PLANNING FOR DAYLIGHT AND SUNLIGHT IN BUILDINGS.*

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Synopsis: The broad problems that come up in planning for daylight and sunlight in buildings are considered and the state of the art of daylight planning is reviewed. Emphasis is laid on the hygienic value of daylight and sunlight in rooms, and on city planning for good daylighting. The factors that enter into the solution of the problem of providing for adequate and suitable daylighting facilities are discussed and formula are given for the calculation of daylight illumination in buildings. By the simple expedient of a wire frame (representing the solar path) mounted on a small cardboard model of a building made to scale, the penetration of sunlight and obscuration by shadows are quickly predetermined in actual cases. A new instrument for sunlight and shadow determinations is described and illustrated. Daylight illumination measurements in a test room and in several court rooms of the County Court House, New York, are given. The application of the principles involved is illustrated by a discussion of the daylighting facilities of the new New York Court House, accompanied by data, charts and plans of the building and court rooms. A bibliography is appended.

The purpose of this paper is to discuss some of the broad problems that come up for consideration in planning for daylight and sunlight in buildings, and to review briefly some of the steps that have been taken in advancing scientific daylighting of interiors. In illustrating the application of principles involved reference will be made to a recent investigation by the writers of the natural lighting of the court rooms of the proposed new County Court House, New York City.

To the lay mind planning for good daylight in buildings means simply providing plenty of window openings, just as planning for good artificial light means to the novice usually nothing more than providing sufficiently powerful lamps to give a blaze of light at night. The TRANSACTIONS of the Illuminating Engineering Society for the past eight years give evidence that planning for good artificial lighting of interiors is by no means a simple problem and, on the contrary, involves considerations which often

baffle even the expert. The mass of data which the Society has published has gone far to give illuminating engineering a definite status especially with reference to the use of artificial light, but thus far has left almost untouched the vital problems connected with planning for the best use of natural light.

As civilization advances we are becoming more and more a nocturnal nation dependent upon artificial light, but this is all the more reason why it becomes increasingly necessary to take the fullest advantage of the benefits to be derived from the use of daylight and sunlight.

In planning for the lighting of buildings our first thought is naturally to provide for illumination that will permit of good vision. But there are other considerations of fundamental and vital importance from a hygienic and pathogenic aspect. Dr. S. A. Knopf, professor at the New York Post-Graduate Medical School and Hospital, in a recent statement submitted to the Heights of Buildings Commission,[1] New York City, laid great stress on the importance of securing adequate daylight and sunlight in buildings to prevent the spread of tuberculosis; he states:

Tuberculosis, which is propagated by bad air, foul air and lack of sunlight causes annually a loss of 200,000 citizens to the United States. This disease could be largely prevented would we live and work in pure air, in air relatively free from mineral and vegetable dust, and last, but not least, would we construct the buildings in which we live and labor so as to allow sunlight to enter more freely.

At a recent meeting of the Municipal Art Society a prominent speaker said:

I read in my newspaper to-day of the benevolent project to build a great hospital for consumptives, the victims of tuberculosis, where they may have air and sunlight. And in the same paper I read of plans for a 30-story building. What are we trying to do? What do we mean by putting up these horrible structures, to the lower floors of which no light can ever penetrate? We build hospitals for the poor consumptive, and then we turn around and erect sky-scraping structures where consumption may breed, so that we shall not lack for patients.

In areas where high buildings are crowded together most of the rooms even on the street front are inadequately lighted and

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[1] Report of the Heights of Buildings Commission, New York City, December 23, 1913. This report contains a mass of valuable data relating to building regulations, etc., and has been freely quoted herein.

many are decidedly dark. In the lower section of New York City where the office buildings range from ten to twenty-two stories high, it was found by the Heights of Buildings Commission that on a bright day at noon in mid-summer artificial light was being used next to the windows in almost all of the street rooms. The conditions in the interior courts in parts of the tall building district are even worse. Fig. 1 gives an illustration of the conditions found in this district. The black windows indicate where artificial light was being used near the windows at noon on a bright summer day.

BUILDING CONDITIONS AND REGULATIONS.

Regulations Based on Street Width.—In planning for the artificial lighting of buildings we locate our light sources inside of the buildings and therefore need not consider whether the buildings are high or low, close together or far apart; but in planning for daylighting, especially in cities, the height of buildings, their shape and distance apart are naturally fundamental considerations; hence many municipalities have passed regulations restricting the height of buildings and specifying the minimum street width.

For example, in New York City the height of tenements is at present limited to 1½ times the width of the widest abutting street. In the second class cities of Massachusetts, no tenement may have more than one legally habitable floor for each full 10 ft. (3.0 m.) of street width, unless it is set back from the street a distance equal to the excess of its height over that permitted at the street line. The height of other buildings is limited to 125 ft. (38.1 m.). In Chicago, the height of tenements is limited to 1½ times the street width while the height of other buildings is limited to 200 ft. (60.9 m.). In Boston, the height of all buildings is limited with the exception of coal hoists, grain elevators and sugar refineries.

In European cities the limitation based on street width is in most cases the fundamental restriction on the height of buildings. In America this restriction at present plays a much less important part. It may be said to be fundamental in the general height restrictions of Washington and to be of great practical impor-

tance in the buildings of Boston. It is also a very important factor in height restrictions for tenement houses.

In Boston, except as above noted, Charleston, Cleveland, Erie, Fort Wayne, New Orleans and Youngstown, the height of buildings is restricted to 2½ times the width of the street. With Washington, these cities are the only cities in America that base the general height limitation of all buildings on the street width. Washington is the only city that bases the permissible height of buildings upon the width of the street diminished by an arbitrary amount; the height of buildings on residential streets more than 70 ft. (21.3 m.) in width may not exceed the width of the street diminished by 10 ft. (3.0 m.). In cities of the second class (population 50,000 to 175,000) in New York State, no building to be used for living purposes, except a hotel, may exceed in height the street width nor in any case may exceed 100 ft. (30.5 m.) in height.

Regulations Based on Maintenance of a Minimum Angle of Light.—A limitation based directly on street width maintains a constant minimum angle of light for the front of the building at the ground floor. If the prescribed height is equal to street width this minimum angle of light is 45 deg.; if 1½ times street width, it is 33⅔ deg.; if 2 times street width, it is 26½ deg.; if 2½ times street width, it is 21⅔ deg. The converse of this is that the maximum angle of light obstruction will be the difference between the above amounts and 90 deg., *i. e.*, 45 deg. for height limit equal to street width; 56⅓ deg. for height limit 1½ times street width; 63½ deg. for height limit 2 times street width; 68⅓ deg. for height limit 2½ times the street width.

From Fig. 4 it is clear that a flat limit of height is not necessary in order to secure a minimum angle of light. If the height limit based on street width is made to apply only to the elevation of the building at the street line and other portions of the building are set back in the same ratio as height limit to street width the angle of light is maintained. If the height limit is twice the width of the street a set-back after reaching the height limit at the street line of 5 ft. (1.5 m.) for every 10 ft. (3.0 m.) of increase in height will maintain the angle of light at 26½ deg.

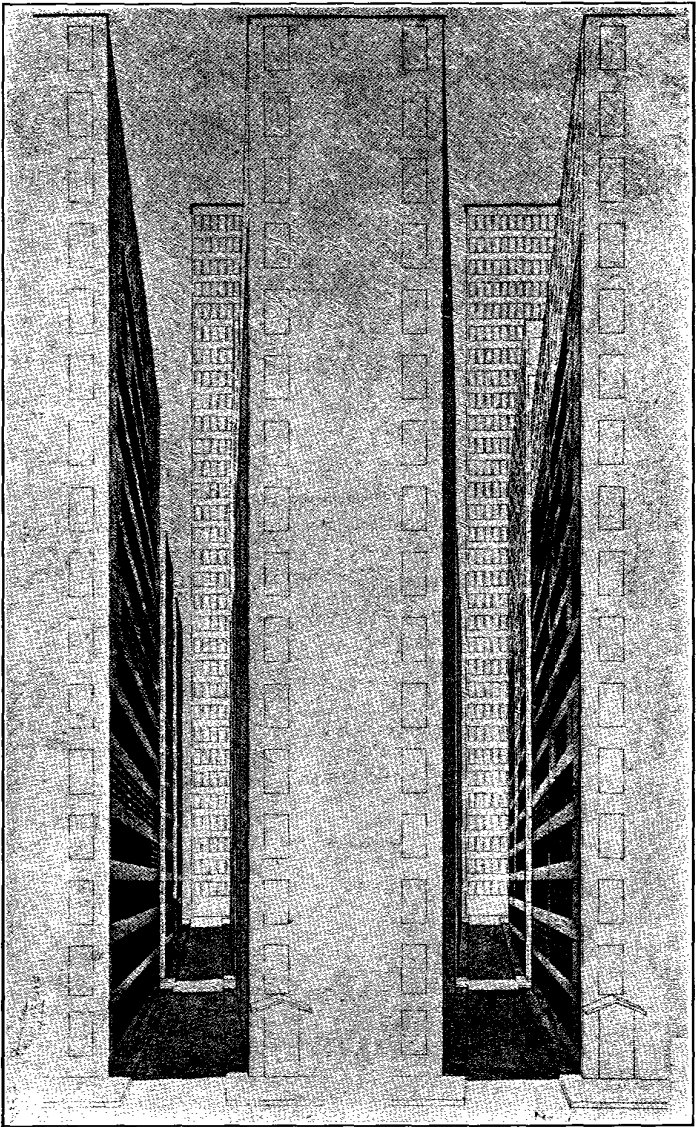In London, the angle of light is more expressly stated. The

