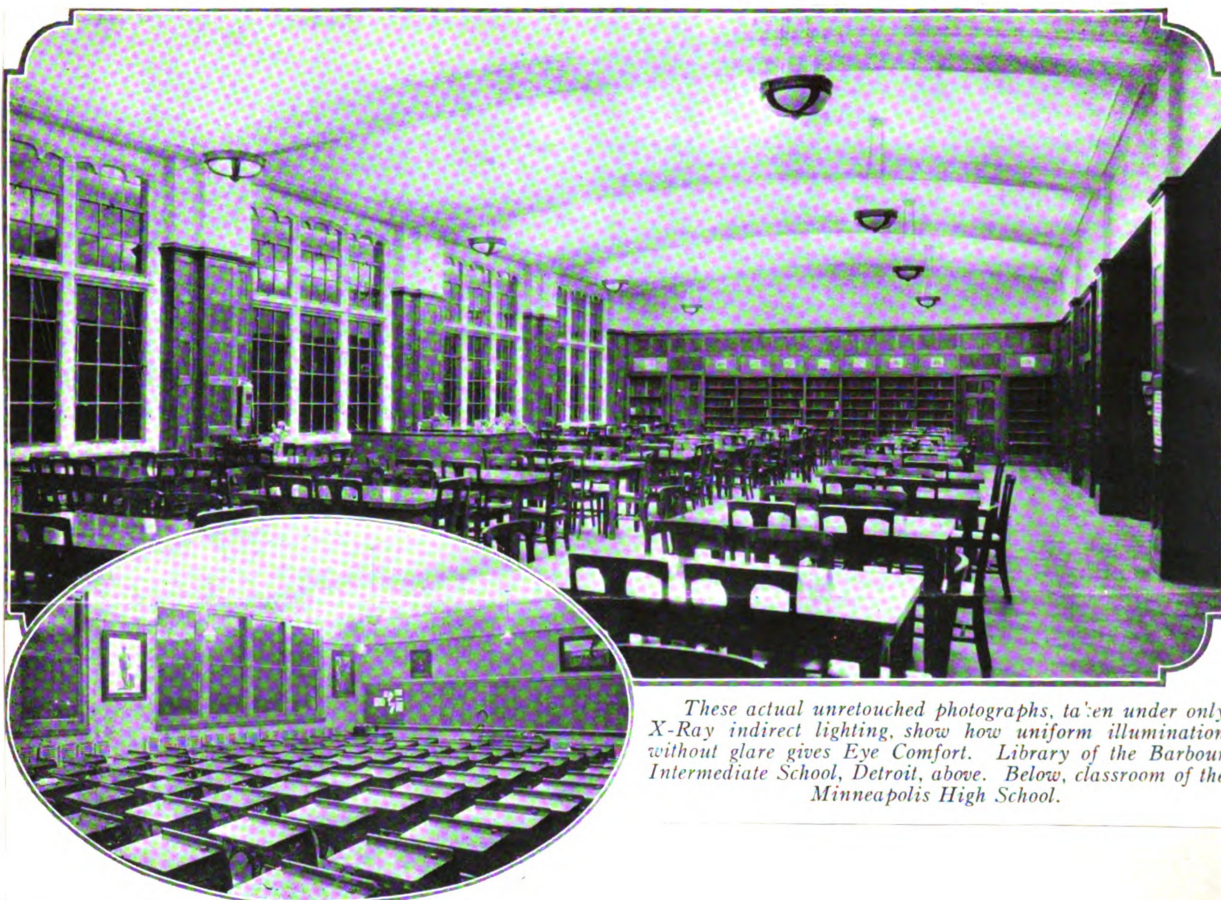
Direct-lighting systems. The open-bottom luminaire is subject to criticism even though the light sources are shielded from the normal angle of vision because of the harshness of shadows and the glare due to reflected images of light sources on shiny paper, textbooks, and polished

desk tops. Diffusing-bulb or bowl-enamelled lamps or frosted inner cylinders for gas effect a considerable improvement when used in this type of luminaire. One of the chief advantages of this type of equipment is its relatively high efficiency.

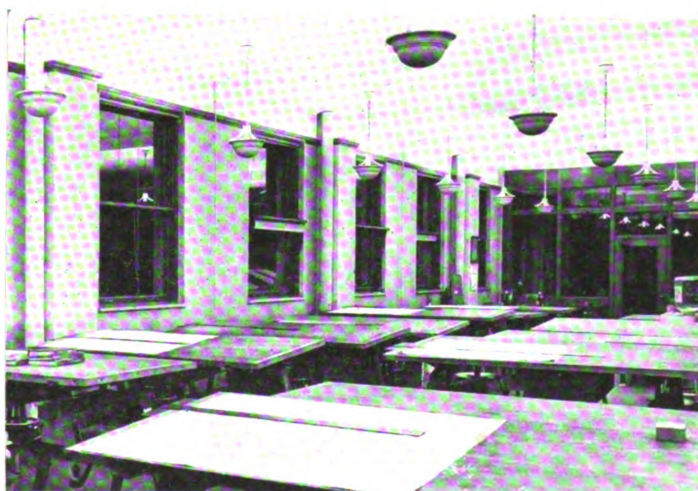
The inclosed luminaire, when made of a good diffusing glass and of sufficient size to insure low brightness of both the luminaire and reflected images, produces satisfactory lighting results from the standpoint of shadows and glare. Furthermore the coefficient of utilization is high. The depreciation due to the collection of dust and the resultant loss of light are less than in most systems. Partly because of economy, the inclosed unit is one of the practicable solutions of school-lighting problems. It is generally advantageous to select glassware having the horizontal dimension large as compared with the vertical dimension in order to obtain a satisfactory utilization of light.

The semi-indirect system employing good diffusing glass, of sufficiently low transmission to insure low brightness, provides excellent lighting. Inasmuch as this system employs the ceiling and upper walls for redirecting a large part of the light reaching the work place, these surfaces should have fairly high reflection factors. For this reason these surfaces should be properly maintained. When used in smoky or dirty environment very material losses in the illumination result unless frequent cleaning is adhered to.

The indirect system provides excellent lighting as characterized by the desirable qualities of good distribution, absence of strong shadows, and low surface brightness. As in the case of the semi-indirect luminaire,



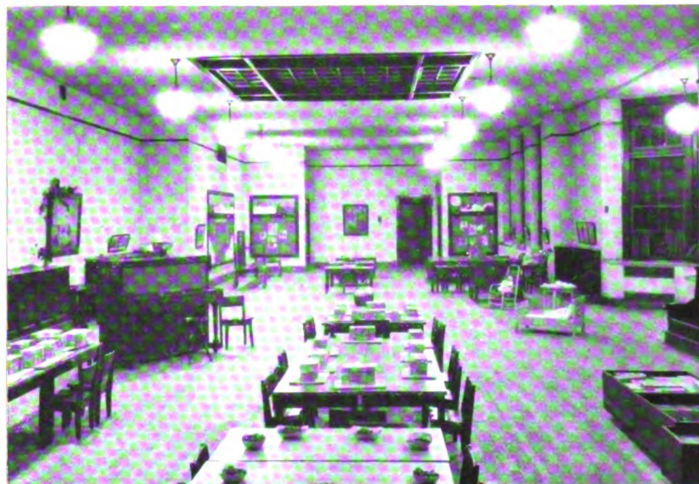
These actual unretouched photographs, taken under only X-Ray indirect lighting, show how uniform illumination without glare gives Eye Comfort. Library of the Barbour Intermediate School, Detroit, above. Below, classroom of the Minneapolis High School.



