April, 1993

Urban Development Patterns for Daylighting

Mark DeKay, University of Tennessee, Knoxville

Available at: https://works.bepress.com/mark_dekay/15/
URBAN DEVELOPMENT PATTERNS FOR DAYLIGHTING

Mark DeKay
Department of Architecture
Virginia Polytechnic Institute and State University
Blacksburg, Virginia 24061-0205

ABSTRACT

In this paper, land use and density implications of daylighting are explored by reasoning from the massing characteristics of daylit buildings and by applying the results from a study of street width to building height ratios. This study explored the idea that, if generalizations could be made about the form of atria buildings, then blocks and streets could be laid out to support daylighting as a design strategy.

The most efficient (highest density) atria buildings that can be built on an unobstructed site are determined, then intersected with actual patterns of streets and blocks from Pacific Northwest cities. Analysis of these suggests a set of generic building/block patterns for grid cities.

The relationships between daylight factor inside a room and the ratio of street wall height to street width were used to determine allowable prescriptive daylight access envelopes. The building bulk allowed by these daylight access envelopes was then calculated.

1. INTRODUCTION

Daylight access can be defined broadly as the availability of daylight to buildings and/or open spaces. Daylight access is a precondition to the use of daylight for any purpose in buildings. Zoning laws, have been used since the early twentieth century to address both the need for and value of access to light and air.

A previous study (1) which surveyed daylight planning tools found that each tool was designed in some way to control sky exposure by limiting street wall height or spacing between buildings. Building Height to Street Width Ratio (H/W) recommendations varied between 1:1 and 3:1. Volumes allowed between tools vary from a Floor Area Ratio (FAR) of 5 to over FAR 18. The study suggested that a defensible method of determining daylight access that insures a quantifiable daylight level within buildings is needed. None of the tools reviewed accomplished this, so a study to determine H/W to Daylight Factor (DF) relationships was conducted (1,2). This paper applies the results from those previous studies to determine appropriate limits to development envelopes and their implications for maximum urban density.

Simultaneous to these studies of daylight planning and building/street geometry (1,2), another study (3) addressed ideal forms for atria buildings, including the variables of building height and thickness, latitude, interior light levels, and percentage of rentable space daylit. This paper uses the results about ideal atria buildings to develop suggestions for ideal block sizes and daylit building types in grid cities.

2. BLOCK FORMS FOR GENERIC ATRIA BUILDINGS

Ideal plan sizes for atria buildings were proposed in a matrix varied by building height and latitude (3). These plans were used as the building blocks or increments of development to design block sizes supportive of atria as a daylighting design strategy. Fig. 1 shows combinations of four-, six-, and ten-story atrium building modules for latitudes between 40° and 48°. They assume a 20 fc (215 lx) minimum illumination level during 85% of working hours. It is important to note that in buildings with multiple atria, the occupied area between atria is the same dimension as the basic building thickness between atrium and outside wall. This means that the basic plan module that can be multiplied to form a building with multiple atria is the sum of the atria length (L) and...
one building thickness (T):

\[ \text{Atria Building Plan Module} = L + T \]

Using this atrium building module, blocks were sized for patterns with and without alleys. On blocks with alleys, the building mass shown will have to be reduced on upper floors along the alleys to allow access to daylight for the lower floors.

Footprint Floor Area Ratio (FAR) does not vary significantly between block size option, but 100% site coverage may be unreasonable for some occupancies. For a particular ideal atria building type shown in Fig. 1, increasing the block size reduces the possible FAR. Reducing the block size for a given building type would decrease building’s percentage of rentable area daylit (%RAD) efficiency and raise its gross to net ratio (G/N). In an urban pattern of high site coverage and street-oriented buildings, open space becomes a publicly provided amenity and must be planned in advance.

These patterns of atria building blocks can be combined with variations in street width, and then modified using a daylight access restriction. This process yields the theoretical maximum building envelope for daylight-sensitive development. In an existing city, the block dimensions are already set, thus only certain buildings can be built efficiently on them. Some (perhaps a tall building at a high latitude) will be too large and will not fit on the block. Others will be too small, and will not make efficient use of the available land. For example, ten story buildings must be sidelighted in Portland because efficient atria are not possible on the small blocks.