Fig. 1.—Use of artificial light in offices on Exchange Street, New York City. The black windows indicate where artificial light was being used near the windows at noon on a sunny summer day.
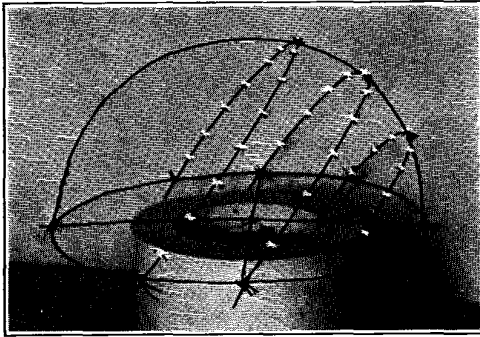
Fig. 2.—Cardboard model of New York Court House made to scale showing wire frame (representing the solar path) mounted to determine penetration of sunlight and obscuration by shadows.
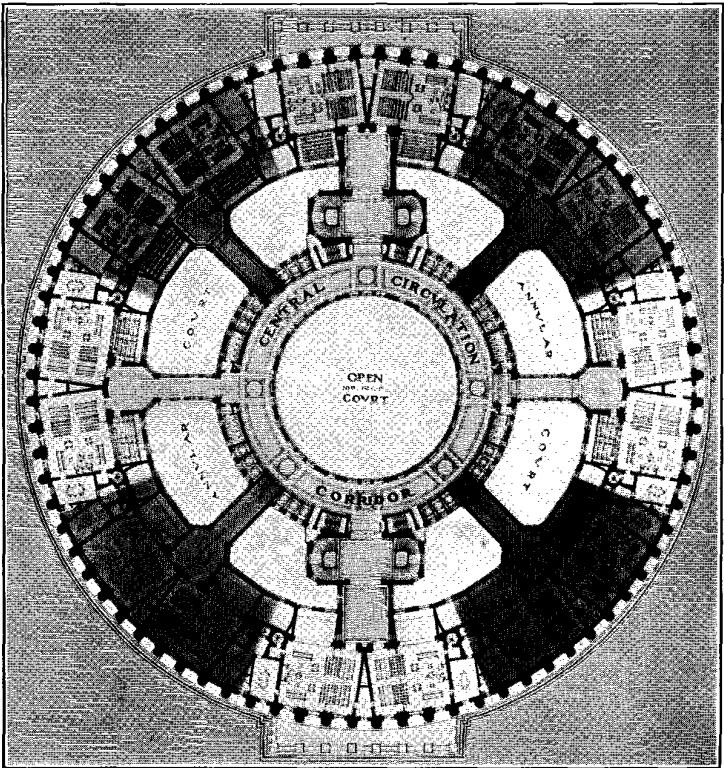

Fig. 3.—Architects' typical court room plan, No. 3, new County Court House, New York City, showing by shading the grouping of court rooms into separate units.

rear heights of a building are generally regulated by a line drawn at an angle of 63½ deg. to the horizontal toward the building from the rear line of the lot. That is, a building may not be built so as to obstruct the light of the adjoining lot in the rear at an angle of more than 63½ deg.

Height Limitations in American and European Cities.—The maximum height limit in America is, as a rule, set so high that it limits the height of buildings only when what might be termed the logical height limit for that particular city or locality has been very much exceeded. In other words, the maximum height limit is no height limit at all so far as most buildings are con-
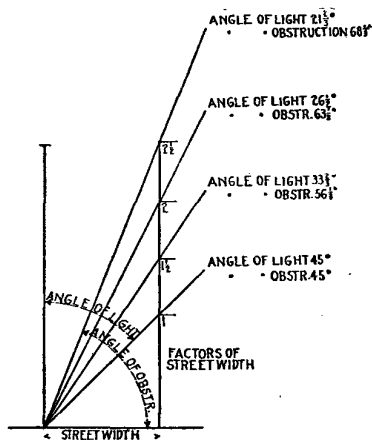

Fig. 4.—Angles of light and of light obstruction on ground floor on street front.

cerned; it only prevents the erection of a few exceptionally high buildings. It does not limit or condition the character of the great mass of buildings erected even in the central business district. In Boston, Chicago, and Washington, however, the present maximum height limits do constitute a very practical restriction, as evidenced by the tendency in certain districts to build up to the full height allowed by the restrictions.

A tabulation of height limits in some American and European cities is given in Appendix 1.

DAYLIGHT.

Determination of Sky Obstructions.—In most cases, planning

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for daylight involves consideration of sky obstructions, such as
buildings or other structures, or natural objects such as an ad-
jacent hill or mountain, etc.   The interception of daylight by such
sky obstructions depends upon several factors, the most important
of which is the average height of the sky obstruction and its
position upon the horizon with reference to the room or building.
For example, a tall adjacent building situated off to one side
within the line of light intercepted by the window apertures will
have little influence in reducing the light entering the room,
whereas if the same building were situated directly opposite the
window of the room, it would result in cutting down a large
proportion of the daylight that would otherwise enter the room.
Similarly, a long line of low buildings or distant buildings would
have a very much less effect in diminishing the light entering
the room, than would a corresponding area of sky obstruction
situated at such a point as to intercept the light that would other-
wise enter the room at higher and more favorable angles.

   1. *Photographic Method.*—A sky obstruction forms an artificial
sky line which is above the natural horizon; it represents the
outline of buildings and ground or other obstructions.   This
sky line can be approximately determined by taking a series of
over-lapping photographs of the horizon from the same station,
the series to include such portion of the entire horizon as it is
desired to show.   By properly joining, a panoramic view is se-
cured showing the actual sky line formed by the obstructions.
The natural horizon (which will be a horizontal line drawn across
the center of the picture if the camera is held level) is first de-
termined on the panorama, and from the known angle of the
camera lens (corrected for distortion) parallel lines representing
the degrees of altitude above the natural horizon can be drawn
on the panorama, from which the altitude of the artificial ob-
struction may be determined at any point of the compass.

   2. *Mathematical Method.*—Another method for determining
the artificial sky line consists in measuring or determining from
a map the distance from the point at which it is desired to de-
termine the results, to given obstructions and at the same time
using the known height of each obstruction from which the
altitude in degrees of each obstruction can be readily figured

and an artificial sky line plotted. Except in the simple cases this method involves much more work than the photographic method.

The object of such a panorama is to determine the percentage of sky obstructed in a given direction, and this may be determined with sufficient accuracy by drawing upon the photographic panorama or graphically constructed sky line, horizontal lines representing the degrees of altitude (5 deg. intervals are generally sufficient). The approximate area of sky obstructed in each of the zones of altitude may then be easily determined by inspection or, if more accurate results are required, by means of a planimeter. In view of the fact that the panorama is drawn with horizontal and vertical co-ordinates, and is on a plane surface instead of being upon the surface of a sphere representing the visible sky, it is necessary to multiply the area of obstruction in each separate zone of altitude by a factor which will give the proper weight to each of the horizontal zones. The approximate factors or relative areas for each 5 deg. zone from the horizon to zenith are given in the accompanying table. Typical sketches showing sky lines determined in accordance with the above methods are shown in Appendices 4 and 5.

Table giving relative area of zones at 5 deg. intervals from horizon to zenith; horizon of 180 deg. with radius unity:

Zone: degrees above the horizon	Factors or relative areas
0 deg. to 5 deg.	0.2738
5 " " 10 "	0.2716
10 " " 15 "	0.2675
15 " " 20 "	0.2613
20 " " 25 "	0.2532
25 " " 30 "	0.2432
30 " " 35 "	0.2310
35 " " 40 "	0.2173
40 " " 45 "	0.2020
45 " " 50 "	0.1855
50 " " 55 "	0.1670
55 " " 60 "	0.1475
60 " " 65 "	0.1264
65 " " 70 "	0.1048
70 " " 75 "	0.0824
75 " " 80 "	0.0593
80 " " 85 "	0.0358
85 " " 90 "	0.0120

Total area of quarter sphere representing the sky visible
between horizon and zenith with horizon of 180 deg.. 3.1416

It is also possible to determine from such a panorama the average angle of sky obstruction, and the consideration of this angle is an important factor in planning for daylight, as it is obvious that a sky obstruction at a very low angle will be very much less effective than a sky obstruction at a higher angle, and also that the depth of the room and the angle which may be considered the most favorable for the entrance of light in a given room will have an important bearing in determining the reduction caused by the sky obstruction. The effect of these sky obstructions will also depend to a considerable extent upon the color and reflecting power of the obstructions which in the case of buildings may modify the effect materially. For example, a tall building of light color may return a great deal (often more than 50 per cent.) of the light received by it, and present a surface which may have a brightness as great as if not greater than that of the sky.

In taking account of the effect of sky obstruction in planning for daylight in a given case, it is necessary to consider not only the existing factors and conditions so far as they may be determined, but also the possibility of *future* changes in buildings, etc. The four general cases which are encountered are:

1. Unobstructed sky;
2. Partly obstructed sky—buildings of low diffusion;
3. Partly obstructed sky—great diffusion;
4. Sky completely obstructed.

