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THEESIS
for the
DEGREE OF B.S.
in the
SCHOOL OF ARCHITECTURE:
ILLINOIS INDUSTRIAL UNIVERSITY.

ON THE
LIGHTING OF BUILDINGS.
S.A. Bullard.
Class '78.
The Lighting of Buildings.

There is a wide difference between the amount of light diffused in the old field than in any part of a well lighted house. There is now difference, indeed, between the amount of light which reaches the world on a cloudy day than one which is perfectly clear. But it is not necessary nor desirable to admit into any room of the dwelling the total number of lights that light up the field. Indeed, good taste sometimes seems to lose darkness rather than light when their contrasts are in the balance in favor of darkness. But when we have decided not to admit all the light from the outside as not desirable, the question naturally arises, What is the amount of light that is necessary? This question, though important, is one which has generally been guessed at by
was only the exception when they were used. This gave way to the lighting of the night. Being a hot country naturally made darkly as by the
and desert heat, it was a great relief to step into a place where light was greatly diminished. But as supposed then the houses were rather dark, enough light was admitted through other openings, the Egyptian temple, however, were different, excepting the most secluded places not much of the gods dwelled or priests associated. Of the three ancient halls of the temple at Car
mac, the modern Egyptian temple, the first third are open courts surrounded on the inside with a colonnade. The second is a large colonnade hall in which the central range of colonnade raised nearly twenty feet above the floor, and this twenty feet of space
in height is needed for the admission of light, the pillars plus seven, being partly to the north and to the left of the right, being of different
country, need the window above more freely. The rear court was used, though not extensively, and windows in all courts where solid walls were used, in some cases, however, the walls were made with cas
defines being lovely and supported by wooden pillars. These could be managed to suit the necessities of the case, and no windows technically so called were needed. The Chinese temple also have in some cases no light except from above. The temple temple, built by Solomon was surrounded by a large open court. In the holy place where the priests daily sacrificed, the window were placed very high up in the wall, more not of large pro
cutume. The reverberating
place had no light from external source. The Semitic Jewish houses were thus constructed and built throughout the form. The Greeks were not far from the Jews in the importance which they attached to their temples. The temples of the Greeks were made with solid walls all round. At the front end was an entrance, light was admitted through an aperture made by an opening in the roof. On the temples were made for external appearance, the light admitted was gradually increased by various devices which gave so much life to Greek literature and learning, were simply made in the sun as both no evening gave preference to an awning, and depended no other method of lighting than the natural light. Their dwellings were such miserable hovels that no remaige of them exist, but few notices of them have been made by their writers.

The Romans immediately following the Greeks gave form to the modern window, in most of the Roman buildings, permitting definite for lighting. For some pages was used, but the improvement has been constantly making changes till today we enjoy forms multiple that perfectly answer their functions.

The existence need for filling windows and rooms with diffusing light which the different buildings have used have been few. The Egyptians need nothing, as much, simply a little work. The mildness of the climate allowed them freedom in this respect which could not be enjoyed in many other countries.

The Chinese used still use sometimes a sort of semi-transparent paper. The wall would be built solid for a few feet above the floor, while above yes, either all round or in large windows, this paper was used. The papers
would tranquillize but a very
small fraction of the light. There
fore a large amount of
window area was needed.
The Egyptians had
invented a device which served the
purpose of glass in their
houses, although apparently
incapable of being made for
properly, were extensively
used. Glass was introduced
as an article of commerce
as early as before Christ;
but was not brought into
England till the latter
part of the eight century.
A law for the proper
amount of window surface
necessary for the proper
lighting of rooms, cannot
be general because of the
great number of modifying
influences which are
varying and different countries.

The density is a governing
influence. The intensity of
the light thro' the glass of
countries make the glass
surface necessary there in
the colder regions of the
world, were the days are short
and dark. We notice this at
once in Egyptian architec-
ture.

Another distinction too is
noticed in the position of
the glass, whether it is hori-
izontally, the light entering
perpendicular to the sur-
face, or vertically, if it is vertical
when compared with it.