Mechanical drawing room; indirect lighting units spaced about 10 feet apart; 300 watt lamps



~~Figure 1~~
A Kindergarten Room Illuminated by the Totally Indirect Method. The eyesight of the young child should be carefully protected and would be with such lighting



Kindergarten; direct lighting units spaced about 10 feet apart; 200 watt lamp.

ceiling, upper walls, and the luminaire require frequent cleaning in order to maintain the illumination intensity for which the installation was designed.

There is comparatively little choice between the various fixtures of the type under consideration as to their efficiency with light colored surroundings. If the ceiling is dark, it is apparent that any type which emits considerable light upward will not be as efficient as the semi-enclosing unit or those provided with some sort of a reflector which have the property of directing the major portion of the light into the lower hemisphere.

The shape of the uniformly diffusing globe is, however, very important. The squat or flat type is more efficient than the spherical or stalactite shape in directing the light downward and emitting less toward the upper part of the side walls where it is of comparatively little service.

Light on the ceiling is not at all objectionable, in fact, is desirable, as when reflected downward it reduces contrasts and softens shadows. Therefore it is generally advisable to paint the ceiling a light tint, regardless of the type of lighting installed.

The general appearance of the units is important, but this is largely a matter of personal taste and impossible to evaluate.

Any decorations of glassware should be very simple, for appearance of excessive ornateness is out of keeping with the character of the

schoolroom. Deep crevices in the glass, although they might be considered decorative, would be objectionable from the standpoint of dust accumulation.

A typical specification for a suitable school lighting unit of the diffusing inclosing type might be drawn up as follows:

The glassware shall be of thin blown opal or cased glass giving diffusion of the same order as that produced by (substitute trade name of suitable diffusing glass, such as Genco, Radiant, or Monax).

It shall be of such a size that the brightness, with recommended size of lamp, is not over (substitute desirable candle-power per square inch).

The light output of the complete unit with holder shall be better than (substitute per cent of clear bare lamp output desired).

It shall be of such a shape that a horizontal section is greater than a vertical section.

The supporting holder shall be sufficiently strong and of such a type as to preclude any possibility of the glassware falling.

The method of support shall be such that the globe can be readily removed for cleaning.

Similar specifications can be readily drafted for other forms of equipment.

Wash, Locker, and Cloak Rooms

The lighting of these portions of the building is purely utilitarian. The decorative element is not especially important; the desirable intensity of light should be supplied in the most efficient manner. Direct lighting with prismatic or dense opal bowl reflectors, with outlets spaced symmetrically throughout the room is suitable, allowing from $\frac{1}{4}$ to $\frac{1}{2}$ watt to each square foot of floor area.

Cafeterias and Lunch Rooms

Many of the schools today have cafeterias or lunch rooms and in order to utilize less valuable space are often located in the basement. On account of such locations artificial illumination is frequently required even in the daytime and consequently adequate provision for these places is essential.

An even intensity of illumination from two to five foot-candles is desirable. Inclosing globe glass reflectors with Mazda C lamps are well suited to places of this kind as shown in Figure 13.

Corridors

While the primary function of corridor illumination is to provide light for anyone to pass along without danger of stumbling or interfering with another person, yet the general appearance must be taken into consideration. Frequently a small, ornamental type of fixture is desirable, particularly in the lobby and main corridors.

The lighting can be accomplished with relatively low-wattage lamps, on fairly wide spacings, provided diffusing glassware is employed.



FIG. 15
Night Photograph of a Gymnasium Locker Room Lighted by 60-watt Clear MAZDA B Lamps in Flat Prismatic Glass Reflectors. The room is finished in dull gray paint, and lamps are spaced 8 by 14 ft. located close to the 11-ft. ceiling



FIG. 16
Night View of a Swimming Pool Lighted by 150-watt MAZDA C Lamps in Round Glass Globe Reflectors. The average intensity is two foot-candles. Note that the lighting equipment is accessible from the edge of the pool, a desirable practice. When properly arranged, lighting fixtures are not necessary over the middle of the pool as evidenced here



FIG. 12

Night View of a School Corridor. A simple type of diffusing globe with 150-watt MAZDA C lamp is used on 26-foot centers. The corridor is 15 ft. wide and the intensity on the floor is approximately two foot-candles



FIG. 13

Night View of a Well Lighted High School Cafeteria. Enclosing globe glass reflectors with 100-watt MAZDA C lamps spaced on centers 11 by 12 feet give an average intensity of three foot-candles

Uniform illumination is not necessarily essential. Smaller sizes of the same general type of equipment as used in the classroom can be utilized for the corridor. A row of outlets, symmetrically spaced along the center line of the ceiling, is generally to be preferred, although sometimes the structure is such as to make ceiling outlets inadvisable. In these cases, brackets, or wall fixtures, must be employed. In general, 75-watt Mazda C lamps on 12-foot centers are adequate. With corridors over 8 feet wide, larger lamps are necessary.

Miscellaneous Rooms

The machine and pattern shops have especial demands for artificial illumination which are quite different from those of the other parts of the buildings.

The laboratory requires a relatively high intensity of illumination in order that the progress of experiments may be carefully watched. The general layout suggested for the classroom is satisfactory for the laboratory. In the chemical department, however, acid fumes will attack metal parts of ordinary fixtures and soon make them useless. For this reason porcelain enameled reflectors and porcelain receptacles or sockets are well adapted. The RIM standard dome reflector with bowl enameled Mazda C lamp makes an excellent lighting device for such rooms. It is efficient, durable, inexpensive, and diffuses the light satisfactorily, and likewise the Glasteel diffuser with clear Mazda C lamp is well suited to the laboratory.

Convenience outlets (baseboard or floor receptacles) are a most desirable feature of the wiring layout for the school. These enable vac-

uum cleaners, electric floor mops, and scrubbing devices to be used at will. They provide a means of attaching electric fans and other appliances of this nature.

The stereopticon and motion picture machines are becoming important factors in our educational system. Every classroom should have an outlet to which these can be attached.

The auditorium should have a well equipped motion picture booth for exhibiting standard films. The Mazda lamp for motion picture projection, with its economy and convenience of operation, is a boon to the school.

In the manual training room, convenience outlets are advisable, with a capacity sufficient to take care of electrically heated glue pots and small motors. In the physics, chemistry, and biology laboratories, each station should have its convenience outlet to which the student can attach electric bake ovens, centrifugal machines, immersion heaters, and other appliances.

Gymnasium

General Considerations - Main Exercising Floor:

This is usually rectangular in shape with a moderate height of ceiling. The arrangement most frequently used has the running track as a balcony 6 to 8 feet wide around all four sides of the room. In the center of the main floor are the principal pieces of apparatus, horses, bucks, jumping standards, and parallel bars, while the flying rings and horizontal bars hang from the main ceiling. These can usually be pushed