To determine comparative results quantitatively for the four cases, the most practical way is to make tests by a luminometer under conditions which most closely resemble those of the problem in hand; such tests must of course be made under conditions which are most typical and representative of the working conditions under which the daylight is to be used in the building or rooms for which its utilization is being planned.

The variations due to the seasons of the year in the presence or absence of snow on the ground, and the orientation of the building with reference to the points of the compass, etc., etc., should be given due weight.

Illumination Due to Direct Light from the Sky on the Vertical Surface of a Window of a Building Front, with Obstructed Uniform Horizon.—In Fig. 5, let A and B represent the buildings

on the opposite side of the street of width W. The formula for determining the illumination on the vertical window at point of observation a in building A in a case where the building B opposite is of constant elevation H above the point of observation a is derived as follows:

The sky may be represented by a spherical surface with its center at the point of observation a. A plane passing through the point a and through the top line of the opposite building front cuts a circle from the surface of the sphere drawn to represent the sky, and the opposite building obscures all the direct light from the sky which would otherwise enter below the plane drawn through a and the top line of the front of building B, and the
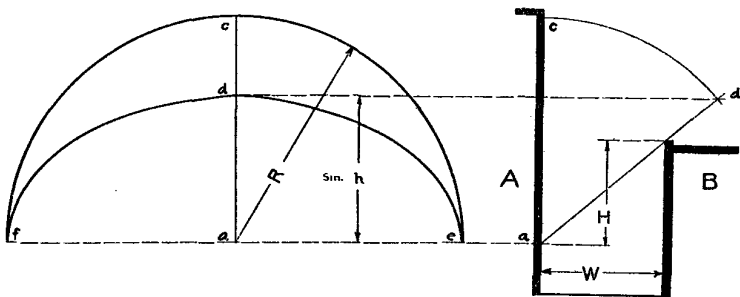

Fig. 5.—Illustrating the derivation of the formula for determining the illumination due to direct skylight falling on the vertical surface of a window of a building front with obstructed uniform horizon.

amount of sky obstructed may be represented graphically by the projected intersection of this plane with the spherical surface drawn to represent the sky, giving the semi-ellipse e-a-f-d-e. The projected area of the visible sky is therefore the lune f-c-e-d-f. The area of the semi-ellipse is the area of the semi-circle on the sphere projected on the plane through a and c as shown by the semi-ellipse and is equal to:

$$\tfrac{1}{2}\pi R^2, \sin h$$

where h is the angle between the line ad and the horizontal. Subtracting this area from that of the semi-circle e-c-f, $\tfrac{1}{2}\pi R^2$, gives:

$$\tfrac{1}{2}\pi R^2 (1 - \sin h)$$

for the area of the lune.

If B represents the brightness of the sky in candles per square foot, the illumination at a in foot-candles will be:

$$I = \tfrac{1}{2}\pi\, B\, (1 - \sin h).$$

If we use W as the width of the street, that is, the distance from A to the face of the building, and H as the height of the opposite building front, not above the ground, but above the point of observation, a, we can express sin h in terms of H and W, thus:

$$\sin h = \frac{H}{\sqrt{H^2 + W^2}}$$

and our expression for the illumination at a becomes:

$$I = \tfrac{1}{2}\pi\, B\, \left(1 - \frac{H}{\sqrt{H^2 + W^2}}\right) \quad \ldots \ldots \ldots \ldots \ldots (1).$$

Illumination on a Horizontal Plane within a Room.—The illumination directly due to the sky at a point on a horizontal plane in a room depends on, (a) the amount of sky visible from that point, (b) the brightness of this area of sky, and (c) its angular elevation. If the light comes through vertical windows, the solid angle subtended by the visible sky at any working position in the plane of reference is usually small enough for the illumination in foot-candles there to be given by the formula:

$$I = B\, \omega\, \sin \theta \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots (2).$$

Where B, represents the brightness of the sky in candles per sq. ft.

ω, the solid angle subtended by the visible sky at the test station.

θ, average angle of elevation.

The solid angle may be expressed in "square degrees" as used by Weber and Cohn, and more recently in the British committee report on daylight illumination of schools in which the recommendation is made that "The darkest desk in any school room should receive an illumination equivalent to that derived directly from 50 reduced square degrees of visible sky." A square degree is equal to the solid angle subtended by a square each of whose sides subtends one angular degree.

Factors Governing Daylight Admission.—The amount of daylight available from a window depends upon—

(a) The size, shape, depth and position of the window opening.

(b) The brightness of the sky.

(c) The sky angle, that is, the angle formed by a vertical plane passing through a window in the wall of a building, and a line from the window through the top of the opposite building. (In the case of an unobstructed horizon the sky angle is 90 deg.)

    (*d*) The diffusion from the street surface and from adjacent
        buildings.
    (*e*) The character of glassware in the windows.

Only a comparatively small percentage of the flux of daylight
that reaches the window is effective in the illumination of the
interior. The effect of blinds, curtains and other decorative and
absorbing media in obstructing the entrance of light is often con-
siderable. Furthermore if the color of the walls and furnishings
is dark a large portion of the light is absorbed.

Fig. 6 shows two windows of equal area, one of which is
vertical and the other horizontal. These two windows will give
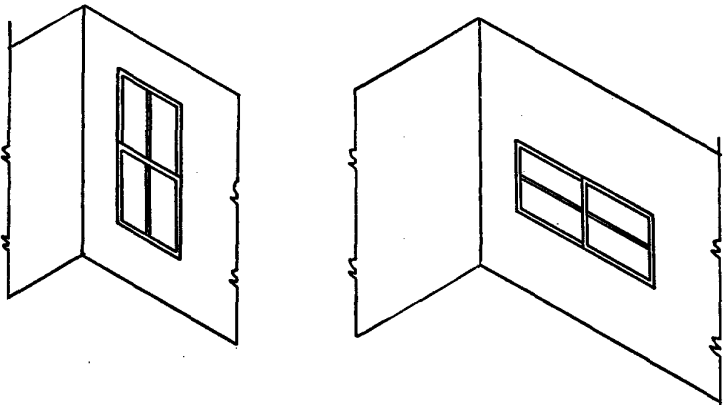very different results in the lighting of a room. Daylight will

Fig. 6.—Windows of equal area. Daylight will be received through the vertical window
at a much more favorable angle for interior illumination.

be received through the vertical window at a much more favor-
able angle for interior illumination, even with an unobstructed
horizon in both cases. If the sky is obstructed for some little
distance above the horizon the vertical window will have a still
greater advantage over the horizontal.

Obstruction to Light at Window Openings.—It is customary
to determine limiting angles at which the light is completely inter-
cepted by window walls, cap stones, columns and other obstruc-
tions to light; for example, in Fig. 7 the daylight received in the
Court House window shown is from a horizontal visual angle of
129 deg., and from a vertical visual angle of 73 deg.; from such

measurements the proportion of the total amount of daylight intercepted by the windows may be determined.

Relation of Window Area to Floor Area, etc.—With reference to the size of the windows for a given interior room, certain ratios are frequently used as a basis for design and comparisons. Among the ratios used are the following:

> Ratio of window to floor area.
> Ratio of window area to depth of room.
> Ratio of height of windows to depth of room.
> Ratio of window area to outside or window—wall area.

In some classes of interiors the ratio of the area of the window space to the floor area to be lighted is sometimes specified to be
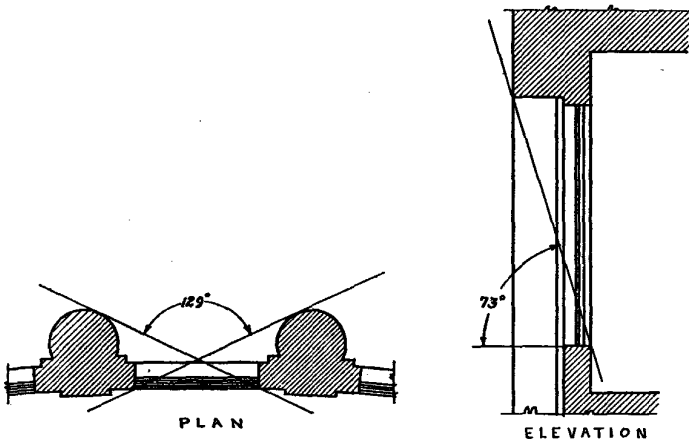

Fig. 7.—Plan and elevation of a window showing obstructions to admission of daylight and limiting horizontal and vertical visual angles.

1 to 4 or 1 to 5, as in factories for example; while in other cases such as office buildings, this ratio may be specified as 1 to 7 or 1 to 10, etc., depending to some extent upon the depth of the room. This system of computation, however, is evidently limited in its application, because the ratio of window space to floor area taken alone does not give a true relative value of daylighting facilities. For example, the ratio of window space to floor area for the lower floors of a building might be quite different than that of the upper floors for equivalent illumination, especially if

part of the direct light of the sky is cut off by an adjacent tall building.

While the ratios above referred to are often of considerable value in comparing the window openings of rooms of the same character, arrangement and exposure, the relative values indicated may be very misleading, as for example where the shape of a room is quite out of the ordinary or where windows of unusual shape are provided.

Limiting Angle of Light.—Account is frequently taken also of the angle of a point half way between the top and bottom of the window and a given reference point within the room, such as a point 2 ft. 6 in. (0.76 m.) or 3 ft. (0.9 m.) above the floor at a working distance near the most distant wall; account is also taken of the angle between such a reference point and the top of the window.

