ABSTRACT

The daylighting and sunlit value of an atrium are considered the main reasons for including the atrium in the built environment. However, most atria today are either overlit, which causes tremendous cooling loads, or underlit, requiring continuous artificial lighting. Furthermore, rules-of-thumb for sizing atrium physical parameters do not exist. The objective of this study was to determine the optimum transmittance of the top-fenestration that would meet the lighting criteria at the atrium floor, so that the cooling loads could be minimized. Illumination measurements were collected in physical scale models of two and four-story atria in a clear sky simulator. The two key variables of this study were: a) horizontal and vertical south-facing top-glazing area, and b) the percentage and the reflectance of the solid area of the atrium walls. The calculated Daylight Factors (DF) were then compared to the daylight availability of selected cities with warm climates. The increase of the effective reflectance (i.e., solid area and the reflectance) reduced the optimum top-fenestration transmittance, which would reduce the heat gain in the atrium space.

BACKGROUND

Atria have become common design features in the architectural environment. In addition to several amenities, atria are often incorporated into buildings for their role as a metaphor for the exterior. Both sunlight and daylight contribute great deal to this feeling of being outdoors. The sunlight provides a golden color and sparkle, and daylight provides more uniform light. The deliberate use of these top-lit spaces has led to several design dilemmas. Atrium research rarely acknowledges the conflict between lighting and thermal loads. As a result, the as-built atrium is often in need of artificial lighting due to solar control or in need of an excessive amount of cooling loads, particularly in hot climates. This is due to oversized top-fenestration (Navvab and Selkowitz, 1984).

The conflict between daylighting and thermal performance (mainly cooling) in atria stems from the lack of design tools that would size atrium physical parameters to meet lighting criteria and to minimize both the lighting and the cooling loads. The top-fenestration dictates the amount of light and heat in the space. Therefore, there is a need to determine the optimum top-fenestration area for efficient daylighting that, in turn, would reduce the cooling loads. An oversized top-fenestration may cause tremendous cooling loads, especially in hot climates (Gillette and Treado, 1988). However, the optimum fenestration is also a function of the area and the color of the solid area of the atrium walls. On the one hand, horizontal top-glazing (with no shading devices and commonly used in atria) enhances the daylighting contribution, but aggravates the cooling loads. On the other hand, south-facing vertical top-glazing allows for solar control while providing sun sparkling on the atrium walls. However, the daylighting performance of this top-fenestration type is not well-documented (Atif and Boyer, 1991). The scope of this study focuses also on the effect of the mass of the atrium walls on the thermal performance of atria. However, the primary concern of this article is to investigate the daylighting performance of atria designed to allow sunlight to function as an aesthetic part of the design process. The article also mainly applies to shallow four-sided atria, considered to be the best candidates for daylighting the atrium space and the adjacent spaces without excessive cooling loads.

OBJECTIVES

This study investigates the daylighting performance of atria with respect to two atrium physical parameters: top-fenestration and atrium walls. The objectives of this paper are: a) to determine the optimum top-fenestration transmittance that would meet the lighting criteria at the atrium floor without aggravating the cooling loads, and b) to determine the effect of the atrium wall treatment on the optimum top-fenestration for daylighting. The data are intended to raise the body of knowledge pertaining to daylighting and thermal design of atrium buildings. The sunlighting value of an atrium will be enhanced by the determination of the optimum choice of physical parameters that would meet the lighting criteria, which in turn would limit the excess of cooling loads. The general trend of the daylighting data has already been published (Atif and Boyer, 1991). The purpose of this study is to develop daylighting prediction tools.

METHODOLOGY

Materials

The daylighting performance was evaluated by the Daylight Factor (DF). The DF was determined through illumination measurements, collected on physical scale models in the sky simulator of Texas A&M university, using the Illumination Data Acquisition System (IDAS) (Boyer and Degelman, 1989). The IDAS consists of a computer, Serial Analog Module (SAM), and eight sensors. Each sensor has a unique calibration system stored in the program disk. The scale of the model was a half inch to one foot. The floor of all the models were simulated by a foam core sheet with a reflectance of 15% (±) with white strip grid (4 by 4 ft) for the tiles. Beams and columns were also simulated in the models. The illumination levels were collected for 100 tests, which included variations in atrium physical parameters and in sky conditions.

Sky Conditions

The sky simulator was set for both clear and overcast skies. The completely overcast sky, also called the C.I.E. (Commission International de l'Eclairage) Standard Sky, was used to represent overcast sky conditions. The clear sky was simulated by the Clear Sky Simulator (CSS), which provides a clear blue sky with a reflectance of approximately 15%. The overcast sky was simulated by the Overcast Sky Simulator (OSS), which provides a grey sky with a reflectance of approximately 5%.

The IDAS was located in the atrium space and the adjacent spaces without excessive cooling loads. An oversized top-fenestration may cause tremendous cooling loads, especially in hot climates (Gillette and Treado, 1988). However, the optimum fenestration is also a function of the area and the color of the solid area of the atrium walls. On the one hand, horizontal top-glazing (with no shading devices and commonly used in atria) enhances the daylighting contribution, but aggravates the cooling loads. On the other hand, south-facing vertical top-glazing allows for solar control while providing sun sparkling on the atrium walls. However, the daylighting performance of this top-fenestration type is not well-documented (Atif and Boyer, 1991). The scope of this study focuses also on the effect of the mass of the atrium walls on the thermal performance of atria. However, the primary concern of this article is to investigate the daylighting performance of atria designed to allow sunlight to function as an aesthetic part of the design process. The article also mainly applies to shallow four-sided atria, considered to be the best candidates for daylighting the atrium space and the adjacent spaces without excessive cooling loads. This study investigates the daylighting performance of atria with respect to two atrium physical parameters: top-fenestration and atrium walls. The objectives of this paper are: a) to determine the optimum top-fenestration transmittance that would meet the lighting criteria at the atrium floor without aggravating the cooling loads, and b) to determine the effect of the atrium wall treatment on the optimum top-fenestration for daylighting. The data are intended to raise the body of knowledge pertaining to daylighting and thermal design of atrium buildings. The sunlighting value of an atrium will be enhanced by the determination of the optimum choice of physical parameters that would meet the lighting criteria, which in turn would limit the excess of cooling loads. The general trend of the daylighting data has already been published (Atif and Boyer, 1991). The purpose of this study is to develop daylighting prediction tools.
Test Points

measurements (i.e., perpendicular to the center of the each of the
distributed just below the top-fenestration, to measure light
daylight transmittance of each top-fenestration system. Vertical