3. **ATRIA BUILDINGS FOR NORTHWEST CITIES**

In order to study the patterns generated by the intersection of ideal atria building forms with non-ideal (for atria) city grids, urban patterns of blocks and streets from three Pacific Northwest cities were documented and overlaid with combinations of atria modules. The major atria building forms possible in these cities are shown in Figs. 2-4.

Eugene, OR is platted on a 400’ (122 m) grid running the center of streets, thus the width of the street right of way (ROW) determines the dimension of the block face. 60’ (18 m) streets are the most common, leaving a 340’ (103 m) typical block face. Alleys may run either or both directions, the latter being more common in the city center. Eugene’s block sizes work best for four and six story buildings. Divisions of the block with alleys creates plots undersized for both six and ten story buildings. Gridded center city blocks with cross alleys are well sized for four single atrium buildings, one in each quadrant. Blocks divided with a single alley are also well suited for four story buildings. Blocks with no alleys are used efficiently by six story buildings with multiple atria.
Typical blocks in Portland, OR are 200’ x 200’ (61 x 61 m) in the older part of the city; 200’ x 400’ (61 x 122 m) blocks are also common. 60’ (18 m) is the most common ROW, with arterials up to 100’ (30 m). The small center city blocks are large enough for four and six story single atrium buildings, but not for ten-story buildings. The larger blocks, still limited by the 200’ (61 m) dimension, are best suited for four-story multiple atrium buildings. Six story multiple atrium buildings on these blocks intersect inefficiently with the street grid.

Seattle’s blocks are 256’ x 240’ (78 x 73 m) and 256’ x 360’ (78 x 109). The 256’ (78 m) face typically fronts 90’ (27 m) ROW N/S avenues, while 240’ (73 m) and 360’ (109 m) faces typically front 66’ (20 m) secondary streets. Alleys are typically 16’ (5 m) running N/S. The 240’ (73 m) square blocks yield hybrid atria/sidelighted forms at four- and six-stories. A single ten-story atrium building fits the block well, but covers the alley. The lot size generated by crossing a narrow block with an alley is too small for any efficient atria building, and larger blocks show the same possible patterns of development. Multiple atria buildings covering the alley or E-type sidelighted buildings are the best daylight building form alternatives in Seattle.

4. DAYLIT BUILDING TYPES IN GRID CITIES

The foregoing analysis of typical street/block patterns for atria buildings in existing Northwest cities suggests a limited set of atria building typologies. Similar analysis could be done for sidelighted buildings, but none has been done as apart of this study. Sidelighted building plans are most often laid out in thin wings and generates several characteristic building types when limited by and intersected with the city grid (4). Urban block/building patterns for atria buildings are shown in Fig. 5.

Three basic patterns are evident for atria buildings in grid cities:
• Buildings that fill an entire block, with either single or multiple atria.
• Buildings that fill a partial block, leaving open space.
• Hybrid buildings that combine atria and sidelighted or shorter atria forms to fill an entire block.

Atria buildings can fill an entire block, sometimes with multiple atria in the same building (full block/single atria; full block/multiple atria). On narrow blocks with alleys, the atria can be located on the alley (alley block/coincident atria). For wider alley blocks, the half block between the alley and the street can be occupied by a full atria building (full alley block).

Taller buildings requiring larger atria will often fill only a partial block (partial block). The leftover space is not enough to repeat another atrium module of the same building height, but may be large enough for a shorter building module (stepped height/multiple atria). Low rise multiple atria buildings on wider blocks can generate hybrid atria/sidelight types, with E-type edges on one side.

Small square blocks are ideal for single atrium buildings (full block/single atria). Square blocks divided by cross alleys require shorter single atrium buildings (single atrium/cross alleys). Square blocks with alley in only one direction generally require a single atrium coincident with the alley.

