A Comparative Review of Daylight Planning Tools and a Rule-of-Thumb for Street Width to Building Height

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Available at: https://works.bepress.com/mark_dekay/18/
17th National Passive Solar Conference

Conference Proceedings
Cocoa Beach, Florida
June 15-18, 1992

Edited by
S. Burley and
M.E. Arden

American Solar Energy Society
A COMPARATIVE REVIEW OF DAYLIGHT PLANNING TOOLS AND A RULE-OF-THUMB FOR STREET WIDTH TO BUILDING HEIGHT RATIO

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ABSTRACT

This study gives a comparative analysis of available daylight planning tools and develops a Rule-of-Thumb method for determining street width to building height ratios, related to actual illumination levels inside urban buildings. Nine daylight planning tools for site planning and urban design decisions were identified, their characteristics compared, and the tools classified. Six of these tools were compared by applying them to a 200' x 400' (61 x 122 m) urban block at 40° lat. FAR allowed by the generated envelope was calculated for each tool and compared. A wide range of allowable building envelopes was found.

All prescriptive tools either specified or implied a street height to width ratio (H/W), but none provided a quantified basis for its proportion or exposure plane. A study was initiated to determine H/W in relation to average and minimum daylight factors within a building. A test was conducted using physical modeling in a mirror box artificial sky. Results of this test, plotting H/W against average daylight factor can be used as a preliminary design tool or as a way to determine zoning restrictions, while protecting daylight access.

1. INTRODUCTION

Daylight access can be defined broadly as the availability of daylight to buildings and/or open spaces, for use as interior illumination, or as a public amenity. Daylight access is a precondition to the use of daylight for any purpose in buildings. Zoning laws, requiring setbacks in low density areas and height restrictions in urban areas, have been used since the early twentieth century to address both the need for and value of access to light and air. With increasing height and density comes a reduction in light levels, which decreases toward the street.

Contemporary U.S. regulatory models deal more commonly with solar access (direct beam) protection, although a few major cities have adopted performance-based, explicit daylight ordinances. Protection of daylight access is more complex than protection of solar access, because it is usually not based on a specific orientation, and should account for exterior reflections. The protection of daylight access, as distinct from solar access, "has not yet been generally perceived as necessary, [and]... very few models for establishing reasonable criteria for developing protective covenants or legislation exist" (10, p. 151).

The level of available daylight to buildings is affected by such factors as latitude, climate, relation to adjacent obstructions, and reflectivity of adjacent surfaces.

There are three main classes of daylighting strategies: sidelighting, toplighting, and atria. Each has unique impacts for daylight access. Beyond the general factors impacting daylight planning, the design strategy used by a building or group of buildings can have a great impact on the form of the building. A context supportive of particular building forms could theoretically be matched with a appropriate daylighting design strategies. For example, if sidelighted buildings require a particular spacing angle between them to insure adequate daylighting; then block dimensions could be designed as multiples of a typical building thickness plus the space between buildings.

In designing the form of a city, the regulation of building envelopes is important to insure the access to daylight for every building. Designers and planners need tools which relate form to predictable daylight performance in buildings. Since many tools are available for daylighting design at the site scale, are any of these appropriate and justifiable for daylight planning when considering the urban scale?

2. REVIEW OF DAYLIGHT PLANNING TOOLS

2.2.1 Framework for Daylight Controls

White (12) distinguishes two basic classes of daylight regulation: urban design regulations, which affects the level of daylight reaching a building or street and applied primarily to the exterior of buildings, and energy conservation regulations, which concerns interior lighting levels and the integration of daylight with electric lighting, applied primarily to the building interior and envelope. Urban design regulations deal more directly with daylight access, while energy conservation regulations usually address how the available daylight is used. "White also distinguishes between explicit and implicit legal controls."

Implicit controls may affect the amount of sunlight or daylight admitted to a space but because they omit critical factors and variables such as climate, orientation, and latitude, do not allow a predictable level of daylight. Examples of this type of lighting control are conventional zoning using setbacks and floor area ratio (FAR), and building code requirements for minimum window area. Explicit controls systematically control the major variables (12).

Two other terms, prescriptive and performance controls or criteria, are commonly used to distinguish types of rules or codes. In daylight controls, both performance and prescriptive methods are used for defining explicit controls. Figure 1 presents these distinctions graphically, showing examples of various methods of daylight control. The techniques which are relevant to this study are discussed below.
Each latitude is also associated with only one climate, and daylight factors are not explicitly stated. For instance, 0-10 degree latitudes are paired with a warm, humid climate, and 35 degrees is paired with a "Mediterranean" climate. The chart must therefore be used with some degree of interpretation if the climate under consideration does not match the climate given for the site's latitude.