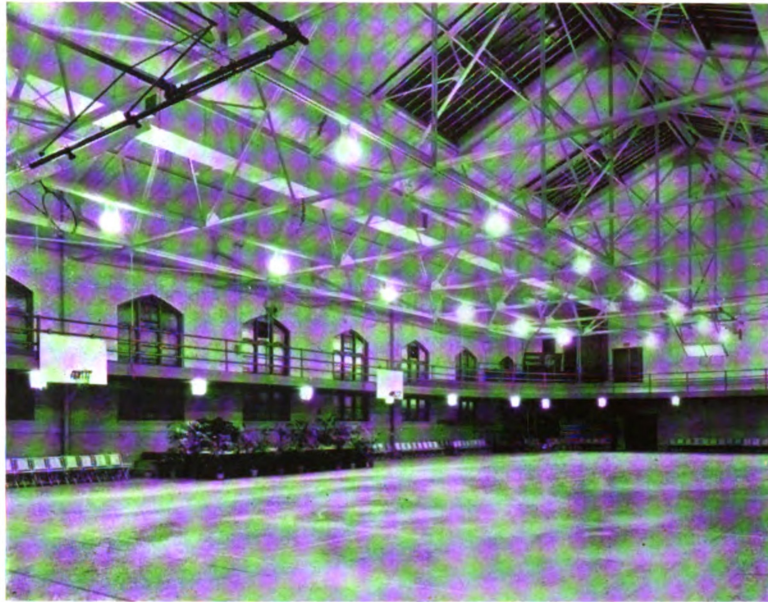
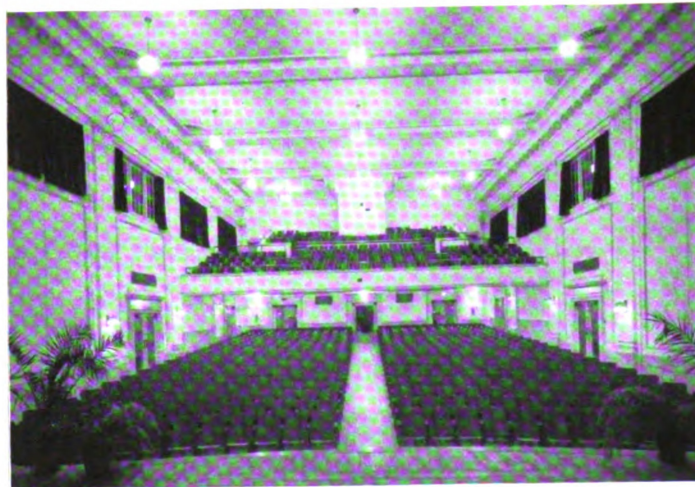


FIG. 12

Night Photograph of a Gymnasium Lighted by 300-watt Bowl Enameled MAZDA C Lamps in Holophane #651 Units. The Spacing is 18 ft. by 18 ft. and The Hanging Height 22 ft. An Intensity of 6 Foot-candles is Provided on the Floor



Auditorium; direct lighting units spaced about 15 feet apart; 200 watt lamps

aside or drawn up out of the way for basketball, indoor baseball, and wrestling matches or practice. Below the balcony are found the exercisers of the various types and racks for wands, dumb-bells, and Indian clubs.

The center part of the space requires even illumination of a moderate intensity with lamps so located that the hanging apparatus will not cause dense shadows. Particular attention should be paid to the shielding of the eye from the lamp filament, for one is forced to look upward a great deal when playing basketball and often faces the ceiling in ring and bar work. A blinding effect is particularly serious at such times and may cause a bad accident.

The illumination on the apparatus attached to the side wall below the track need not be as high as in the open space, yet in many cases it is necessary to provide a few outlets here with small lamps properly shaded to prevent dense shadows.

An average intensity of illumination ranging from four to six foot-candles is desirable. Different types of reflecting equipment may be employed but the average practice indicates a preference for some one of the three types of direct lighting reflectors, viz., RIM standard dome, deep bowl glass, inclosing globe glass. Wire guards are usually provided to protect the reflectors or lamps, or both, as the case may be. When open mouth reflectors are used bowl enameled Mazda C lamps are desirable in order to reduce the glare, except that with hanging heights of 18 feet or over clear Mazda C lamps will be satisfactory.

In some instances, the ceiling of the building is of such a character that efficient lamps in deep bowl mirrored glass reflectors can be recessed so that the mouths of the reflectors are flush with the ceiling. This arrangement directs light strongly downward; lamps are not visible unless one looks directly upward and there is no danger of breakage.

Sometimes when opaque reflectors are used for direct lighting, a number of small lamps are also provided in inverted reflectors which direct light to the ceiling and prevent this from being totally dark.

Where direct lighting with opaque reflectors is employed for the main portion of the floor, it is sometimes advisable to utilize bowl shaped opalescent glass units beneath the running track or balcony. These provide good illumination on the side wall apparatus and at the same time emit some light in a horizontal direction, overcoming the "dead" effect which results if only strongly directional light is employed.

Swimming Pool:

This room, from a lighting standpoint, is practically a modified Ulbricht sphere, for the side walls and ceiling are generally white tile. The type of reflecting device employed makes but little difference in the illumination. Care should, of course, be taken to insure satisfactory eye protection.

An examination of eight pools using the following reflecting devices, prismatic glass bowl, opalescent glass bowl, mirrored glass bowl, and enamel steel reflectors, showed the watts per square foot employed

to vary from .3 to .7 with an average of .5.

Shower and Locker Rooms:

In the shower room, there is no special problem in regard to lighting, but on account of the high percentage of vapor present in the air, it is advisable that moisture-proof electric fittings be employed.

In the locker rooms, double rows of lockers with aisles between in most cases extend to the ceiling. The athletes dress in these aisles. Mirrors are ordinarily placed at the ends of rows on the main aisle. Low ceilings of light color make practical the use of low candle-power, all frosted lamps without reflectors, with sockets set flush. In a number of the installations examined 25-watt Mazda B lamps are used on 8 foot centers. Larger lamps with suitable reflectors localized near the mirrors on the main aisle are essential. A 75-watt Mazda C lamp with bowl-shaped dense opal reflector between pairs of mirrors proves satisfactory.

Running Track:

Although in most cases this extends about the main exercising room and the general illumination is sufficient for the track, sometimes a long track is installed in the form of a low tunnel. For such conditions, angle type reflectors pointing in the direction the runner is proceeding avoid any likelihood of glare and direct the light where it is required.

Miscellaneous Exercising Rooms:

These comprise the wrestling, boxing, and fencing rooms, together with the medical director's office. Fencing requires a relatively high in-

tensity of illumination and it is probable that one room only will be provided for all these sports. In such cases the lighting layout must be considered from the standpoint of fencing.

Since the action is rapid, it is essential that the light be well diffused and of high intensity in order that all movements may be readily followed.

The finish of these rooms is usually light in color with smooth ceilings, making indirect and semi-indirect systems of illumination quite feasible. Approximately 1.5 watts per square foot of floor area with Mazda C lamps prove satisfactory with semi-indirect lighting. As the rooms are often decorated with prizes, pennants, etc., the decorative element of the fixture is important.

In the medical director's office, the ordinary requirements for office lighting are experienced, as well as the necessity for plenty of light in all parts of the room for physical examinations. Totally indirect or dense glass semi-indirect units are suitable.

Many of the companies that design lighting systems for public buildings, are recommending indirect units or lighting from concealed sources. It is a difficult task to convince men who have not made a study of scientific lighting, that light from concealed sources is better than direct or even semi-indirect lighting. In the first place, the fixtures are more expensive, due to their size, and also the installation costs are much higher. Indirect lighting units that hang from the ceiling are usually larger than

direct units and the necessary equipment is more difficult to install and more expensive. Then in most cases higher wattage lights are required to give the necessary intensity than when using direct units. All of these factors tend to discourage members of a school board or directors of an organization who are contemplating on installing new lighting fixtures in the buildings under control. Then, too, in many places where indirect lighting would be advisable, artistic tastes take precedence over proper lighting requirements. People want the light source exposed at least enough to know where it is and depend on the exposed portion for color effects.

In schools, however, the problem of properly lighting the room should have precedence over all other factors pertaining to the lighting equipment. A bright light fairly in the field of view means a very brilliant light on the retend, producing fatigue. Everyone knows the blinding sensation of looking up to the sun with its effect of colored images. When a bright light is in the field of view, the pupil tries to shut it out; and in so doing it renders all things less visible. An example which illustrates this point, is the difficulty a person has in driving an automobile with the bright lights of an approaching car shining in his face.