Fig. 2 Atria Buildings for Eugene, OR Blocks (340’ x 340’; alleys either or both ways; 60’ ROW)

Fig. 3 Atria Buildings for Seattle, WA Short Blocks (256’ x 240’; alleys @ 16’; 66’ & 90’ ROW)

Fig. 4 Atria Buildings for Portland, OR Blocks (200’ x 200’ & 200’ x 400’; 66’ typ & up to 100’ ROW arterials)
5. **DAYLIGHT ACCESS ENVELOPES**

When daylight access criteria are applied to an urban pattern of blocks and streets, a development envelope can be generated which describes the limit of building boundaries that will provide lower floors of a building with daylight sufficient to meet a given planning goal. The H/W : DF relationships explored in earlier studies (1,2) can be used to determine a maximum H/W for a given DF goal. If street width is fixed, a maximum street wall height can then be determined from the H/W ratio. A *sky exposure plane* can then be defined by striking a line from the opposite side of the street at ground level through the top of the street wall, as illustrated in Fig. 6. When applied on all four sides of a block, a hip-roof-shaped pyramid is formed above the street wall–defined rectangular volume. This is a daylight access envelope.

The height of atria buildings affects atria sizing, thus building footprint; blocks can therefore be sized to support the desired building height and daylight factor planning goal. This block size must be matched to an appropriate street width if the same daylight factor access planning goal that is achieved by the atria sizing is to be achieved in the exterior sidelighted zones of the buildings.

Example: For buildings of four, six and ten stories having two atria, ideal block sizes are 298’ x 184’, 340’ x 205’, and 428’ x 248’, respectively (91 x 56 m, 103 x 62 m, and 130 x 75 m). To match these block sizes with an appropriate street width, we can use Fig. 7 to determine a maximum H/W ratio. For the 20 fc (215 lx) goal described above, an average DF of 2.5-3.0 is required in the latitude class of 40°–48°. Assuming an average exterior surface reflectance of 33%
(representing an opaque material of 40%) and a generous 50% of the facade on the lower floor as windows, Fig. 7 indicates that a 2.5% Daylight factor requires a maximum H/W ratio of 1, corresponding to a 45° exposure plane. Using this H/W ratio of 1, and assuming a story height of 12’ (3.7 m), the following associations of block size, street width, and building height can be made:

**TABLE 1. MATCHING BUILDING HEIGHT, BLOCK SIZE, AND STREET WIDTH**

<table>
<thead>
<tr>
<th>Height</th>
<th>Block Size</th>
<th>Street Width</th>
</tr>
</thead>
<tbody>
<tr>
<td>4 story</td>
<td>298’ x 184’</td>
<td>60’ (18 m)</td>
</tr>
<tr>
<td>6 story</td>
<td>340’ x 205’</td>
<td>80’ (24 m)</td>
</tr>
<tr>
<td>10 story</td>
<td>428’ x 248’</td>
<td>120’ (36 m)</td>
</tr>
</tbody>
</table>

A ten story building with 12’ (3.7 m) story heights would be 120’ (36 m) high and for H/W = 1, would require a 120’ (36 m) street width. Since 100’ (30 m) is about the widest arterial commonly used in the U.S., eight stories should be the maximum street wall in most cities. For each of these three development patterns, a daylight access envelope was generated. Fig. 8 shows one such pattern of daylight access envelopes. Hip roof type forms indicate the envelope. Stepped forms indicate the maximum building within that envelope, shown in two story increments. A generic flat roofed atria mass is also shown for comparison. It is obvious that an atria building would not fill the entire envelope. Remember also that the envelopes are illustrated at the scale of the block and that several buildings may fill a block, but collectively, they should not penetrate the envelope.

6. **DENSITY IMPLICATIONS OF DAYLIGHT ACCESS**

To get some idea of the limitations on density created by daylight access envelopes, building bulk and FAR were calculated for the development patterns described above. Calculated bulk is shown in Table 2.