The Egyptians were not igno-
rant of this fact as can be
seen from the Pantheon
at Rome, in which there
is but one entrance for
lights and that is the area
of the dome. The total
number of cubic feet in
the building according
to Buon is 1,734,460; the
amount of light area is
273 square feet, one of which
lights about 3350 cubic
feet of the volume, more than
possible for lighted
from vertical openings of
the same size even under
the most favorable circum-
stances.
The final size of the build-
ing is influenced in deter-
mining the minimum of
glass surface required, get a
jeweller's store or watch fac-
tory would need more light
than a shoe factory or a woolen
mill.
The position of the openings
have a great influence upon
the proper distribution of the
lights admitted. In a long
room, a window will be of
greater service if placed at
the end where the rays
will have to traverse the whole
distance without change of
direction than if it be placed
in the side to thus the
lights must be reflected
so as to be able to do much good.
When we consider squares
or round rooms where reflection
of light is used very much
to assist in the lighting, the
color of the wall must have
a great influence upon the
general results. If the walls
were black + reflected abso-
lutely no light the wind-
dows alone would have to
be depended on. All the
colors intervening between
black + white - with this
varying power of reflection
would vary the amount
of glass surface needed.
This difficulty is generally
met by making lights at
a certain amount of glass surface very
large + then using shades
+ curtains to cut off the
lights thus is not necessary.
From this we have the fol-
lowing rules:

\[
\text{Area of glass} = \sqrt[3]{\text{Volume of room}}
\]

1 sq. ft. glass should be used for
every 100 sq. ft. of volume of
room.

Experiments were made no re-
gard to the light admitted
by windows in different parts
of the room, + also the amount
of glass surface required for the
proper amount of light. They
were principally made in
the physical lecture room
of the University which has
a volume of 48,500 cubic feet
Thus while plaster walls
all sides except in the north
which is partly broken on the verso half by a blackboard, and on the recto half by a walnut case. The windows were closed with a cover of heavy paper which effectively excluded all the lights. This paper could be removed whenever desired, and in this way the amount of light was prepared for and controlled at the positions where the light was taken.

But all these experiments, the center of the room was taken as the best experimental.

The weather was overcast, cloudy during the time, also with an absent uninterrupted leader color.

The method of measuring the quantity of light at any point was by a photometer, so constructed that it could be easily manipulated.

The standard of light taken was a paraffine candle burning on an average 6,705 grams per hour.

By physics we know that the brightness of lights as a power varies with the square of the distance of the source of the light from the point.

A photometer is an instrument used to grade these leakage lights by which to determine the relation of the intensity of two lights.

If we take the two lights illuminating each other, we can find their relative intensities by noting the movable diaphragm, an image of the two light paper. By standing on the side of from & you can tell which of the reflected light from A = the transmitted light from B, then it is evident that the relation of the intensities of the two lights is the same as the square of their distances from C. so we have this proportion:

\[ \frac{\text{Power of } A}{\text{Power of } B} = \frac{C^2}{B^2} = \frac{C^2}{A^2} \]

If finding one in terms of the other, suppose the distances were known, we have:

\[ \text{Power of } B = \frac{C^2}{A^2} \times \text{Power of } A \]

which is the intensity of B in terms of A.
The figure shows the felicitations used. A is the open end covered with tissue paper. B is the movable plate at the end of which inside the box slides the candle C. D shows the end of the slab made larger.
the photometers used in our experiments was made in the shape of a long rectangular tube 8" in length and 4 1/2" x 6" on the sides. It was open at one end only which was fastened a tissue white tissue paper. The other end was closed but a notch was left in the lower edge of the 2" x 1/2", through which a narrow strip of paper was allowed to slide. This strip could be slid the entire length of the box and in the end inside, the candle was placed which by moving the slide could be properly adjusted to read accurately to the tissue paper in front. The entire box was lined on the inside with lamp black, mixed with clay, so that the light from the candle would strike on the paper unaided by reflection.

This photometer could be easily read by one standing some distance in front of it, and a scale had been marked on the movable strip showing at once the distance of the candle from the tissue paper the entire reading was readily taken. Along with the amount of light at any one point, the photometer was read in three different positions of the three points of the compass, by this means taking into consideration all the light coming to the print. In each direction, four readings were made, and the average of all taken as the profit. The box was moved from the drainpipe to two as it was moved toward it.