One of the objections to indirect lighting units, is that the maintenance is high due to dust and dirt collecting in the bowls. Many concerns have concentrated their efforts in attempts to remedy this feature. There are now on the market several types of enclosed indirect units. The upper portion of the globe is of very thin, clear glass and the lower portion practically opaque to light rays. This type of unit has the advantages of the closed semi-indirect unit and also the good lighting feature

of the indirect unit. Units of this type are being used in many of the new schools and other public buildings.

Chapter VI.

DESIGN OF LIGHTING INSTALLATIONS

The subject is too involved to be handled in a short treatise unless limitations are set on the scope of the discussion. These considerations therefore will be confined to the design of a lighting installation for a classroom 32 feet by 24 feet, with a ceiling height of 12 feet, the ceiling having a reflection factor of 70 per cent and the walls having a reflection factor of 50 per cent.

To comply with rule 2 on the "Avoidance of glare" it is necessary to diffuse and redirect the light proceeding from the filament or mantle. To comply with rule 3 on "Distribution of light" it is necessary to specify the number of lamps, their size, spacing, hanging height, etc. Rule 4 on "Color and finish of interior" plays an important part in this discussion.

For the sake of simplicity and brevity a typical lighting installation, employing totally inclosed diffusing luminaires, will be discussed.

The factors which should be considered in determining the size and number of lamps to be used in a given room are: First, the illumination in foot-candles to be supplied; second, the floor area, which in this case is 32 feet by 24 feet or 768 square feet; third, the amount of light in lumens emitted from each lamp obtained from Table II; fourth, the coefficient of utilization of the lamps and their accessories as installed in the room. The last quantity involves many factors, such as the relative

dimensions of the room, the reflection factor of the surroundings, the number and character of luminaires, their locations and hanging height. In Table III coefficients of utilization for modern lighting equipment are given for a typical standard classroom. These values refer to the initial installation without any allowance for depreciation due to aging of lamps and dust collection. The plane of the work in this case is the desk tops, generally 24 inches above the floor.

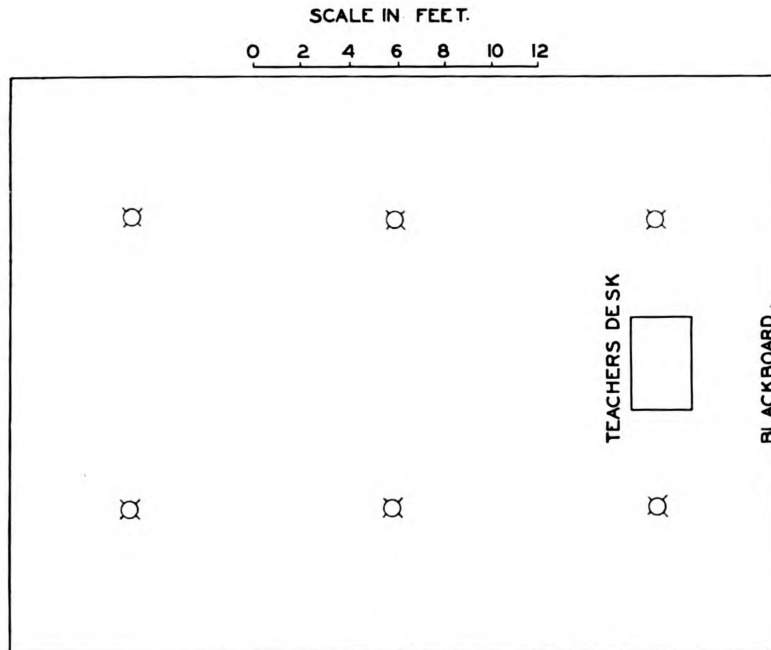
Table II. Luminous flux emitted: By gas-filled incandescent tungsten lamps.¹

(Standard lighting service 110 - 115 - 120 volt)

Lamp size (watts)	Clear lamp (initial lumens)
75.....	885
100.....	1,290
150.....	2,145
200.....	3,060
300.....	4,950
500.....	9,050
750.....	14,325
1000.....	20,000

¹These data, while correct at the time of writing, are subject to change.

Note:- "Daylight" lamps of a given wattage emit approximately two-thirds the amount of light emitted by the clear lamp. The "daylight" lamp is a gas-filled tungsten lamps with a blue-glass bulb producing light more closely approximating daylight.

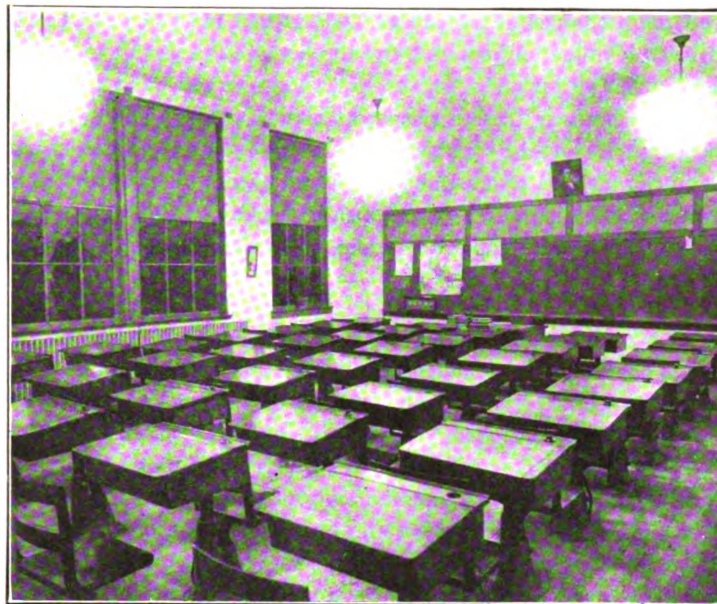


○ - INDICATES ENCLOSING GLOBE REFLECTORS.

Typical Classroom (24 ft. by 32 ft. and 13 ft. high) Illustrating a Desirable Arrangement of Outlets for Direct Lighting Luminaires. Using enclosing diffusing globes the following approximate intensities would be obtained: with 200-watt MAZDA C lamp, 8 foot-candles; with 300-watt MAZDA C lamps, 12 foot-candles. With semi-indirect reflectors four lighting units would be sufficient. The approximate intensities with 300- and 500-watt MAZDA C lamps would be 6.5 and 12.5 foot-candles respectively, with dense opal glass reflectors and 7.5 and 15.5 foot-candles respectively with light opal glass reflectors



—Insufficient light. One bare lamp hung from centre of ceiling; corners of room too dark. Bare lamps are a source of glare.



~~Fig. 4~~—Good general lighting with enclosed luminaires.



"Sight-saving" classroom; semi-indirect lighting units spaced about 11 feet apart; 300 watt lamps




 Night View Chemistry Laboratory, 36 by 32 ft. Lighted by Ten 150-watt
 Bowl Enameled MAZDA C Lamps in RLM Standard Dome Re-
 flectors. An intensity of ten foot-candles prevails on
 the benches



Laboratory; direct lighting units spaced about 10 feet apart; 200 watt lamp.

Table II. Luminous flux emitted: By gas mantle burners² at gas pressure of 2.5-inch water column

Number of mantles to each burner	Size of mantles (inches)	Gas consumption (cubic feet per hour)	Base mantle (lumens)
1.....	1-1/8	3.66	994
2.....	1-1/8	4.37	1,326
3.....	1-1/8	6.71	1,978
4.....	1-1/8	9.14	2,445
5.....	1-1/8	10.60	3,654
6.....	1-1/8	12.10	4,125

By gas mantle burners which are self-contained³ at gas pressure of 2.5-inch water column

Number of mantles in each burner	Size of mantles (inches)	Gas consumption (cubic feet per hour)	Mantles inclosed in clear glass cylinders (lumens)
1.....	1-1/8	2.21	686
1.....	1-5/8	4.00	866
1.....	2-1/8	8.15	2,486

²These burners are known as horizontal inverted burners and are made for use in semi-indirect luminaires. By combining two or more of these burners in a single luminaire the total lumens available can be increased as desired. If 1-5/8-inch mantles are used, 10 per cent increase in total lumens is available.