**TABLE 2. DENSITY IMPLICATIONS OF DAYLIGHT ACCESS**

<table>
<thead>
<tr>
<th>Development Pattern</th>
<th>FAR Block</th>
<th>FAR inc. Streets</th>
<th>FAR Atria Bldg.</th>
</tr>
</thead>
<tbody>
<tr>
<td>298’ x 184’ blks./ 60’ ROW</td>
<td>8.0</td>
<td>5.1</td>
<td>3.8</td>
</tr>
<tr>
<td>340’ x 205’ blks./ 80’ ROW</td>
<td>10.1</td>
<td>5.9</td>
<td>5.3</td>
</tr>
<tr>
<td>428’ x 248’ blks./ 100’ ROW</td>
<td>12.5</td>
<td>7.2</td>
<td>7.6</td>
</tr>
</tbody>
</table>

From this comparison, several interesting conclusions can be drawn, remembering that these results represent a particular set of variables. First of all, the 12.5 maximum FAR indicates that dense urban FAR limits of 15 or 18, as found in parts of Manhattan, can not support daylighting to all buildings. The FAR for the atria buildings alone are probably the maximum development potential for each of the respective development patterns, since sidelighted portions of the building, which might fill the upper portion of the daylight access envelope, would require significant spacing between wings, similar to atria sizing.

The above results suggest a maximum height limit of 100’ (30 m), or about eight stories on major arterials of 100’ (30 m) ROW. An eight story building at 48° latitude has a Height to Length Ratio of its atrium of 1 : 1 and a maximum FAR of 6.6 for a two atria building (ideal block size, 227’ x 384’ or 69 x 117 m). This would seem to be the maximum development density that will support daylighting at these latitudes. At lower latitudes, greater density and street wall height will be allowed. At higher latitudes, less density will be possible. Theoretically, in clear sky climates, higher density would be allowed because the higher available daylight outside requires lower daylight factors, thus lower atria H/L ratios and lower building height/street width (H/W) ratios. No clear sky investigations have been done as a part of this study.

7. **VARIATIONS IN DAYLIGHT ACCESS ENVELOPE BY LATITUDE**

Fig. 9 shows daylight access envelopes generated on the same urban pattern for 28° and 52° latitudes. For the same
average minimum 20 fc (215 lx) interior illumination level at 85% of working hours under overcast skies, a 1.5% DF is required at 28° and a 4% DF at 52°. Assuming 50% of the exterior wall of the ground floor in windows and a 33% average exterior wall reflectance, H/W ratio is 1.5 at 28° and 0.5 at 52°. This means that the street wall must be no more than one half of the street width in the high latitude city and can be up to one and one half times the street width in the low latitude city.

9. CONCLUSIONS

Atria buildings can cover significant site area. If expensive urban land is to be used efficiently, the urban pattern can be planned based on daylight building forms. Streets could be laid out to serve buildings, rather than building limits being determined by streets. The plan form implications of generic atria buildings can be used as building blocks for determining street/block patterns. Block sizes for new development could be set with dimensions appropriate to the generic atria building module that corresponds to the city’s latitude (or specific daylight resources) and the desired height limit in the neighborhood. This would insure that land is used efficiently, while still providing for daylighting of interior spaces. It would also contribute to the regional identity of a city.

In existing cities, the block dimensions are already set, thus only certain buildings can be built efficiently on them. Ideal atria building forms were overlaid onto non-ideal block sizes from three Pacific Northwest cities. The results show the importance of matching block size to building height, if daylighting is considered important. The analysis suggests a limited set of atria typologies; three basic patterns are evident for atria buildings in grid cities. Similar analysis could be done for sidelighted buildings, but none has yet been done. There are still no basic massing rules for sizing O types or reentrant C, F, and H types to insure that the massing decisions intended to provide daylight are actually dimensioned within parameters that allow sufficient levels within the rooms of lower floors. This is clearly an unresolved subject for future research efforts.

Daylight access envelopes offer a prescriptive development control. The method as presented in this study allows the H/W ratio, that defines the sky exposure plane and thus the envelope, to be determined for the variables of latitude, exterior reflectance, window area, and daylight illumination goal. The daylight access envelope, as developed in this study, is more restrictive than necessary; the same results can theoretically be achieved with a performance tool such as BRADA, which measure the percentage of sky exposure. What is helpful about the prescriptive approach is that it gives a base line standard for use in interpreting the results of performance tools, such as BRADA. As a development tool, the daylight access envelope will tend to produce street oriented buildings of high site coverage, and, when a site is developed to its full potential, stepped building forms.

10. REFERENCES