Standard experiments were made at a time in the evening when it was scarcely light enough to read by the light of the light compared with a candle which burned 6,708 grams per hour. That is, it was found at what distance from a print light from a paraffine candle could be equal to the minimum light required in reading easily. The candle burned 6,708 grams.
The photometer was used four times in each of the four directions: north, east, south, and west, and the average of all taken.

<table>
<thead>
<tr>
<th>No.</th>
<th>Direction of Photometer</th>
<th>Av. Dist. of Candle from Diaphragm</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>West</td>
<td>2 ft. 6 in.</td>
</tr>
<tr>
<td>2</td>
<td>North</td>
<td>6 ft. 4 in.</td>
</tr>
<tr>
<td>3</td>
<td>South</td>
<td>6 ft. 6 in.</td>
</tr>
<tr>
<td>4</td>
<td>East</td>
<td>8 ft. 8 in.</td>
</tr>
</tbody>
</table>

We will first find the value of intensity of the light from all directions, on the power of the candle, i.e., the summation of all the lights in the direction north, south, east, west, and west.

The method is as follows:

Let 

\[ A = \text{Intensity of West side} \]

\[ B = \text{Intensity of North} \]

\[ C = \text{Intensity of South} \]

\[ D = \text{Intensity of East} \]

\[ X = \text{Intensity of all sides} \]

\[ X = \text{Distance A from point Y} \]

We have

\[ A^2 = B^2 = C^2 = D^2 = \frac{1}{X} \]

Finding the values of each in terms of \( X \) we have

\[ B = \frac{512.25}{2916} A \]

\[ C = \frac{512.25}{3080} A \]

\[ D = \frac{512.25}{336} A \]

If we find the values of all the lights in terms of \( A \), we then can find at what distance the candle may be placed from the diaphragm or point so that the intensity there will be as great as from all of the lights burning at their stated distances.

To find this we have

\[ A : X^2 + X^2, \text{ all of which are known but } X \]

Of course \[ X = A + B + C + D \].

Solution

by \( \frac{512.25}{2916} = 2.9093 \)

\[ 2.9093 \times 3.4447 = 10.1446 = \log 2753 \text{ lumens vol} \]

\[ 3.4447 \times 7.4208 = 2635 \text{ lumens vol} \]

\[ 3.364 \times 7.2526 = 2412 \text{ lumens vol} \]

\[ \text{total} = 1782 \text{ lumens vol} \]