³These burners are furnished complete with clear inner cylinders and shade or globe holders to take outside globes and shades as selected. These are inverted burners and are used generally as complete luminaries. Semi-

inclosed shades or totally inclosed globes can be used as desired.

Table III. Coefficients of utilization for a classroom 32 feet by 24 feet,
ceiling 12 feet high.¹

(Reflection factor of ceiling, 70 per cent)

Lighting System	Reflection factor of walls	
	50 per cent	30 per cent
Direct Lighting		
1. High reflection factor open-bottom glass reflectors with bowl-enameled lamp.....	0.47	0.43
2. Prismatic inclosing unit; clear lamp.....	.47	.42
3. Inclosed unit of white glass (highly diffusing, one in which the lamp position can not be seen) clear lamp.....	.39	.34
Semi-indirect Lighting		
4. Low transmission, high reflection factor glass bowl with clear lamp.....	.33	.29
5. Medium transmission, glass bowl with clear lamp..	.37	.33
Indirect Lighting		
6. Metal, compo or glass bowl containing mirror reflector; clear lamp.....	.30	.27

¹Transactions Illuminating Engineering Society, Vol. XV, No. 2, Mar. 20, 1920.

Computations to determine the proper size of incandescent electric or gas lamps may be made by the use of the following equation:

$$L = \frac{AI}{EN}$$

In this equation:

L = the lumens emitted by the lamp (Table II)



A = the area of the floor or horizontal work plane in square feet.

I = the illumination in foot-candles (Rule 1)

E = the coefficient of utilization (Table III)

N = the number of lamps required.

The first step in using this equation is the determination of the number of lamps required. From experience it is ascertained that in order to obtain the desired distribution of illumination, the light sources in direct lighting should not be spaced farther apart than a distance of 1.5 times their elevation above the desk tops. For instance, if the light sources are hung 8 feet above the desk tops, the maximum spacing between should not exceed 12 feet, in order that the requirements of rule 3, "Distribution of light," may be fulfilled. Now, considering the problem of a classroom (32 by 24 feet) having the minimum ceiling height of 12 feet, we must first determine the number of luminaires required. The plane of the work will be that of the desk tops which is a horizontal plane approximately 24 inches above the floor. Then if the luminaires are installed in ceiling-type fixtures and an allowance of 18 inches for depth of fixture and globe is made, the elevation of the light source above the plane of work will be approximately 6½ feet. Hence the maximum spacing between luminaires must not exceed 12 feet 9 inches. With a room of these dimensions, six luminaires therefore would be required, spaced approximately 12 feet apart. In this example we will assume that an illumination of 10 foot-candles is desired. We will also assume that a luminaire of the type listed under item 3, Table III, is chosen and that the ceiling and walls have reflection factors of 70 and 50 per cent, respectively. Under these conditions the coefficient of utilization will be 0.39 (see Table III). Now applying the formula, we have:

$$L = \frac{32 \times 24 \times 10}{0.39 \times 6} = 3,282 \text{ lumens.}$$

To offset the decrease in illumination due to lamp depreciation and dust collection on the luminaires the number of lumens required per lamp will have to be somewhat increased. For this a safety factor should be used which will insure adequate illumination when the lighting installation shows a maximum depreciation under the system of cleaning adopted. How much to allow for depreciation, with a given type of luminaire, depends to a considerable extent on the locality and nature of work carried on. Experience has shown that a factor of 1.3 provides for average conditions if a schedule of regular and frequent cleaning is adhered to. Applying this factor to the problem at hand it will be necessary that each lamp supply (3,282 by 1.3) 4,257 lumens.

Referring to Table II, lamps for standard 110-120 volt service, it will be noted that the 300-watt lamp is the nearest size of clear-bulb gas-filled tungsten lamp which will supply the required lumens, whereas the nearest size of "daylight" gas-filled tungsten lamp which will supply the required lumens is the 500-watt lamp. The nearest size of gas burner that will supply the required lumens is two 2-mantle burners consuming a total of 12 cubic feet of gas per hour.

The above example is intended solely to illustrate the method of computation. Estimates of the illumination obtained from an actual installation may also be made by a similar computation.

Only four outlets are necessary if indirect-lighting luminaires or semi-indirect luminaires with dense glass bowls are used in a room of

this size. In Table III it is seen that the utilization factor for semi-indirect lighting with dense glass luminaires is 0.33 for the same room and conditions used in the previous computation. Applying the formula we have;

$$L = \frac{32 \times 24 \times 10}{0.33 \times 4} = 5,818 \text{ lumens.}$$

Allowing for depreciation, we have 5,818 multiplied by 1.3 or 7,563 lumens necessary from each of the four light-sources. The nearest size of clear-bulb electric filament lamp is seen in Table II to be 500 watts. Here a total of 2,000 watts would be used as compared with 1,800 watts in the direct-lighting case, but the illumination intensity would be slightly greater in the former case. Of course the illumination intensity would be identical in the two cases if it were possible to obtain lamps of the exact size computed in the two cases.

Selecting a luminaire: It is not possible with bare incandescent electric or gas lamps to meet the requirements of the school-lighting code in respect to rule 2, "Avoidance of glare" or economically in respect to rule 3, "Distribution of light." It therefore becomes necessary to equip the lamp with reflecting and diffusing accessories. Far from being a hardship however, this is actually an economy since the light flux from the unshielded lamp is not distributed in an economical manner. Efficient reflecting and diffusing accessories re-direct the light, thereby increasing the efficiency of utilization considerably over the value obtainable with the bare lamps, irrespective of the fact that the diffusive and re-directing media in themselves absorb a portion of the light flux. Aside from this, the ability to utilize the light produced, because of "eye ease" and lack

of brilliant sources within the field of vision, is noteworthy, and justifies the use of proper reflecting and diffusing accessories.

Any of the types of luminaires from 1 to 6, inclusive, in Table III will meet the requirements for overhead lighting provided lamps of the proper size and type for the particular accessory are employed. It is particularly necessary to guard against the use of lamps too large for the reflector or globe in the direct or semi-indirect systems if rule 2, "Avoidance of glare," is to be fulfilled.

The following table shows the sizes of inclosing globes of high efficiency (80 per cent output) good diffusing glassware (through which the position of the lamp filament can not be seen) to be used with various sizes of clear lamps.

In this table the brightness of the brightest square inch is given rather than average brightness or some other specification. An average brightness specification allows wide variations of brightness between maximum and minimum. In effect two samples of diffusing glass, one practically uniform in brightness and the other having a small area exceedingly bright but with the rest of the globe sufficiently low in brightness to average the same as the first, could be rated alike although their acceptability from the standpoint of glare could be widely different.

Table IV. Recommended globe sizes of high efficiency good diffusing glass.

1	2	3	4	
Size of lamps (watts) to be used with (3)	Lamps, lu- mens (Maximum)	Minimum globe di- ameter (measured at maximum width) to be used with (1)	Brightness of bright- est square inch (can- dles per square inch)	
			Zone 35°	Zone 70°
		Inches		
75-100.....	1,300	12	4.0	3.5
100-150.....	2,100	14	4.5	4.0
150-200.....	3,000	16	4.5	4.0
300.....	4,900	18	5.6	5.0

From the utilization factors in Table III, it will be noted that some luminaires have the advantage of being more efficient than others. This characteristic should be given considerable weight in the selection of a lighting accessory. However, other items should be considered, such as the appearance of the lighted room, quality of light and freedom from glare, reflected glare from images of the luminaire in polished surfaces, character of shadows, and ease and cost of maintenance.