**Daylight Indicators**
The *daylight indicator* (Dept. of the Environment, n.d.), also known as the *daylight overlay* (Robbins, 1986) or the *permissible height indicator* (Hopkinson, 1967), is a graphic technique developed in England, and used in the British "Daylight Code." The daylight indicator is essentially a graphic performance tool that establishes a height/width ratio and allows for more variability in design than was allowed by early zoning approaches such as the sky exposure plane. It is a graphic tool used with site plan drawings. Daylight indicators are used to site buildings, to determine obstructions, and to determine allowable building heights that will still protect a view to a portion of the skydome from all or part of the building (11).

Different daylight indicators are used for differing sky conditions, building types, and relationships to the property edge. In general, all indicators establish a cone of view defined by a horizontal and vertical angle of acceptance. Concentric rings around the point of view give increasing acceptable heights for a building. Thus, the farther away from the point of view, the higher the allowable height. This tool measures exposure at a height of 2 meters above the ground plane and is orientation-neutral. Under overcast conditions, the vertical angle is the same for all locations, while it varies under clear sky conditions.

Hopkinson's tool was based on providing for commercial buildings a minimum 1% "sky factor" under specified conditions. The Department of the Environment, in a shift from earlier explicit daylight criteria, shifted to an emphasis on providing sufficient daylight "in the environment as considered broadly" (4). The standards were relaxed somewhat from earlier criteria; it is no longer clear what quantifiable criteria is met by the daylight indicators.

**Solar Envelopes**
The solar envelope is a defined, maximum developable volume derived from the sun's motion relative to a particular parcel of land, which insures that development within the container will not shade adjacent land and/or buildings during critical times. It is defined both by time constraints and property configuration (7). It is used as a means of development control, as an extension of zoning regulations, and is intended to protect sunlight access, not access to daylight specifically.

Sunlight can potentially contribute significantly to interior building illumination. The solar envelope is a technique for limiting development bulk and generally limits development to moderate densities; therefore, it has the potential to insure daylight access on more than equatorial orientations. Where sunlight is insured by the envelope, it is reasonable to assume that daylight is also well supplied.

**Daylight Evaluation Chart**
In 1980, a revised zoning ordinance for Midtown Manhattan was proposed that addressed lighting to the street and the placement of building bulk. The *daylight evaluation chart* (DEC), a modified version of the Waldrum Diagram, was the performance-based approach chosen. An image similar to a fish-eye lens photograph is produced. The chart is divided into gridded boxes over which the building outline is drawn, as viewed from a particular point. The obstructed boxes are then multiplied by weighted values to obtain a daylight obstruction value (1,3). Scoring varies by zoning district, so the
level of acceptable daylight available is based on the existing surrounding urban context. This method of manually constructing a building outline and counting boxes was deemed too complex and is seldom used today. A computerized version was proposed but never developed.

NYC Prescriptive Curve
In 1982, the city proposed a two-tier approach to daylight zoning, with both a prescriptive and a performance component. The developer may opt for an entirely prescriptive approach that is defined by a curved daylight exposure plane similar to the 1916 plane. Encroachment into the defined bulk free zone can be traded against compensation of reduced bulk in other areas of the site. Most buildings in the past decade have been built under this prescriptive or "as-of-right" regulation.

BRADA: Boston Redevelopment Authority Daylight Analysis
This tool was developed as a computerized version of the earlier DEC tool. BRADA is a public domain microcomputer program that analyzes sky obstruction of a proposed building by plotting the building profile onto a flat rectangular projection of a half-sky dome. A value measured in percentage of sky obstruction is calculated by comparing the obstructing building to the daylight availability on a vacant site (1).

The tool can be used for urban design tool or for zoning compliance. It is most useful for large bulk buildings in dense urban environments. BRADA determines a sky obstruction value, but the judgment of the value is left to the user or the regulatory official (1). Even though it is performance based, as a daylight access tool, it is still partially implicit, since it is not tied to any quantitative standard of light within a building.

2.3 Comparison of Tool Characteristics
Characteristics and major variables controlled are compared for nine tools. The results are shown in Figure 2. Sunlight and Skylight indicate which condition the tool attempts to control. Daylight indicators address both. Latitude indicates whether the tools account for variations in daylight availability or sun angles by latitude. Tools based on determining a percentage of sky cover could incorporate this variable in the valuation of their results (higher scores required in northerly latitudes).