Light-value of a Window.—It has already been pointed out that the ratio of the window area to the floor area taken alone may convey a very imperfect and even erroneous idea of the amount of daylight that reaches an interior. This is clearly shown in Fig. 6 previously referred to, in which two windows of the same area but differently located with respect to floor space, obviously give very different results in lighting. The ratio referred to does not take cognizance of the effect of obstructions outside of a window, of the amount of sky visible, of the contour and depth of the window or of the height and depth of the room. Prof. L. Weber of Kiel, Germany, introduced the conception of the "light-value" of a window to give a more correct basis for estimating daylight entering a window. The "light-value" is the ratio between the actual illumination of the vertical window pane and the illumination which would be received from an unobstructed sky; that is to say, the ratio between the solid angle subtended at the window by the visible sky to the solid angle subtended by the sky with free horizon.

If this quantity is modified so as to include the percentage of the window area through which unobstructed sky can be seen it becomes even more useful. If the light value be denoted by L and this be multiplied by the permissible ratio of window space to floor area we obtain a new quantity, P, which is a measure of

the usefulness of a window for admitting daylight. Having determined L, we have $P = L \cdot \frac{g}{b}$ where g is the area of the glass surface of the window and b the area of the floor of the room. This formula is of course limited in its application as explained in the preceding paragraph.

Ratio of Indoor to Outdoor Daylight.—Cohn found that a school room was sufficiently lighted by day if the minimum horizontal intensity on any desk was about 2½ foot-candles. Weber found that with the average value of the sky brightness likely to be met during the hours of study, this illumination should be obtained on any desk in a school room receiving 0.5 per cent. of the unobstructed daylight illumination out of doors; that is to say, 0.5 per cent. of unobstructed roof light. As the vertical window is exposed to only one half of the sky with a free horizon, the figure given by Weber is equivalent to 1 per cent. of the daylight on the window sill.

Window Glass.—In cases where buildings are necessarily built close together or where it is impracticable to secure a reasonably unobstructed horizon, it is possible to redirect the light from the sky by means of prismed windows. By this means the light in the rear of a room say 60 ft. (18.3 m.) deep may easily be increased to from 10 to 15 times, though it must be understood that the total flux of light in the room is not increased by the substitution of prismed windows for clear glass.

When windows are equipped with prismatic glass the incident rays of daylight are deflected from the course which they would naturally take if plain glass windows were used and instead of striking the floor at points near the position of entry of the light, the rays reach the inner portions of the room thus lighting parts of the working section where more light is required.

In the crowded tenement districts in large cities the substitution of daylight prisms for ordinary glass would be a boon to those who are now compelled to live in rooms that scarcely see the light of day. Fortunately the movement now on foot to enforce regulations providing for direct daylight and sunlight in tenement houses will soon make the dingy tenement a thing of the past.
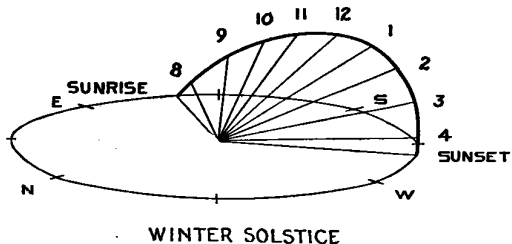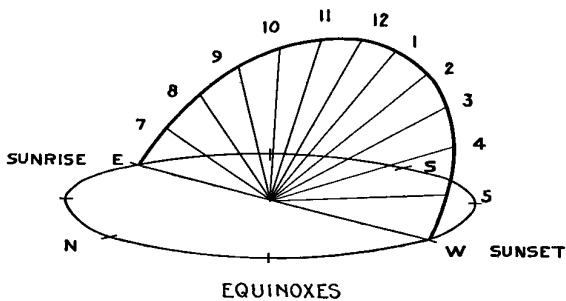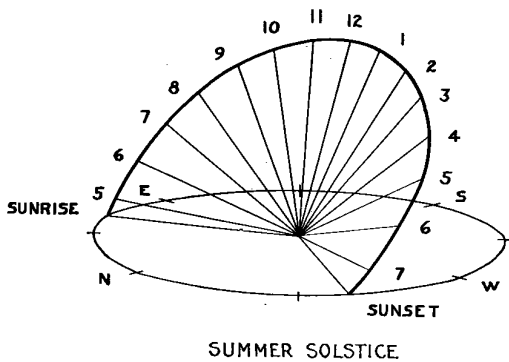
SUMMER SOLSTICE

EQUINOXES

WINTER SOLSTICE

Fig. 8.—Apparent path of the sun at latitude of New York City illustrating angles of sunlight at different hours of the day at the solstices and equinoxes.

DIRECTION OF SUN'S RAYS
AT NOON, SUMMER SOLSTICE

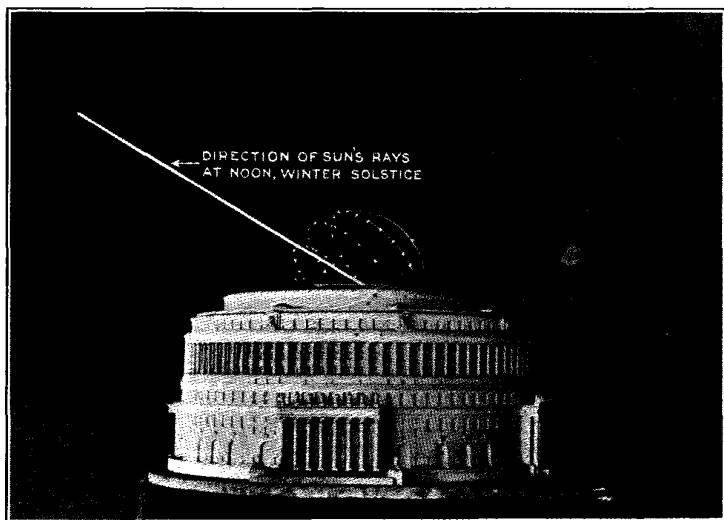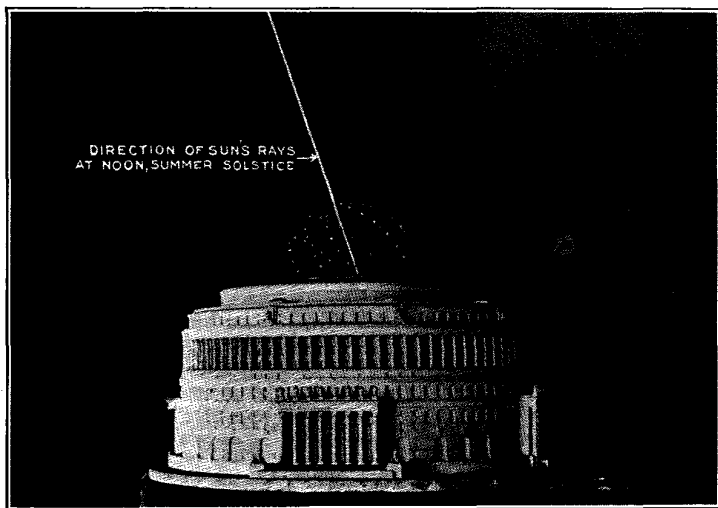DIRECTION OF SUN'S RAYS
AT NOON, WINTER SOLSTICE

Fig. 9.—Plaster model of new County Court House, New York City, showing wire frame
(representing the solar path) mounted to determine direction of sun's rays for all
seasons of the year.

SUNLIGHT AND SHADOWS.

Variations Due to Latitude, Seasons of the Year and Hours of the Day.—The apparent path of the sun at the summer and winter solstices and the equinoxes for latitude about 41 deg. north (approximately that of New York City) is shown in the perspective diagrams, Fig. 8. These diagrams also show the angles of sunlight at the different hours of the day, solar time.

In order to determine in a practical way the direction of the rays of the sun at any hour of the day for the winter and summer solstices and the equinoxes, a simple frame representing the celestial sphere was constructed of wire with the apparent sun paths shown by wire circles as indicated in Fig. 2. The common axis of the circles representing the apparent paths of the sun makes an angle with the horizon corresponding to the latitude chosen, namely 41 deg. in this case. Hour marks (consisting simply of pieces of twine, knotted) were placed at 15 deg. intervals on each of the three circles. Another circle of wire was placed on the north and south axis of the wire frame, and the points of intersection of this circle with the circles representing the apparent paths of the sun, correspond with the zenith or twelve o'clock position of the sun, solar time. By placing an artificial light source of small size at some distance from the wire frame the direction of the rays of the sun could be reproduced for any hour of the day, or for any of the four seasons of the year by locating the artificial light source at such a point that the rays of light are in line with the desired hour of the day on the sun path circle representing the season chosen and the center of the wire frame corresponding with the center of the celestial sphere. The wire frame may then be mounted on a miniature wood or cardboard scale model of a building or buildings adjusted to correspond with the points of the compass established by the wire frame. By using models of light color, a partially darkened room and a concentrated beam of light from a miniature lamp with parabolic reflector, it is possible to secure clear, sharp shadows on the scale models, sufficiently accurate to form the basis of conclusions with respect to the penetration of sunlight and the obscuration by shadows in any given case

From the observations thus taken drawings or charts may be made showing the direction of the sun and the shadows produced during any period of the year and for various hours of the day between sunrise and sunset.