The characteristics of the luminaires related to these desirable or undesirable features of a lighting installation are, diffusive ability, relation between the size of the lamp and diameter of the diffusive unit, shape of the unit, correct centering of light center to secure the correct surface brightness, and relation between the holder and the reflecting surface, and the over-all efficiency.

The first point is that of efficiency. Since inclosing glassware is being extensively used in school-lighting systems, some of the

pitfalls which might be encountered in considering this phase of the question may be pointed out. Variations in the distribution curves obtained from individual units of lighting equipment are sufficient to make it undesirable to place too much dependence upon tests secured by measurements made upon a completed installation shall show values corresponding to the representative luminaire offered by the manufacturers or installers of such equipment.

To be representative of the efficiency, 10 or more globes, selected at random, should be tested.

The factors of direct and reflected glare should be made the paramount ones for schoolrooms. Brightness and diffusive ability are closely allied. Globes of the best diffusive ability only should be considered. A test for diffusive ability is the inability of the observer to locate the position of the light source within the luminaire when the lamp is correctly centered. Under these conditions all parts of the projected area appear equally bright.

A consideration of shadows on the work is closely allied with brightness and diffusion of the luminaire. There should be no shadows so dense as to make vision difficult or so sharply defined as to cause confusion between the edge of the shadow and a drawn line, as in drafting. Shadows should be soft and luminous, and where we are concerned with work on a horizontal plane only, as in study rooms, they should be reduced as much as practicable.

Excessive and objectionable brightness can occur even when the

table of recommended globe diameters for various sized lamps is adhered to. The light source should be so centered within a diffusive enclosing globe that no area of the globe is made unduly bright because of its proximity to the incandescent lamp filament or mantle. If this precaution of correctly centering the filament is overlooked, one of the essential characteristics of a good diffusing glass is sacrificed.

It should be realized that 2 to 10 per cent in the over-all efficiency of a luminaire may be gained by using a holder which is white enameled on the inside. When stress is laid upon high efficiency of units such a point can not be disregarded.

Electric luminaires ventilated by means of holes in the globe, reflector, bowl, or accessory parts are subject in most cases to greater depreciation, due to dust, dirt, and insects, than is found with luminaires in which there are no ventilating holes. In addition to the normal collection of dust on exposed surfaces, holes in the luminaire permit dust accumulation due either to air currents through the luminaire or to "breathing" of the luminaire when it is turned on and off. That satisfactory cooling of luminaires can be effected by radiation has been proved by many nonventilated luminaires now in service. Whether or not ventilation holes are used, care must be exercised in the design to insure against excessive temperatures of sockets, fixtures, etc.

Avoidance of Glare.

There are five principal causes of glare:

Brightness of source:- The light source may be too bright;

that is, the candles per square inch of area may be too great. A glance at the sun proves that an extremely bright light source within the field of vision is capable of producing acute discomfort. Light sources of far lower brightness than the sun, such as the filament of an incandescent electric lamp or the incandescent mantle of a gas lamp, may also cause discomfort, although the annoying effect is usually not quite so marked.

Total volume of light:- Experience has shown that a 500-watt lamp in a 10-inch opal globe hung 7 or 8 feet above the floor and a similar distance ahead of the observer, will prove quite as glaring as the exposed filament of a 50-watt incandescent lamp in the same location. The brightness of the "opal" globe luminaire is only a few times that of a candle flame, but the quantity of light which reaches the eye is so great that its effect is worse than that of the bare filament of lower candlepower, although the latter may have a brightness as high as 3,000 candles per square inch. An unshaded window often causes glare, due, of course, to the large volume of light rather than to the high brightness of the sky.

Location in the field of view:- A given light source may be located at too short a distance from the eye, or it may lie too near the center of the field of vision for comfort; that is, within too small an angle from the ordinary line of sight. For example, the 500-watt "opal" globe unit discussed in the previous illustration would seldom cause discomfort if placed, say, 80 feet away from the observer, for at this distance the total quantity of light entering the eye would be only one one-hundredth of that received at 8 feet. Again, the same light source would probably be found quite unobjectionable at a distance of 8 feet from the

eye, provided this distance was obtained by locating the lamp 4 feet ahead of the observer and 7 feet above the eye level; in this case the lamp would scarcely be within the ordinary field of view.

The natural position of the eye during intervals of rest from any kind of work is generally in a horizontal direction, and it is desirable that during such periods the pupil should be freed from the annoyance caused by glare. Glare becomes more objectionable the more nearly the light source approaches the direct line of sight. While at work the eye is usually directed either horizontally or as an angle below the horizontal. Glaring objects at or below the horizontal should especially be prohibited. The best way to remove light sources out of the direct line is to locate them well up toward the ceiling. Local lamps -- that is, lamps placed close to the work -- if used at all, must be particularly well screened.

Contrast with background:- The contrast may be too great between the light source and its darker surroundings. It is a common experience that a lamp viewed against a dark wall is far more trying to the eyes than when its surroundings appear relatively light. A light background requires, first, that the surface should be painted in a color which will reflect a considerable portion of the light which strikes it, and, second, that the system of illumination employed should be such as to direct light upon the background. In many cases the ceiling appears almost black under artificial light simply because no light reaches it. With daylight, on the other hand, the walls of a room are often so well illuminated that they appear brighter than the work itself, and this also

is a condition which is not conducive to good vision. In general, a light tone for ceilings and upper portions of walls and a paint of medium reflecting power for the lower portion of walls will ordinarily be found most satisfactory under both artificial and natural lighting.

Where strictly local lighting systems are employed -- that is, where individual lamps are supplied for all benches and machines and no overhead lighting is added -- the resulting contrasts in illumination will usually be found so harsh as to be objectionable even though the lamps themselves are well shielded. The eyes of the pupil looking up from his brightly lighted machine or bench are not adapted for vision at low illuminations; hence, if adjacent objects and aisles are only dimly lighted, he will be compelled either to grope about, losing time and risking accident, or to wait until his eyes have become accommodated to the low illumination. Glancing back at his work, he again loses time while his eyes adjust themselves to the increased amount of light which reaches them. If long continued, this condition leads to fatigue, as well as to interference with vision, and to accidents. In other words, where local lamps are employed there should also be a system of overhead lighting which will provide a sufficient illumination of all surrounding areas to avoid such undesirable contrasts.

Time of exposure:- The time of exposure may be too great; that is, the eye may be subjected to the strain caused by a light source of given strength within the field of vision for too long a time.

When a pupil is seated and his field is fixed for several hours at a time, light sources of lower brightness and lower candlepower are re-

quired than where the pupil stands at his work and shifts his position and direction of view from time to time. In the first case the image of the light source is focused on one part of the retina for considerable periods of time and is obviously more likely to cause discomfort and eyestrain than when present for short periods only. Those who are forced to work all day at desks facing the windows are particularly likely to suffer from this form of glare. Such conditions should not be tolerated.

Rating light sources from the glare standpoint: It is evident that the first two factors mentioned as causes of glare, namely, excessive brightness and excessive candlepower, concern the light source itself, the third factor concerns its location in the field of view, and the fourth and fifth depend upon the conditions of its use.

Measurements of brightness and candlepower have been made on a number of light sources found in everyday practice, both natural and artificial, and Grades from I to X have been assigned to them. (See Tables V and VI.)

Light sources in Grades I and II may be termed soft or well diffused; those in Grades VIII, IX, and X are harsh and almost certain to cause glare.