Sky Condition Distinguished indicates whether a tool distinguishes between overcast and clear sky conditions at a given latitude and/or takes into account the differing sky dome luminance distribution. Street Wall/Exposure Plane indicates a prescriptive requirement for these variables. Seasonal Schedules denotes the ability of a tool to distinguish between summer and winter sun angles or the seasonal variation in daylight availability. Orientation indicates whether a building or site's azimuthal declination and/or aspect are addressed. Tools marked in the Reflectivity category give credit for higher exterior building material reflectivity.

Tools marked in the Building Type column distinguish between daylight requirements for residential and commercial buildings. Weighted Sky Units indicates the tool's ability to give greater value to a sky view of a portion of the sky with higher luminance. Tools marked under the Unlimited Height Provision allow a tower of unlimited height under certain restrictions.

The Quantitative Light Standard column gives the standard or method used by the tool to measure daylight. Only daylight

<table>
<thead>
<tr>
<th>Daylight Planning Tools</th>
<th>Characteristics</th>
<th>Skylight</th>
<th>Sunlight</th>
<th>Sky Condition Distinguished</th>
<th>Seasonal Schedules</th>
<th>Orientation</th>
<th>Building Material Reflectivity</th>
<th>Unlimited Height Provision</th>
<th>Quantitative Light Standard</th>
<th>Interventions To Protect</th>
</tr>
</thead>
<tbody>
<tr>
<td>Daylight Spacing Angles</td>
<td>○ ☀ O ☀ R</td>
<td>Res. D.F.</td>
<td>Section/Formula</td>
<td>Bldg.</td>
<td>20-50° plane by lat.</td>
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<td></td>
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<tr>
<td>Daylight Indicators</td>
<td>☀ ☀ ☀ ☀ 1* 1*</td>
<td>% Sky Factor</td>
<td>Plan Overlay</td>
<td>Bldg./Property</td>
<td>40° overcast 23-40° clear</td>
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<td></td>
<td></td>
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<tr>
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<td>☀</td>
<td>☀</td>
<td>Section/Formula</td>
<td>Bldg./Street</td>
<td>51° plane</td>
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<td>Bldg./Property</td>
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<td></td>
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<td>Numeric</td>
<td>Zone Character</td>
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<td></td>
<td></td>
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<tr>
<td>New York, 1916</td>
<td>☀</td>
<td>☀</td>
<td>Section/Formula</td>
<td>Bldg./Street</td>
<td>70° plane</td>
<td></td>
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<tr>
<td>New York, 1980 Curve</td>
<td>☀ ☀ T ☀ T</td>
<td>☀</td>
<td>Section/Formula</td>
<td>Street</td>
<td>Standard based on context</td>
<td></td>
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<tr>
<td>Daylight Evaluation Chart</td>
<td>☀ ☀ T ☀</td>
<td>☀ ☀</td>
<td>% Sky, Weight</td>
<td>Modified Waldram</td>
<td>Street</td>
<td>Standard based on context</td>
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<td>BRADA</td>
<td>☀ ☀ ☀</td>
<td>☀</td>
<td>☀</td>
<td>☀</td>
<td>% Sky</td>
<td>Computer</td>
<td>Street</td>
<td></td>
<td></td>
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</tr>
</tbody>
</table>

Fig. 2. Comparison of Daylight Planning Tool Characteristics

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Spacing Angles (DSA) and Daylight Indicators (DI) address explicitly light to buildings. DSA are said to provide daylight factors suitable for residences, a rather vague standard. DI assure a given percentage of sky as viewed from inside a room, generally considered one component of the daylight factor. The *Format* in which the tool is applied and the general intention of the tool (*Intent to Protect*) is also given.

From this comparison of daylight planning tools, it is evident that no single tool addresses all the important variables that influence daylight access. All tools except BRADA either employ a prescriptive street wall height for a given street width, imply a H/W ratio by means of a prescriptive exposure plane angle, or are used in conjunction with such a prescriptive standard. Furthermore, street wall height continuity is an important urban design standard within a given neighborhood. It is also evident that the H/W (or exposure plane angle) varies significantly between tools.