\[ A = 11832 \text{ lumens vol} \]
<table>
<thead>
<tr>
<th>Place of Window</th>
<th>In. of Camelle Pav. per Hour</th>
<th>Direction of Camellet</th>
<th>Av. Reading of Camellet</th>
<th>Intensity = $\frac{Av. Reading}{Stand. Camellet \text{ or Distance}}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Physical</td>
<td>1</td>
<td>South East</td>
<td>1.25 in</td>
<td>10 inclue</td>
</tr>
<tr>
<td>South Cane</td>
<td>2</td>
<td>North</td>
<td>1.5 in</td>
<td></td>
</tr>
<tr>
<td>East Side</td>
<td>3</td>
<td>South</td>
<td>2.0 in</td>
<td></td>
</tr>
<tr>
<td>West Middle</td>
<td>4</td>
<td>South</td>
<td>24.75 in</td>
<td></td>
</tr>
<tr>
<td>Physical</td>
<td>1</td>
<td>North West</td>
<td>16.6 in</td>
<td></td>
</tr>
<tr>
<td>South Cane</td>
<td>2</td>
<td>East</td>
<td>15.75 in</td>
<td>11. inches</td>
</tr>
<tr>
<td>Middle S Window</td>
<td>3</td>
<td>Front West</td>
<td>27.75 in</td>
<td></td>
</tr>
<tr>
<td>Rear Window</td>
<td>4</td>
<td>East</td>
<td>24.37 in</td>
<td></td>
</tr>
<tr>
<td>Elyp. Lec. Room</td>
<td>1</td>
<td>$S. W.$</td>
<td>11.25 in</td>
<td>8.96 inches</td>
</tr>
<tr>
<td>2 Windows</td>
<td>2</td>
<td>$S. E.$</td>
<td>26.75 in</td>
<td></td>
</tr>
<tr>
<td>E. in W. side</td>
<td>3</td>
<td>$S. W.$</td>
<td>26.15 in</td>
<td></td>
</tr>
<tr>
<td>W. in S. side</td>
<td>4</td>
<td>N. W.</td>
<td>29.25 in</td>
<td></td>
</tr>
<tr>
<td>Elyp. Lec. Room</td>
<td>1</td>
<td>S. W.</td>
<td>17.5 in</td>
<td>11.44 inches</td>
</tr>
<tr>
<td>2 Windows</td>
<td>2</td>
<td>S. W.</td>
<td>21.25 in</td>
<td></td>
</tr>
<tr>
<td>E. in W. side</td>
<td>3</td>
<td>S. W.</td>
<td>23.25 in</td>
<td></td>
</tr>
<tr>
<td>W. in S. side</td>
<td>4</td>
<td>N. E.</td>
<td>28.75 in</td>
<td></td>
</tr>
<tr>
<td>Elyp. Lec. Room</td>
<td>1</td>
<td>S. W.</td>
<td>17. in</td>
<td>12.03 inches</td>
</tr>
<tr>
<td>2 Windows</td>
<td>2</td>
<td>S. W.</td>
<td>17.25 in</td>
<td></td>
</tr>
<tr>
<td>E. in W. side</td>
<td>3</td>
<td>S. W.</td>
<td>31.75</td>
<td></td>
</tr>
<tr>
<td>W. in S. side</td>
<td>4</td>
<td>N. E.</td>
<td>36</td>
<td></td>
</tr>
<tr>
<td>Elyp. Lec. Room</td>
<td>1</td>
<td>S. W.</td>
<td>17. in</td>
<td>8.97 inches</td>
</tr>
<tr>
<td>2 Windows</td>
<td>2</td>
<td>S. W.</td>
<td>17.25 in</td>
<td></td>
</tr>
<tr>
<td>E. in W. side</td>
<td>3</td>
<td>S. W.</td>
<td>17.5 in</td>
<td></td>
</tr>
<tr>
<td>W. in S. side</td>
<td>4</td>
<td>N. E.</td>
<td>16.25 in</td>
<td></td>
</tr>
<tr>
<td>Place of Window</td>
<td>No. of Wdgs.</td>
<td>Candle Brass</td>
<td>Direction of Ecliptometer</td>
<td>Rev. Reading of Ecliptometer</td>
</tr>
<tr>
<td>-----------------</td>
<td>-------------</td>
<td>--------------</td>
<td>--------------------------</td>
<td>------------------------------</td>
</tr>
<tr>
<td>Phys. Lab. 1st Fl. Windows</td>
<td>1</td>
<td>6.31 grms.</td>
<td>N. N.</td>
<td>15. 4 in.</td>
</tr>
<tr>
<td>2nd Fl. Windows</td>
<td>2</td>
<td>5.51 grms.</td>
<td>N. N.</td>
<td>13. 2 in.</td>
</tr>
<tr>
<td>S. &amp; W. of 2nd Fl.</td>
<td>3</td>
<td>6.31 grms.</td>
<td>S. W.</td>
<td>11. 7 in.</td>
</tr>
<tr>
<td>3rd Fl. Windows</td>
<td>4</td>
<td>6.31 grms.</td>
<td>S. W.</td>
<td>11. 7 in.</td>
</tr>
<tr>
<td>Library, North East End</td>
<td>1</td>
<td>6.61 grms.</td>
<td>S. W.</td>
<td>33. 3 in.</td>
</tr>
<tr>
<td>2nd Fl. Window</td>
<td>2</td>
<td>6.61 grms.</td>
<td>S. W.</td>
<td>33. 3 in.</td>
</tr>
<tr>
<td>3rd Fl. Window</td>
<td>3</td>
<td>6.61 grms.</td>
<td>S. W.</td>
<td>37. 2 in.</td>
</tr>
<tr>
<td>4th Fl. Window</td>
<td>4</td>
<td>6.61 grms.</td>
<td>S. W.</td>
<td>37. 2 in.</td>
</tr>
<tr>
<td>Regent's Lecture Room</td>
<td>1</td>
<td>7.132 grms.</td>
<td>S. W.</td>
<td>16. 23 in.</td>
</tr>
<tr>
<td>2nd Fl.</td>
<td>2</td>
<td>7.134 grms.</td>
<td>S. W.</td>
<td>16. 23 in.</td>
</tr>
<tr>
<td>3rd Fl.</td>
<td>3</td>
<td>7.134 grms.</td>
<td>S. W.</td>
<td>16. 23 in.</td>
</tr>
<tr>
<td>4th Fl.</td>
<td>4</td>
<td>7.134 grms.</td>
<td>S. W.</td>
<td>16. 23 in.</td>
</tr>
</tbody>
</table>
From above where