Fig. 2 shows the wire frame set up on a small model made to scale for the purpose of determining the shadows cast by the inner court and connecting bridges on the inner wall of the proposed new County Court House, New York City. Typical shadows thus determined are shown in Appendix No. 6. The degree of penetration of sunlight in the court rooms during the working year was determined by this method.

The use of this wire frame for determining the direction of the rays of the sun on the large scale model of the court house is shown in Fig. 9. Some idea of the great change in direction of light due to the change in the path of the sun from the winter solstice to the summer solstice, and the consequent effect upon the production of the shadows at different times of the year may be obtained by reference to this figure.

Molesworth's Planisphere Diagram.—Molesworth[2] describes a unique, graphical method whereby with the use of the planisphere,—or the plane projection of a sphere,—the hours during which any particular window receives direct sunlight can be determined. This method is mathematically correct, but requires the following data with regard to each obstruction, namely :—

    (*a*) The angular elevation of the different salient points.
    (*b*) The true bearing of these points.
    (*c*) The true bearing of the side of the building in which the window is located.
    (*d*) The latitude of the place.

As this information is often difficult to obtain, and must be secured for each important obstruction on the visible horizon, considerable time is required to obtain a definite result, even for one season of the year and the process must be repeated if the information is required also for other times of the year.

The determination of shadows by means of models is much simpler than that by the use of descriptive geometry or calculation, or by the graphical method of using a planisphere diagram. Moreover the models may be readily shifted to study the effect

    [2] Molesworth, H. B.; Obstruction to Light; London, 1902.
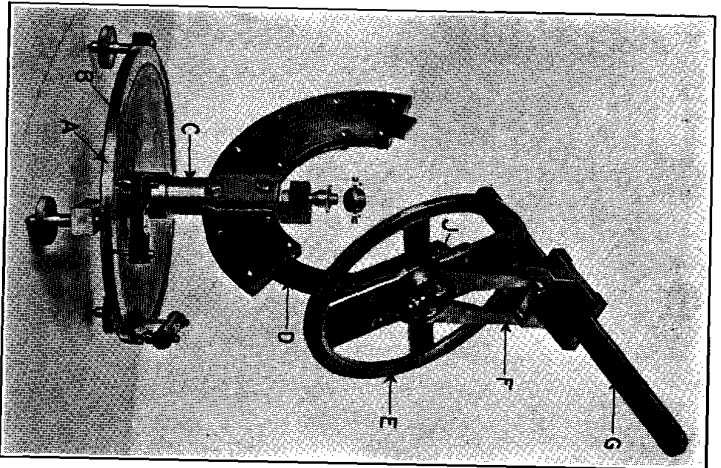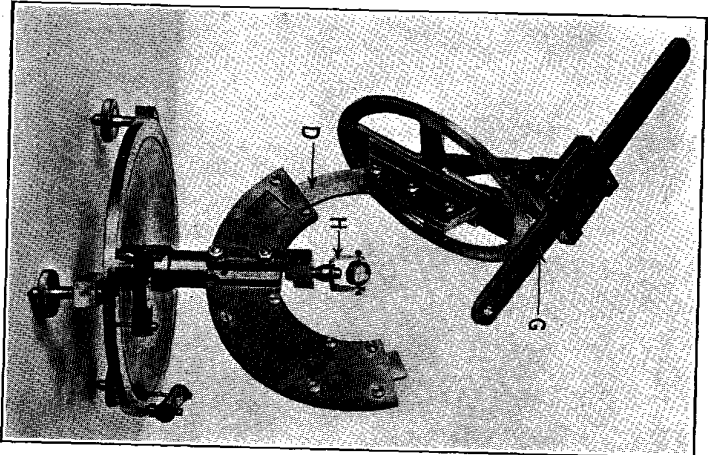
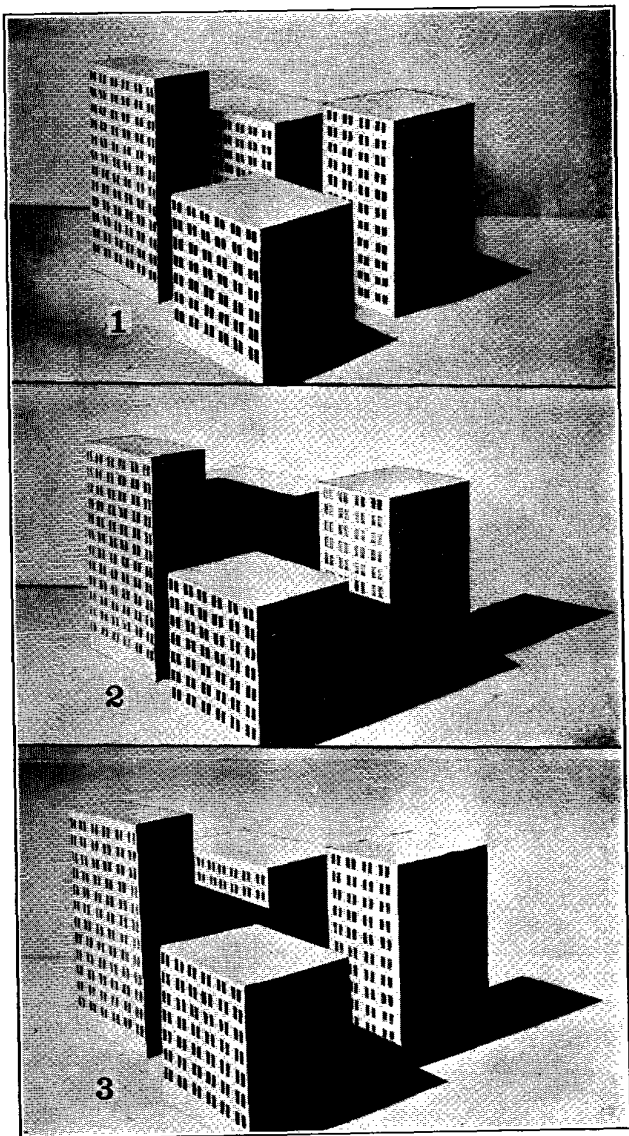Fig. 10.—New instrument for sunlight and shadow determinations.

Fig. 11.—Cardboard models of buildings made to scale showing shadows at noon hour, (1) summer solstice, (2) winter solstice, (3) vernal and autumnal equinoxes.

of orientation with respect to the points of the compass, and the effect of the shadows at various times of the day may also be easily compared and studied, as well as the changes due to the variations of the path of the sun at the various seasons of the year. Even in the case of buildings of complicated shape, the shadows may be determined with sufficient exactness for all practical purposes for any time of the day and any time of the year and for any position of the building.

A New Instrument for Sunlight and Shadow Determination.—A new instrument designed by J. E. Woodwell for rapidly and accurately determining the apparent position of the sun at any hour of any day in the year is shown in two views in Fig. 10. This instrument is constructed in accordance with the same underlying principles as those that hold for the wire frame previously described, but it is adjustable for any latitude between the equator and 60 deg. north or south latitude, and also for any time of the year.

The instrument consists of a stationary base A carrying a horizontal or horizon circle B to set the instrument at any desired azimuth. The vertical post C carries a vertical support for the vertical circle D by which adjustments are made for any degree of latitude from the equator or zero to 60 deg. north or south latitude. Upon this adjustable vertical circle D a stationary circle E is so mounted that the axis of the latter passes through the axis of the vertical circle and the vertical axis of the horizontal or azimuth circle. This circle E serves as an hour circle, each hour being represented by 15 deg. intervals.

Settings for the different hours of the day are made by means of a revolving arm F. The revolving arm F carries with it a support for the adjustable sliding arm G, which has, at its inner end a small circular aperture through which a beam of light may be projected upon the crosshairs so mounted upon an adjustable support H that the center of the crosshairs lies at all times in the vertical axis of the horizon or azimuth circle B, the center of the vertical circle D and in the axis of the hour circle E.

The adjustable sliding arm G is set perpendicular to the plane of the hour circle and is calibrated to correspond with the set-

tings of the instrument for any day of the year. At the dates
of the equinoxes, for example, the sliding arm G is so set that
a beam of light received from an artificial light source so placed
as to correspond with the direction of the sun, would pass
through the circular aperture in the sliding arm G and intersect
the crosshairs at the center of the instrument in a line parallel
to the plane of the hour circle and perpendicular to the axis
passing through the center of the hour circle and the center
crosshairs set to represent the latitude of the place for which
the instrument is adjusted.

Due to the inclination of the axis of the earth at 23½ deg.
the settings for the summer and winter solstices are made by
sliding the adjustable arm G towards or away from the hour
circle an amount which is equivalent to the angular distance of
23½ deg. either side of the setting for the equinox. The set-
tings for intermediate months and days of the year are made in
a similar manner by reference to astronomical tables giving the
declination of the sun at zenith, etc.

The instrument may be levelled by means of the adjusting
screws and the levels mounted on the base at right angles to
each other, and when the vertical circle is set for the equator or
at zero, the intersection of a beam of light passing through the
second circular aperture J and the crosshairs at the center of the
vertical circle will be in the plane of the horizon. A point on
the horizon may be established at any point of the compass by
merely revolving the azimuth plate upon which the instrument is
mounted.

As in the case of the wire frame previously described repre-
senting the celestial sphere, the best results in determining shadows
upon small scale models of buildings, etc., are secured by using
a miniature lamp and a small parabolic reflector, the artificial
light source being placed at a sufficient distance away from the
model in proportion to the size of the latter to avoid distortion
due to non-parallelism of the rays of light. In practise it has
been found that a distance of ten times the greatest dimension
of the model is ample to secure accurate results.