2.4 Comparison of Tools for Allowable Envelopes and Density Implications

In order to understand the significance for urban density of these variations between tools, six prescriptive tools were compared by applying them to a 200' x 400' (61 x 122 m) urban block at 40° latitude, 65° (20 m) streets running E/W and 45° (14 m) streets running N/S were assumed. The envelopes generated by this procedure are shown in Figure 3. Gross volume and gross FAR allowed by the generated envelope is calculated for each tool, assuming a 12' (3.7 m) floor-to-floor height. The angle of the exposure plane for each tool is also listed. These figures are presented in TABLE 1.

Methods

The techniques used for each tool are as follows: DSA, angle for 40° lat.; DI, commercial occupancy, overcast sky, building to building overlay; Atkinson, 1.25:1 H/W ratio; Solar Envelope, 40° lat., 9AM - 3PM on Dec. 21 protected access, lower 2 story shading allowed; New York, 1916, 2.7:1 H/W, based on 65° (20 m) street, tower volume not included; NYC 1980, daylight exposure curve as per NYC Dept. of City Planning, 1981. Actual FAR net would be less than gross shown because of building floor setbacks as practical buildings meet maximum sloping envelopes.

2.5 Results of Daylight Tool Comparisons

**TABLE 1. ALLOWABLE VOLUMES OF DAYLIGHT PLANNING TOOLS**

<table>
<thead>
<tr>
<th></th>
<th>Volume (cf)</th>
<th>FAR @12'</th>
<th>Exposure Plane</th>
</tr>
</thead>
<tbody>
<tr>
<td>Daylight Spacing Angles</td>
<td>5.9 x 10^6</td>
<td>6.2</td>
<td>35°</td>
</tr>
<tr>
<td></td>
<td>(1.7 x 10^5)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Daylight Indicators</td>
<td>8.1 x 10^6</td>
<td>8.5</td>
<td>40°</td>
</tr>
<tr>
<td></td>
<td>(2.3 x 10^5)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Atkinson, 1916</td>
<td>1.1 x 10^7</td>
<td>10.5</td>
<td>52°</td>
</tr>
<tr>
<td></td>
<td>(3.1 x 10^5)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Solar Envelope</td>
<td>4.7 x 10^6</td>
<td>5.0</td>
<td>21°/24°</td>
</tr>
<tr>
<td></td>
<td>(3.1 x 10^5)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>New York, 1916</td>
<td>1.6 x 10^7</td>
<td>17.0</td>
<td>70°</td>
</tr>
<tr>
<td></td>
<td>(4.5 x 10^5)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>New York, 1980</td>
<td>1.7 x 10^7</td>
<td>10-18</td>
<td>&gt;79°</td>
</tr>
<tr>
<td></td>
<td>(4.8 x 10^5)</td>
<td></td>
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</tr>
</tbody>
</table>

Each tool was designed in some way to control sky exposure by limiting street wall height or spacing between buildings. H/W recommendations varied between 1:1 and 3:1. Volumes allowed between tools vary from FAR 5 to over FAR 18. The lowest density was mandated by the solar envelope, as expected. It is the only tool considered that controls direct beam radiation. FAR for NYC tools is limited by zoning, and is more restrictive than their daylight envelopes, even when neglecting the unlimited tower provisions.

Fig. 3. Maximum Allowable Envelopes for Daylight Access

A defensible method of determining daylight access that insure quantifiable daylight within buildings is needed. None of the tools reviewed accomplished this. This paper is a task within a larger research agenda which seeks to determine, in a coarse way, the density and land use patterning implications of daylighting as an urban design strategy. Given the wide variation in bulk allowed by tools, all purported to protect daylight access, and the lack of documentation of their basis, an empirical test was devised in order to determine a rule-of-thumb for street width to building height (H/W) that would assure a given daylight factor in a room at ground level.

3. SCALE MODEL TESTING

3.1 Methods

To determine a relationship between interior daylight factor and H/W ratio, a test was conducted using physical modeling in a mirror box artificial sky. A scale model of a "typical" office space, 750 sf, 25' deep (2.5 H max.) by 30' wide, on the ground floor adjacent to a 60' street was built. The height of the building street wall could be increased in the increments: 2, 4, 6, and 10 stories. Openings were sized by a rule-of-thumb method and their areas held constant, giving an average unobstructed interior daylight factor of 3%. Four windows were distributed evenly in the exterior wall. Sill height was 30' and head height 100'. The ceiling height used was 100'.