Grade III is the limiting grade permissible for the lighting of schoolrooms. Softer grades are recommended. Light sources other than those included in Table VI will be found in use; however, from those which are given in the table it is possible to estimate in what grades others should be placed.

Table V. Classification of light sources from the standpoint of glare.
(Grade I indicates sources of maximum softness. Grade X indicates sources of maximum harshness.)

Maximum visible brightness (candles per square inch)	Candlepower in direction of eye				
	Less Than 20	20 to 50	50 to 150	150 to 500	500 to 2,000
	Grade	Grade	Grade	Grade	Grade
Less than 2.....	I	I	II	II	III
2 to 5.....	II	II	III	IV	V
2 to 20.....	II	III	IV	VI	VII
20 to 100.....	IV	V	VI	VII	VIII
100 to 1,000.....	V	VI	VII	VIII	IX
1,000 and up.....	VI	VII	VIII	IX	X

Table VI. Specific classification of light sources from the standpoint of glare as derived from Table V.

Natural Light Sources as seen through Windows or Skylights

	<u>Grade</u>
Sun.....	X
Very bright sky.....	V
Dull sky.....	III
Sun showing on prism glass.....	IX

.....

.....

.....

.....

.....

.....

Table VI, Cont.

Incandescent Mantle Gas Lamps¹

Lamp	Mantles Consuming -		:	Large Single Mantle or Cluster		:	Cluster or high-pres-
	2-5 cu- bic feet per hour	5-8 cubic feet per hour	:	8-12 cubic feet per hour	12-20 cubic feet per hour	:	sure lamp consuming above 20 cubic feet per hour
	Grade	Grade		Grade	Grade		Grade
Clear glassware.....	V	VI		VII	VIII		IX
Diffusing glassware:							
6-inch globes.....	II	III		----	----		----
8-inch globes.....	I	II		IV-VI	----		----
10-inch globes.....	----	----		III-V	V-VII		----
12-inch globes.....	----	----		----	----		VI-VIII
Indirect units.....	----	----		I-II	II		III
Semi-indirect units..	----	----		II-III	II-IV		III-VI

Luminaires Equipped with Tungsten Filament Lamps

Luminaires	Watt	
	Lamps	Grade
Diffusing glass inclosing units: ¹		
12-inch maximum diameter.....	75-100	II-III
	150-200	III-V
	300	IV-VI
16-inch maximum diameter.....	150-200	II-V
	300	IV-VI
18-inch maximum diameter.....	300	III-V

Table VI. Cont.

Luminaires Equipped with Tungsten Filament Lamps

Luminaires	Watt	
	Lamps	Grade
Semi-inclosing units ¹	75-100	III-IV
	150-200	IV-VI
	300	IV-VII
Semi-indirect units ² ,.....	75-100	I-III
	150-200	II-III
	300	II-IV
Indirect-lighting units.....	75-100	I-II
	150-200	I-II
	300	II

¹ Where a range is given, the best grade, that is the lowest applies to globes that are evenly luminous, and the poorest to globes which have a decidedly bright spot in the center.

² Where a range is given, the best grade, the lowest, applies to bowls that are of dense glass; that is, bowls which reflect nearly all of the light to the ceiling.

Table VII.

Table of Illumination Required

The illumination -- natural or artificial -- maintained shall not be less than the minimum values in the first column. Values recommended for ordinary conditions of artificial lighting are presented in the last column. Higher values are often desirable.

<u>On the Space*</u>	Minimum Required Foot- Candles	Recommended Foot- Candles
Walks, drives, and other outdoor areas, if used at night.....	0.1	0.5
Playgrounds, outdoor, if used at night.....	0.5	2.
Playgrounds, outdoor, if used at night for baseball, basketball, etc.....	5.	10.
Storage spaces, passages, not used by pupils..	0.25	2.
Boiler rooms, power plants, and similar auxiliary spaces.....	1.	3.
Stairways, landings, corridors, aisles, exits, elevator cars, warerooms, toilets, locker spaces, dressing rooms.....	1.	3.
Recreation rooms, gymnasiums, swimming pools..	3.	7.
<u>On the Work*</u>		
Auditoriums, assembly rooms.....	2.	3.
Auditoriums, assembly rooms, if used for class or study purposes.....	5.	10.
Classrooms, study rooms (desk tops).....	5.	10.
Classrooms, study rooms (charts, blackboards).	3.	6.
Libraries (reading tables, catalogues).....	5.	10.
Libraries (bookshelves, vertical plane).....	3.	6.
Laboratories (tables, apparatus).....	5.	10.

Table VII. Cont.

Table of Illumination Required.

<u>On the Work*</u>	Minimum Required Foot- Candles	Recommended Foot- Candles
Manual training rooms, workshops, etc.....	5.	10.
Drafting rooms, sewing.....	8.	15.

*Where the space or work is not clearly evident the illumination may be measured on a horizontal plane 30 inches above the floor. Such a case is an auditorium. However, where the space or work is clearly evident, such as stair-steps and desk-tops, the illumination shall be measured on the plane of the steps and desk-tops respectively.

Table VII gives the amount of illumination in foot-candles and should be used in all observations of lighting intensities and calculations.

Other Formulas for Computing Lamp Size

After the outlets have been located on the plan, the lamp size to be used may be determined by the following calculation:

$$A. \quad \begin{array}{l} \text{Area in Square Feet} \\ \text{per Outlet} \end{array} = \frac{\text{Total Floor Area in Square Feet}}{\text{Number of Outlets}}$$

$$B. \quad \begin{array}{l} \text{Lamp Lumens} \\ \text{Required per} \\ \text{Square Foot} \end{array} = \frac{\text{Foot-Candles} \times \text{Depreciation Factor}}{\text{Coefficient of Utilization}}$$

$$C. \quad \begin{array}{l} \text{Lamp Lumens} \\ \text{Required per} \\ \text{Outlet} \end{array} = \begin{array}{l} \text{Area in Square Feet} \\ \text{per Outlet} \\ \text{(From A)} \end{array} \times \begin{array}{l} \text{Lamp Lumens Required} \\ \text{per Square Foot} \\ \text{(From B)} \end{array}$$

Foot-Candles -- Selected from Table I.

Depreciation Factor -- Use 1.3 for fairly clean locations, 1.4 for average,

and 1.5 for dirty locations or where cleaning is infrequent. This is the safety factor or allowance for depreciation due to aging of lamps, dirt, dust, and deterioration of reflecting value of walls.

Reflection Factors of Colored Surfaces

The reflection characteristics of walls and ceilings have an important bearing on the natural and the artificial lighting. The proportion reflected will depend somewhat upon the color of the incident light. The figures here given show what proportion of the light of Mazda lamps various painted surfaces reflect. Reflection Factors are of special usefulness in determining the Coefficient of Utilization (the ratio of light delivered at the work to the total light of lamps) of an interior. The Reflection Factor of any colored surfaces can be approximated by comparing it with these samples on the next two pages.

Reflection Factors

The proportion of light reflected by walls and ceilings of various colors, that is, their Reflection Factors, has an important bearing on both the natural and the artificial lighting. The proportion reflected will depend somewhat upon the color of the incident light. The figures here given show what proportion of

	No. 1 White Paper 80%		No. 9 Ivory White 79%
	No. 2 Gray 56%		No. 10 Caen Stone 69%
	No. 3 Gray 58%		No. 11 Ivory 70%
	No. 4 Gray 49%		No. 12 Ivory Tan 58%
	No. 5 Gray 42%		No. 13 Primrose 65%
	No. 6 French Gray 36%		No. 14 Lichen Gray 64%
	No. 7 Gray 26%		No. 15 Pearl Gray 66%
	No. 8 Gray 17%		No. 16 Silver Gray and Caen Stone 56%

of Colored Surfaces

the light of MAZDA lamps these painted surfaces reflect. Reflection Factors are of special usefulness in determining the Coefficient of Utilization (ratio of light delivered at the work to total light of lamps) applicable to an interior. The Reflection Factor of any colored surface can be approximated by comparing it with these samples.