This instrument may also be used to determine the form of
shadows produced by rays of light from certain definite direc-

tions upon architectural moldings, cornices, relief work, and also for determining the angles at which direct reflection of light is produced in connection with problems in interior illumination.

The accompanying photograph, Fig. 11, shows the obscuration of the direct sunlight at different times of the year for a specific group of buildings by means of small card-board models of the buildings constructed to scale. (1) shows the obscuration of the direct sunlight and consequent shadows at noon at the summer solstice. (2) shows the shadows for the same group of buildings at noon at the winter solstice. (3) shows the shadows of the same group of buildings at the vernal and autumnal equinoxes. The shadows for any intermediate period may be similarly shown.

DAYLIGHTING FACILITIES OF NEW COURT HOUSE.

The new County Court House to be erected in New York City at an estimated cost of $10,000,000, presents unusual problems in daylighting owing to the architectural features of the building which was designed by Mr. Guy Lowell, architect.

The plans of the Court House show a circular building approximately 400 ft. (121.8 m.) in diameter and 200 ft. (60.9 m.) high containing an annular court or open space in ring form 40 ft. (12.2 m.) wide. This court is crossed by bridges connecting with the main building. The inner wall of this court rises 75 ft. (22.8 m.) above the floor line of the fourth floor. The following preliminary plans of the building are submitted in Fig. 3 and Appendices 7, 8 and 9: typical court room plan showing grouping of court rooms into separate units; section of building on north and south axis according to architect's plan No. 3; plan of typical court room corresponding to plan No. 3, showing windows and light court, arrangement of room and exterior columns; section of typical court rooms through fourth and fifth floors at colonnade, corresponding to plan No. 3.

Obstruction of Light by the Walls of the Annular Court.—The reduction of sky angle due to the obstruction of light by the walls of the annular court and by the connecting bridges shown in the preliminary plans submitted will result in cutting out a large percentage of the light that would otherwise reach the working portions of the court room through the rear windows on the

fourth and fifth floors.   In view of the ample provision of light
through the large windows in the outer wall, this reduction is
not serious with respect to adequacy of lighting facilities but
rather with respect to flexibility; that is to say dependence must
be placed very largely on lighting from one side (the outside
windows) only, as the light coming through the windows on the
court side would not alone be sufficient to give adequate illumin-
ation of the room.   The flexibility possible with equal lighting
facilities on both sides of a room is often a great advantage,
especially when the erection of high buildings close by and im-
mediately opposite the windows results in obstructing the light
on one side; and also when it becomes necessary to screen direct
sunlight on one side during working hours.

Reduction of Light Due to Surrounding High Buildings.—
From observations made on the site of the proposed new Court
House at a height of 100 ft. (30.5 m.) above the ground (fourth
floor court room level), it was found that at the present time
there is substantially no sky obstruction at this level with the
exception of that due to a few buildings on the south and west,
the sky angle averaging approximately only 12 deg.   A chart
showing the sky angle at the fourth floor level for 360 deg. is
given in Appendix 5.
The probable growth of tall buildings in the vicinity in the
future will considerably reduce the effective daylight on the
lower floors of the Court House.

*The Effect of the Contour and Depth of Windows and of the
Exterior Colonnade upon the Visual Angle.*—What is sometimes
termed the visual angle of the window is the angle between two
planes that pass through the edges of the glass at the sides of
the windows and the furthest projecting edge of the building
wall or column, as the case may be.   It is very important that
the exterior colonnade be located close to the outer wall of the
building as a very slight increase in the distance of the columns
from the window wall results in a material decrease in the visual
angle of the window, as may be readily seen from the diagram
Fig. 7.   Calculations show that the increase in the visual angle
that would be obtained by the removal of the columns from the
present location shown on the plans, would not secure a material

increase in effective daylight within the rooms. Hence from the lighting standpoint there is no need of sacrificing the exterior colonnade which may be said to constitute an indispensable element of beauty of the exterior.

The contour and depth of the windows as revealed in the plans are favorable to good lighting. On the fourth floor the projecting stone above the lower window will considerably obstruct the ingress of light through this window. However, since the main lighting of the room is carried out by the upper windows this obstruction will not reduce the total daylight in the room to any material extent.

Window Area and Visual Angle.—The ratio of the floor area to the glass area, and the visual angle taken 3 ft. (0.9 m.) above the floor at the wall opposite the windows in several court rooms in the present New York County Court House and in the principal court rooms of the new Court House are given in Appendix 10.

Daylight Illumination Measurements.—Measurements of daylight illumination were made in a test room to determine the actual intensity of daylight on the working plane at different times of day and on different days. Similar measurements were made in several court rooms of the present Court House. The rooms chosen are a court room said to be favored by several of the justices because it has windows on three sides, thus providing for better lighting and ventilation than in most of the other rooms; a court room having three windows on one side only; and a court room having two windows on one side only, chosen because both windows were exposed to direct sunlight. In the last of these, measurements were made when direct sunlight was shining into the room and also when the windows were screened by amber colored shades. The charts submitted contain the records of illumination tests in all these rooms (see Appendices 2 and 3).

Unilateral Lighting as Compared with Lighting from Two or More Sides.—In planning the lighting of school rooms there is a strong tendency towards the adoption of unilateral lighting, with windows located in the wall to the left of the pupils. When this plan is adopted it is desirable that the ceiling, and wall op-

7

posite the windows should be light in color to secure suitable diffusion of daylight. Calculations from the plans submitted for the Court House show that more than 90 per cent. of the light on the working spaces of the fourth floor court rooms will come from the three windows in the outside wall, as the two windows in the wall looking out on the annular court will receive very little direct light. On this floor therefore, if the present plan were followed, we would have a close approach to unilateral lighting. In fact the two windows in the court wall would probably not contribute as much to the effective lighting of the main portion of the room as would a wall placed in front of the wing to be used for a visitors' gallery. Such a wall (light in color) would considerably increase the diffused light in the room.

The chief advantage of the two windows on the court side of each room on the fourth floor would be from the standpoint of ventilation rather than that of lighting.

On the fifth floor more than 80 per cent. of the light on the working spaces would come from the three windows in the outside wall according to the present plan.

The typical court room shown on the plan has a wing containing the visitors' raised platform. The disposition of windows in this room is such as to secure adequate daylight and satisfactory ditribution of light, provided the walls and ceiling are made light in color and suitable means are employed for screening direct sunlight without darkening the room to a prohibitive degree. Although such means can be readily devised it is considered desirable to insure greater flexibility of lighting facilities on the fourth and fifth floors, by added lighting from the court side so as to permit of satisfactorily lighting the room mainly from either one side or the other, thus securing substantially all of the advantages of unilateral and of bilateral lighting.

Lighting from more than two sides is almost always open to serious objections.

In a city like New York, especially in lower Manhattan where high office buildings are likely to be built close together, the provision of a surplus of daylight from the open court of a large building would have the added advantage of compensating for

any obstruction of light by high buildings that may be erected in the vicinity in the future.

There is a great diversity of opinion as to the relative merits of unilateral, bilateral, and skylight lighting for different classes of interiors; except in the lighting of school rooms very little progress has been made towards standardization of methods of daylighting.

Effect of Color of Walls.—The color of walls and ceiling and also of room furnishings plays an important part in the distribution of daylight within the interior. A window area that would be adequate for the provision of good daylight within the room if the walls and ceiling are light in color, might be inadequate if the walls are dark in color. With unilateral lighting or with lighting that comes principally through windows located on one side of the room a light colored interior finish to secure good diffusion of light is a pre-requisite, because with dark walls there would be a marked tendency to strong contrast of light and shadow on the faces of those who do not face the windows—an objection which would have considerable weight in a court room.

Effect of Screening of Windows to Exclude Sunlight during Working Hours.—All of the court rooms are provided with windows on both sides; hence there will never be need of screening all of the windows to exclude direct sunlight. In the present plan, this flexibility of lighting facilities leaves little to be desired in the court rooms on the sixth floor, but is not secured on the fourth and fifth floors. However, with the proper use of suitable shades to screen the direct sunlight, good lighting conditions may be maintained on all of the court room floors.

A photometric test made in one of the court rooms lighted from one side only in the present County Court House Building, showed that when the windows were lighted by direct sunlight and the shades (amber colored) drawn to exclude the sunlight to the required degree, the occupants of the room still had sufficient light to carry on their work with comfort though the intensity of illumination was relatively low. The foot-candle intensities of daylight illumination in the court room under these conditions are given in Fig. 2, Appendix 3. It will be noted that on the judge's desk the intensity of daylight illumination was 2.75 foot-

candles (the minimum intensity in the working portions of the room).   This intensity was considered quite sufficient for comfortable reading of law books and other papers before the court.

Penetration of Direct Sunlight.—A study was made of the exposure of the court rooms with reference to the penetration of direct sunlight at all times during the year; the calculations were checked by tests on a model of the building scaled according to plan 3.   Sample charts containing information on which the periods of direct sunshine in the court rooms may be determined are shown in Appendix 6.

Based upon the preliminary design submitted, the tests and calculations show that a large percentage of the court rooms will receive direct sunlight on sunny days for at least an hour or two a day during the working term of the year.   During the period from the late fall to the early spring there will be no substantial penetration of direct sunlight through the court room windows facing the court on the fourth floor, and for the same period five of the court rooms on this floor will receive no direct sunlight whatever during the working year.