Reflectances represented typical interior and exterior conditions as follows: floor, 30%; ceiling and interior walls, 70%; exterior walls, 40%; windows, 15%; street, 7%; sidewalks, 40%. The street wall was 200' long at 1/4" scale. Mirrors
Fig. 4. Scale Model

were placed at each end of the street to simulate an infinite street wall of equal height. The street walls were assumed to have the same area (33% of wall area) of evenly distributed openings as the reference room. A single weighted average reflectance of 33% was used for these walls. Sidewalks were assumed for 12' on each side of the street.

Nine photosensors were evenly distributed throughout the office space at a work plane height of 30", as shown in Figure 4, and an exterior horizontal control sensor was placed at a height equal to the 10 story street wall. The control sensor's illuminance value was proportionally reduced to account for the difference in measured open field illuminance between its elevation in the artificial sky machine and that of the sensors within the model room.

3.2 Results

The results of this test are shown in Figure 5 as mean daylight factor and mean minimum daylight factor plotted against street width/building height ratio. The significant effect of building height on daylight levels can easily be seen.

Because the relationship is expressed as function of the ratio of street width to building height, the relationship can be applied in circumstances other than the actual widths and heights tested.

The results are valid in the strictest sense only for overcast sky conditions (although lower floors in an urban context see mainly the upper portion of the sky dome), and as a result the variance of daylight distribution in differing sky conditions is probably not a major factor.

The two major variables could alter the DF/H/W relationship are:

- The reflectivity of the exterior walls.
- The area of windows in the exterior wall of the reference room.

Rooms at the ground floor on a street with multistory buildings might have larger windows, but a higher average reflectivity would probably require regulatory incentives. Increasing either of these variables has the effect of moving the curve upward on the X axis. In my opinion, the assumptions used represent achievable reflectivity and reasonable assumptions about window area, based on methods that might be used by an interested but non-expert daylighting designer.

Using the chart, for an average ambient light level of about 2.5% DF, a H/W of about 0.8 is required. This represents a four-story building on a typical U.S. 60' wide street right of way. This suggests for a city concerned with protecting daylight access to lower floors of buildings, the following rule-of-thumb (ROT):

For an average DF > 2%, keep H/W ratios < 1

Typical city ROW's in the U.S. are 60'-66' for residential and secondary commercial streets. Collector and arterial street ROW's are typically 70'-80' with some major streets up to 100'.

Using the above ROT to protect daylight access, and assuming a consistent street wall height, the following street wall height limits would apply (story height = 12'):

- 60' street 5 story
- 80' street 6 story
- 100' street 8 story

With H/W establishing a maximum street wall height, allowable prescriptive daylight access envelopes can then be determined by Atkinson's sky exposure plane method, creating a pyramidal envelope stepping back from the street wall. As long as a window can not "see" a part of the building across the street that is above the specified street wall height, its daylight access will not be impacted further.
This is the method that will be used in further studies to determine approximate bulk limits in planning measures, such as FAR, and to determine relative patterns of land use for daylight access.

If taller buildings are to be allowed on the street or if bulk placement outside a prescriptive envelope is allowed, a defensible set of encroachment tradeoffs should be developed. Alternatively, a performance tool (like BRADA) that correlates a weighted %sky blockage to interior DF should be developed. This is important if “wedding cake” buildings are undesirable.

4. CONCLUSIONS

A conceptual framework for understanding daylight access controls has been presented. This framework includes the distinctions between urban design and energy conservation controls, between implicit and explicit controls, and between performance and prescriptive controls.

Significant twentieth century daylight access controls have been summarized, compared, and analyzed for their density implications. Each tool was designed in some way to control sky exposure by limiting street wall height or spacing between buildings. H/W recommendations varied between 1:1 and 3:1. A wide range of allowable daylight access envelopes and maximum FAR were found. None of the tools reviewed established a defensible method of determining daylight access that insures quantifiable daylight within buildings.

Performance tools for daylight planning, such as SPC and BRADA operate in an analytical way. They require a proposed building, which can then be evaluated for its performance. Prescriptive tools operate in a more generative way, defining what is allowed in a given situation.

The results of the artificial sky test show a simple, approximate relationship between street width to building height and the daylight level found in the adjacent spaces. This rule allows the determination of maximum street wall height for a given street width or the determination of building spacing, given a fixed building height.

This information is useful not only in building design, but also for determining zoning controls for daylight access and street right-of-way dimensions. A community could, in an informed public process, balance its values between daylight access and development rights.

Combined with tools for sizing building thickness and atria, this rule-of-thumb chart has implications for density limits and land use patterns, either from an ideal generative standpoint or in analyzing existing urban patterns for allowable bulk, as limited by concerns for daylight access.

REFERENCES