No. 17
Buff Stone
and Pale
Azure
43%



No. 25
Forest
Green
19%



No. 18
Buff
63%



No. 26
Olive
Green
21%



No. 19
Buff Stone
48%



No. 27
Pale Azure
and White
58%



No. 20
Tan
27%



No. 28
Pale Azure
44%



No. 21
Cocoanut
Brown
17%



No. 29
Sky Blue
34%



No. 22
Satin
Green
63%



No. 30
Shell Pink
51%



No. 23
Bright Sage
and Ivory
Tan
45%



No. 31
Pink
46%



No. 24
Bright Sage
41%



No. 32
Cardinal
Red
19%



Chapter VII

DIRECT OBSERVATIONS

The following observations were taken in the new Walter French Junior High School, Lansing, Michigan, on May 2 and 4, 1926. They were taken in the afternoon and the sky was fairly gray; consequently the readings taken are good examples of the lighting with which the students are required to study. A bright day would bring the intensity up to higher values and would be more desirable for reading purposes. The outside rooms of the school were found to be very well lighted, but the inside rooms are cut off, more or less, by a wing of the building projecting close to the windows.

In these rooms there were blackboards and a large glass cabinet on one side of the room which absorbs most of the light coming to those surfaces. The blackboards were at the front and rear of the rooms. The front board was 15'5" x 2'11", while the boards in the rear of the room were 21'5" x 2'11". Above these blackboards were two bulletin boards of dark brown color, which projected above the blackboards 10".

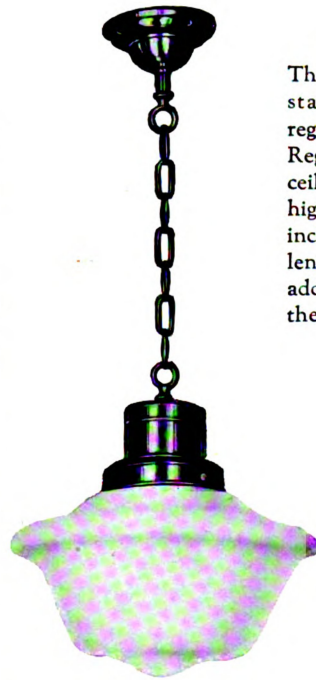
The glass cabinet at the side opposite the windows was 9'4" x 4', thus taking up a little less than half of that side of the room. The rear of the cabinet was made of a glossy finished wood, thus giving considerable glare when the direct rays of the sun fell upon it. The windows were on one side of the room, thus giving unilateral natural lighting. The window area was made up of six windows, each 3' x 7'4". The floor of the room was measured and found to be 28'8" x 21'6". Thus the window area

is slightly 21 per cent of the floor area, which is above the specifications stated in the code for lighting school buildings.

The height of the room was 12 feet, which also checks with specifications very well.

The lighting fixtures used in this room are of one-piece, opal type with a flatlined reflecting top. Fig. 23 shows a cut of the fixture that was used throughout the building. This particular unit is manufactured by the Ivanhoe-Regent Works of the General Electric Company at Cleveland, Ohio. The commercial name for this fixture is, "The Ivanhoe Trojan". It is made in four sizes to serve Mazda lamps up to and including the 500-watt size. The Trojan is made of one piece of light density Genco glass of high diffusing quality and low light absorption. The position of the lamp in Trojan, the high diffusing quality of the glass, as well as the dimensions and contour of the unit assure freedom from glare and objectionable brightness when used with the sizes of Mazda lamps for which it is designed. As this unit has no exposed inside surfaces, it is practically dirt-proof and inside cleaning is seldom required. Outside cleaning is easily accomplished because of the continuous lines and smooth surface of the glass. Ventilation of the Trojan fixture is unnecessary because of the large radiating surface.

The Ivanhoe Trojan lighting fixture is especially suitable for commercial lighting. It distributes diffused light both above and below the mounting plane, and produces a pleasing luminous effect in all directions without sharp shadows or lines of contrast. It is an efficient



Suspension Type

The Ivanhoe TROJAN with standard suspension fixture regularly supplied by Ivanhoe-Regent Works; for use where ceilings are 10 feet high or higher. The suspension is 24 inches long, but can easily be lengthened or shortened by adding or removing links in the chain.

Ceiling Type

The Ivanhoe TROJAN with standard ceiling type fixture regularly supplied by Ivanhoe-Regent Works. This type of suspension is available for low-ceiling installations.



Fig. 23.

unit for all illumination of stores, offices, assembly halls, hotels, churches, banks, schoolrooms, and other places where an opal enclosing unit of pleasing lines is desired.

Five units of the type described above were used for lighting this schoolroom at times when natural lighting was inadequate. The lamps used in these fixtures are 100-watt Mazda lamps. The number of lumens emitted by each lamp is found by the formula (in Chapter 6):

$$L = \frac{AI}{EN}$$

L = Emitted lumens / lamp.

$$L = \frac{625 \times 6}{.5 \times 5} = 1500 \text{ lumens}$$

where A = area = 625 sq. ft.

I = foot-candles = 6

E = coefficient of utilization = .50

N = number of lamps = 5

This must be multiplied by a depreciation factor of 1.3, which makes it necessary for each lamp to emit 1950 lumens.

In the above formula the number of foot-candles used was taken from Table VII. The size of lamps to be used are 100-watts as shown in Table II, thus checking with the sizes used in the building.

Illumination intensity readings were taken at various points of the room during daylight period with the lights on. These are, -- center

of room, 11 foot-candles; side away from windows, 8.5 foot-candles, and window side 22 foot-candles. These values show that good illumination is maintained throughout the room, because these readings are above those recommended for artificial lighting.

Foot-candle intensity was then measured without the lights and was found to be, at center of room, 6 foot-candles; away from windows, 4 foot-candles, and near the windows, 18 foot-candles.

Another room across the hall identical to the one mentioned above had windows near the West projecting wing of the building. This wing reduced greatly the natural illumination in the room. The illumination found in this room without lights, readings taken at the center of the room, was 10 foot-candles, and with lights, 12. These were taken with the shades completely rolled so as to give the maximum amount of natural light, while in the other room the shades were only half covering the windows.

The shades used in this building were of the movable type and can be placed so as to shade any portion of the window; this allows light to be admitted from all or any portion of the window.

Readings were then taken in the auditorium and found to be 2.5 foot-candles with all lights on and less than 1 foot-candle with main lights off and only side lights lighted. This conforms favorably with Table VII. Artificial lighting readings were also taken in the gymnasium and found to be 25 foot-candles. The corridors were found to be of 1 foot-candle illumination.

Night readings were taken in all these rooms and were found to be as follows:

Study room.....	8 foot-candles
Auditorium.....	2.5 foot-candles
Gymnasium.....	5. foot-candles
Corridors.....	1. foot-candles

The above readings and observations were made with a foot-candle meter. Every city school system should be provided with a device for measuring illumination. At present the simplest and cheapest of these is a foot-candle meter, selling at about \$25.00. This instrument is for use in measuring the amount of illumination received on any working surface. It is easily operated and is sufficiently accurate for all ordinary purposes. No computations are necessary inasmuch as the intensities in "foot-candles" can be read directly. It is possible for anyone with this instrument to determine the "foot-candles" on any surface and with a knowledge of the required intensity of illumination as given in the tables it is easily determined whether the lighting installation is giving a sufficient amount of light.



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