APPENDIX 1.

TABULATION OF BUILDING HEIGHT LIMITS IN AMERICAN AND EUROPEAN CITIES.

American Cities

Baltimore	175 feet	
Boston[1]		
District A (Business and commercial)	125	"
District B (Residential section) ...	80–100	"
Buffalo[2]		
Charleston[1]	125	"
Chicago..............	200	"
Cleveland[1]	200	"
Erie[1]................	200	"
Indianapolis	200	"
Los Angeles.........	150	"
Manchester, N. H ...	125	"
Milwaukee	225	"
New Orleans[1]........	160	"
Portland, Ore	160 feet	
Rochester[2]		
Scranton	125	"
Youngstown[1].......		
Fort Wayne[1]	200	"
Providence	120	"
Salt Lake City	125	"
Toronto[3]	130	"
Washington D. C.		
Pennsylvania Ave	160	"
Business Sts[4]	130	"
Residence Sts[5]...	85	"
Seattle.........about	20 stories	

European Cities

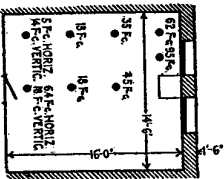|		
Aix-la-Chapelle.....	65.6 feet	
Altona..............	72.2	"
Berlin	72.2	"
Bremen.............	62.3	"
Breslau	72.2	"
Cologne	65.6	"
Dortmund	65.6	"
Dresden	72.2	"
Duisburg.	65.6	"
Dusseldorf.........	65.6	"
Edinburgh..........	60.0	"
Elberfeld	65.6	"
Frankfort	65.6	"
Halle..............	59.0	"
Hamburg	78.7	"
Hanover............	65.6 feet	
Kiel	72.2	"
Leipzig	72.2	"
London.............	80.0	"
Lübeck	59.0	"
Magdeburg	65.6	"
Munich.............	72.2	"
Paris	65.6	"
Posen	65.6	"
Rome	78.5	"
Stockholm..........	72.2	"
Stuttgart	65.6	"
Vienna	82.0	"
Zurich.............	43.0	"

[1] Not to exceed 2½ times width of widest street.
[2] Not to exceed 4 times average least dimension.
[3] Not to exceed 5 times least dimension at base.
[4] Not to exceed street width plus 20 feet.
[5] An intermediate height between 60 feet and 85 feet on streets over 70 feet wide— height not to exceed width of street minus 10 feet; 60 feet on streets from 60 to 70 feet wide; and street width on streets less than 60 feet wide.

FIG.1 NOTES:
DATE FEB. 28, 1914
TIME OF MEASUREMENTS 3:30 P.M. TO 3:45 P.M
SKY: DULL GREY DAY
EXPOSURE: NORTH
PHOTOMETER: SHARP-MILLAR

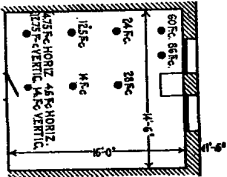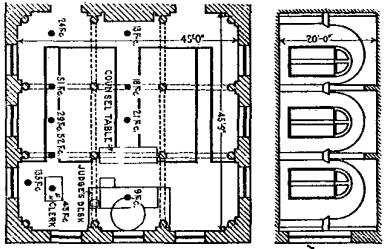F-c-INTENSITY OF DAYLIGHT IN FOOT-CANDLES ON HORIZONTAL PLANE 3'-0" ABOVE FLOOR

• TEST STATION

FIG. 2 NOTES:
DATE, MARCH 2, 1914.
TIME OF MEASUREMENTS 3:10 P.M. TO 4:00 P.M
SKY: DULL GREY DAY
ROOFTOPS AND STREET COVERED WITH SNOW
ILLUMINATION INTENSITY ON HORIZONTAL
PLANE AT BASE OF WINDOW, INSIDE
OF ROOM - - - - - - - - - - - - - -.125 Fc
ILLUMINATION INTENSITY VERTICAL
PLANE SAME LOCATION- - - - - - - .445 F-c
ILLUMINATION INTENSITY AT MOST
FAVORABLE ANGLE - - - - - - -.200 F.c
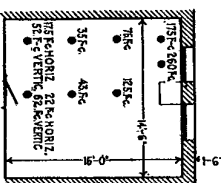
FIG.3 NOTES:
DATE MARCH 4, 1914
TIME OF MEASUREMENTS 10 A.M. TO 11 A.M.
SKY BRIGHT DAY, SUN OBSCURED BY
LIGHT CLOUDS.
SNOW ON STREET BUT NOT ON ROOF TOPS.
ILLUMINATION INTENSITY ON HORIZONTAL
PLANE AT BASE OF WINDOW, INSIDE OF
ROOM - - - - - - - - - - - - - - - -.440 F.c
ILLUMINATION INTENSITY VERTICAL
PLANE SAME LOCATION - - - - - - -
ILLUMINATION INTENSITY AT MOST
FAVORABLE ANGLE, BEYOND THE RANGE
OF PHOTOMETER - - - - - - - .500 F.c
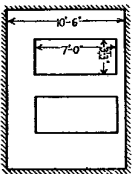
Appendix 2.—Measurements of daylight in test room.

Appendix 3.—Measurements of daylight in court rooms.

Fe. = INTENSITY OF DAYLIGHT IN FOOT-CANDLES ON HORIZONTAL PLANE 3'-0" ABOVE FLOOR
• TEST STATION

FIG.1 NOTES
DATE: MARCH 3, 1914
ROOM: SPECIAL TERM PART 2-1st FLOOR
TIME OF MEASUREMENTS 1 P.M. TO 2 P.M.
SKY: BRIGHT DIM SUN PARTLY OBSCURED BY LIGHT CLOUDS
DIRECT SUNLIGHT
SNOW ON GROUND
THREE WINDOWS ON SOUTH
WALL HALF WAY DOWN
ILLUMINATION MEASURE-MENTS TAKEN UNDER WORKING CONDITIONS

FIG.2 NOTES
DATE: MARCH 3, 1914
ROOM: SPECIAL TERM PART III ROOM 736
TIME OF MEASUREMENTS 3.10 TO 3.30 P.M.
SKY: BLUE WITH FEW FLEECY CLOUDS
DIRECT SUNLIGHT DOWN
DONE SHADES DRAWN TO EXCLUDE SUNLIGHT FROM ROOM
AT 3.35 P.M WITH SHADES UP INTENSITY AT STATION AT N.E. CORNER OF ROOM
AND AT JUDGES DESK 85 Fc.

FIG.3 NOTES
DATE: MARCH 3, 1914
ROOM: TRIAL TERM PART SR 8 398
TIME OF MEASUREMENTS 4.40 P.M.
SKY: BLUE WITH FEW FLOCCULENT CLOUDS
NO DIRECT SUNLIGHT
WINDOWS
SCREEN BETWEEN JUDGES DESK AND CENTRAL WINDOW OBSCURES LIGHT FROM LOWER HALF OF THIS WINDOW

SCALE ¼"=1'-0"