$$A: \sqrt{\frac{A}{4}} = x^2 \text{ we have } x^2 = \frac{A}{4} = \frac{2}{4}$$

$$x = \sqrt{\frac{2}{4}}$$

Substituting known value from above we have

$$x = \sqrt{\frac{812.25}{1.7852}}$$

Solving we have

$$\log 812.25 = 2.9093$$
$$\log 1.7852 = 0.2572$$

$$\frac{2.9093 - 0.2572}{2} = 1.3260$$

$$x = 21.33 \text{ inches.}$$

Thus a paraffin wax candle burning 6.755 grains per hour, at a distance of 21.33 inches from a point, will give at this point the minimum amount of light required to read unless printed matter.

We have given the solution of the problem of determining a standard. The solution of all the problems in the data was made in the same way, the results being found in the intensity of the standard candle mentioned.

We wish now to determine the amount of glass surface needed for the lighting of rooms well, and the correctness of the formula given for determining the amount by height, width, and the influence of the furniture, color of walls, and position of the windows, upon the admitted light.

On the results given in the table we have the following shown:

The room experimented upon, from a window in the middle of the south side, with a glass surface equal to 1 ft. for every 2.973 cfl. placed in the room, was lighted equal to that from 6 standard candles burning at a distance of ten feet from a point, or more than four times the minimum required. But the position of the window was very favorable for lighting the photography, is being in the middle of the room.

An experiment on one of the east middle windows with the same amount of surface gave a resulting intensity of 11 inches for the standard candle.
So was tried, three with two windows, then on 1 ft glass for every 14.77 cu ft vol-

tume. room.

The in which the north window on the east side and the west window on the south side gave a result of lights equal to the standard candle at 8.76 inches dis-
tance. When two were opened at opposite corners of the room, the south window on the west side and the north window on the east side, the light was equal to the standard candle 14.44 in.
distance, which goes to show that the same amount of glass surface will not
lights as well if divided and placed on opposite sides of the room as if placed on the same side.

When the south window on the east side and the south window on the west side were open the lights was equal to a distance of 12.03 inches of the standard candle.

Four windows were not opened having 1 ft glass to
The large architectural room has 107 ft. 2 in. volume to one ft. of glass surface and an intensity represented by 8.61 inches.

The chapel has 222 sq. ft. to one 22 sq. ft. of glass and hides an intensity represented by 12.77 inches.

The conclusions arrived at from these experiments is, that the walls, furniture, position of the windows have a great direct influence on the light in a room than the amount of glass surface. So great is this that no just decision upon the amount can be made without taking these conditions into consideration.

In rooms with white plaster walls, where the windows are placed on two sides of the room, a surface of glass is just needed about 1 ft. for 200 ft. volume. In very large rooms this may be reduced to 1 ft. 4


glass surface to 300 or 400 sq. ft. of volume of room.

In my opinion, formed from the results of the experiments, the rule given by Knibb, one square foot = 15% of room, is not as good as to take the amount directly from the number of cubic feet.

The other rule is that room to 100 cubic feet volume to a larger amount than necessary, unless the room is to be furnished with dark furniture and is the walls are to be of a color that.

The results of the experiments show that no rule can be followed strictly than the conditions of the room must be taken into consideration. In fact, the lighting must be wholly with the architect's judgment.

The experiments were made in Urbana, Ill., about 40° 8' north latitude and about 11° 25' west from Washington.

They were also made on a cloudy day, and the results indicate the minimum amount of light in the room.

1878