COUNSEL TABLE
JUDGE'S DESK
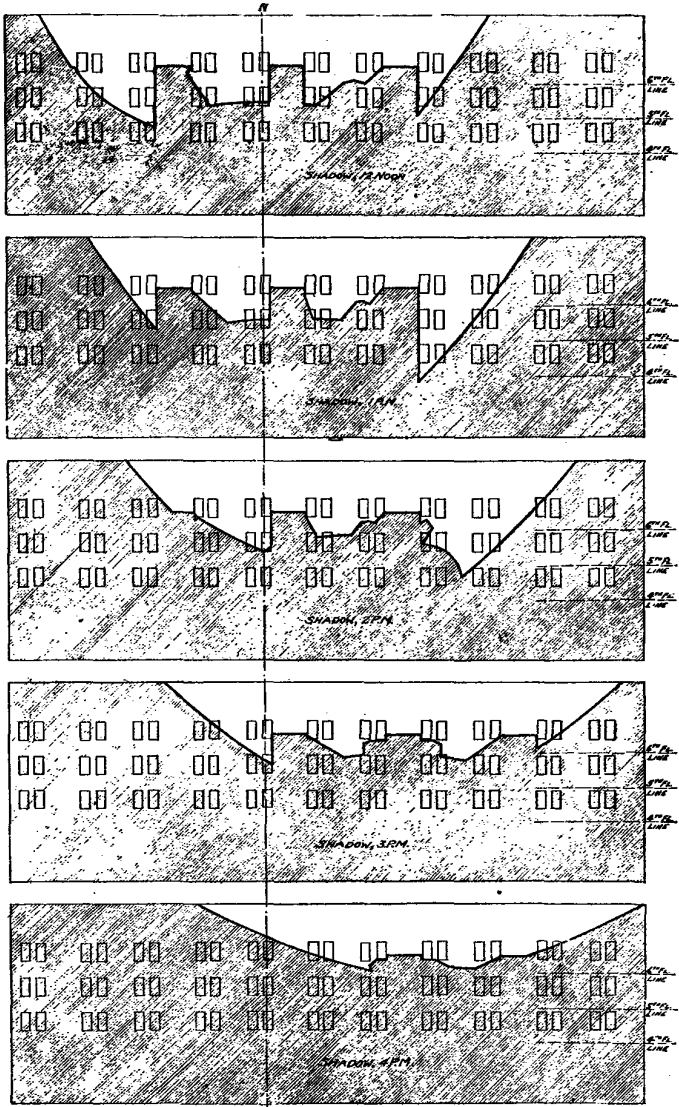CLERK
COUNSEL TABLE
JUDGE'S DESK
JURY BOX
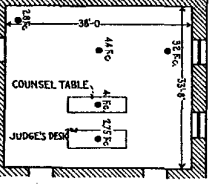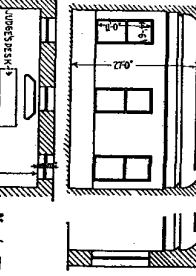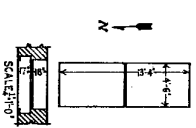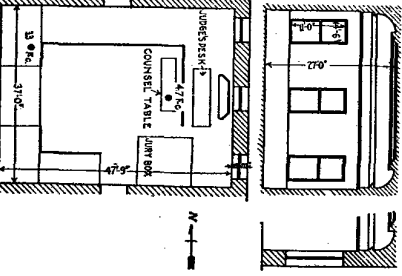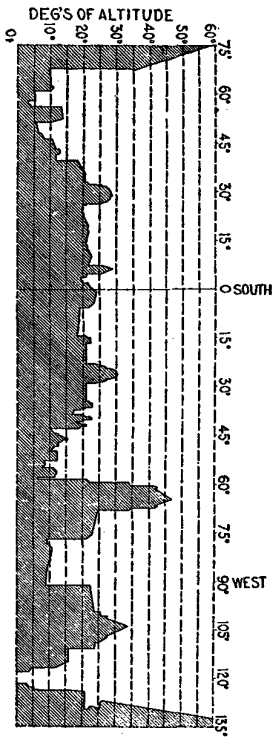
Appendix 4.—Sky line viewed from south wall of New York County Court House.
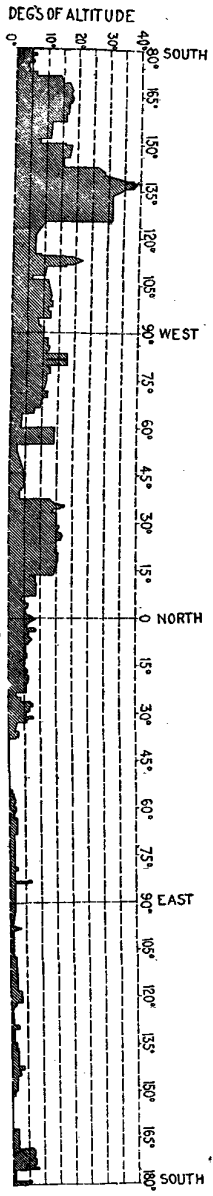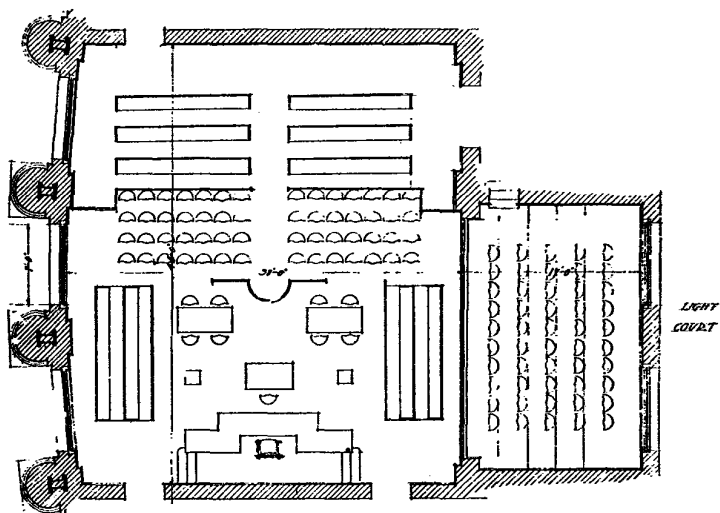

Appendix 5.—Sky line viewed from proposed site for new New York County Court House.
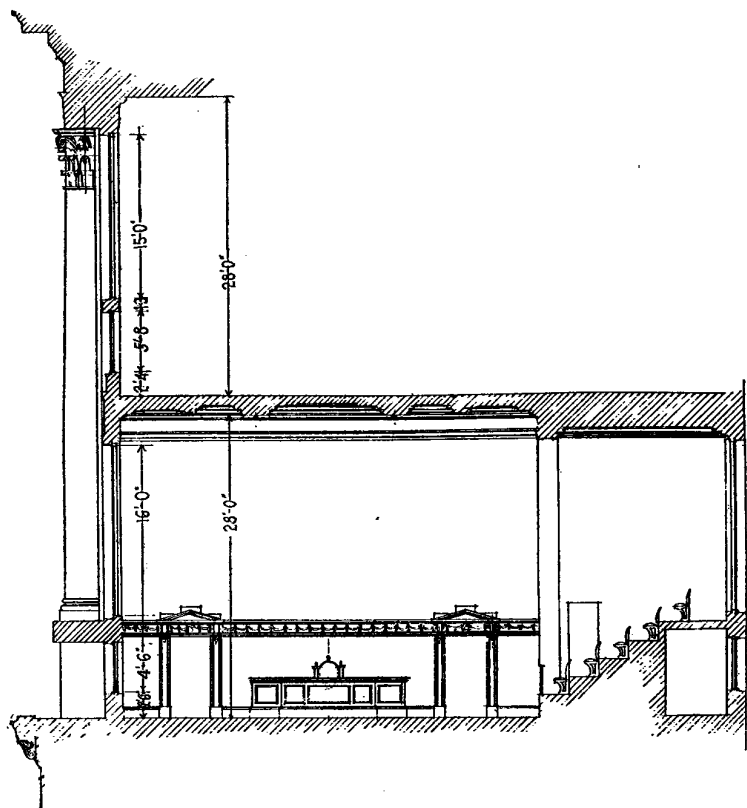
Appendix 6.—Shadows thrown on court room windows by the inner court and connecting bridges new New York County Court House, plotted for months of October and February. Shadows in morning hours similar to those in afternoon.
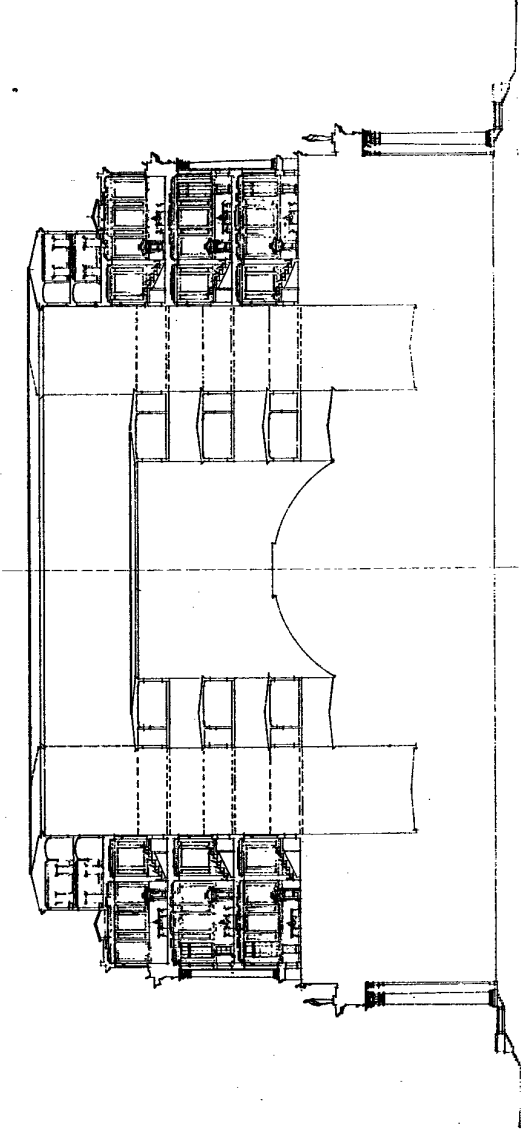
Appendix 7.—Section of building on north and south axis.

Appendix 8.—Plan of typical court room New York Court House.

Appendix 9.—Section through fourth and fifth floors at colonnade New York Court House.

APPENDIX 10.
COURT ROOM DATA.

  I. Proposed new Court House, typical court room, as shown on plans.
 II. Proposed new Court House, typical court room, assuming lighting
       from outside windows only and floor area limited to main room
       (exclusive of wing for visitors' platform).
III. Old New York County Court House.
 IV. Test Room.

Court room type	Location	Floor area (sq. ft.)	Glass area (sq. ft.)	Ratio floor area to glass area	Visual angle[1]
I	5th floor	2,059	661	3.12 to 1	21° 45′
	4th floor	2,059	572	3.6 to 1	21° 45′
II	5th floor	1,639	428	3.82 to 1	27° 0′
	4th floor	1,639	339	4.83 to 1	30° 0′
III	2nd floor—				
	Special Term, Part 3,	2,060	451.5	4.56 to 1	15° 30′
	Special Term, Part 4, (Room 218)	1,279	120	10.67 to 1	24° 30′
	Trial Term, Part 9, (Room 308)	1,768	148.5	11.9 to 1	15₀ 45′
IV	Test Room	232	45.5	5.1 to 1	21° 45′

[1] Taken 3 feet (0.9 m.) above the floor at wall opposite windows.

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