30% ,uld 60% for the two-story atria, and the 27% 'Uld 67% for the
test points on a work plane height of the anulll floor, distributed
of the solid walls were: 25%, 40%, and 90%.

tested in the four-story linear atria. 111e internal reflectance values
through a grid of 20

mathematical expression:

zenith (Stein and Reynolds and McGuiness, 1986).

configurations. TIle width of the alriwn remained conSlant at 40
while the length had two alternate dimensions: 40 and 120 ft. Tlus
translates into four Well Indexes (WI): 0.50, 0.75, 0.90, and 1.35.
The WI, similar to Room-Cavity-Rlllio in electric lighting
calculation, is a dimensioneless index for describing the well
efficacy of a skylighted room (Boyer and Kim 1988; Saxon,
1983). Its computation Call be perfonned by the foUowing

Horizontal and vertical measurements were coUected in the

Atrium Physical Parameters

Variations in the the atrium physical parameters included atrium
proporition, top-fenestration and internal atrium walls. The study
included four types of atria; two-story (height of 30 ft) and four­
story atria (height of 54 ft) were tested with both linear and square
configurations. The width of the atrium remained constant at 40 ft
while the length had two alternate dimensions: 40 and 120 ft. Tlus
translates into four Well Indexes (WI): 0.50, 0.75, 0.90, and 1.35.
The WI, similar to Room-Cavity-Rlllio in electric lighting
calculation, is a dimensioneless index for describing the well
efficacy of a skylighted room (Boyer and Kim 1988; Saxon,
1983). Its computation Can be performed by the following
mathematical expression:

Well Index (WI)=well height *(well width+well length)/
2*well width*well length

(1)

Two types of top-fenestration were tested: horizontal and
vertical south-facing top-glazing areas. The variations in
internal walls included the ratios of the solid wall-to-total wall area
ratio, and the reflectance of the of the solid area. These ratios were
30% and 60% for the two-story atria, and the 27% and 67% for the
four-story atria. Figure 2 shows different wall configurations
tested in the four-story linear atria. The internal reflectance values
of the solid walls were: 25%, 40%, and 90%.

Test Points

Horizontal and vertical measurements were collected in the
physical model for each test. Horizontal measurements included: a)
9 test points on a work plane height of the atrium floor, distributed
through a grid of 20 ft by 20 ft for the square atria and a grid of 20
ft by 60 ft for the linear atria, and b) 5 test points uniformly
distributed just below the top-fenestration, to measure the light
transmittance of each top-fenestration system. Vertical
measurements (i.e., perpendicular to the center of the each of the
atrium wall) were collected for the second and the last floor. The
data were collected in footcandles (fc) and then translated into
Daylight Factors (DF).

Lighting Criteria

The DF was used to assess the daylighting performance. The
average DF's for horizontal and vertical measurements (at each
floor) were calculated for each test. These DF's were then
compared to the outdoor availability of three generic locations: Lake
Charles, LA, Phoenix, AZ, and Fresno, CA (Robbins, 1986). The
target illumination criteria at the atrium floor was dictated by the
lighting requirements for plants, which need at least 92 fc for 12
hours a day (Mpelkas, 1987; Navab, 1990; Navab and
Selkowitz 1984). Daylight availability data were taken for March
21st and December 21st at noon. In a clear sky with no sun on
March 21st, the minimum horizontal DF's at the atrium floor (to
meet 92 fc for plant growth) are 10.6%, 11.0%, and 10.8% for
Lake Charles, Phoenix and Fresno, respectively.

RESULTS

Introduction of the Transmittance and the Effective Reflectance

The transmittance of the top-fenestration was introduced to
account for the variations in the top-glazing system, i.e., type and
area. The transmittance of the top-fenestration system was
obtained by averaging measured horizontal DF's of 5 test points,
uniformly distributed just below the top-fenestration system. Table
1 shows the value of the transmittance for the different top­
fenestration systems. It shows that the transmittance of the
top-fenestration tested varied from 14.0% (vertical south-facing top­
glazing with an area of 37% of the total projected roof area) to
86.0% (horizontal top-glazing with an area of 100% of the total
projected roof area ). It also shows that the horizontal glazing
transmits about 2.5 times more diffuse light per unit of projected
horizontal top-fenestration area than the vertical south-facing top-
glazing system.

By analogy, the effective reflectance was introduced to account
for the variations in the atrium walls, i.e., the solid area and its
reflectance. The effective reflectance was calculated by considering
the reflectance of each component of the atrium walls and its area
(percentage of the total wall area) as a weighting factor. Table 2
Table 1. Measured overall transmittance (diffuse sky) as a function of the area of the different top-glazing systems tested (%)

<table>
<thead>
<tr>
<th>Top-glazing area (percentage of projected roof area) (%)</th>
<th>Atrium type</th>
<th>Horizontal top-glazing</th>
<th>Vertical south-facing top-glazing</th>
</tr>
</thead>
<tbody>
<tr>
<td>100.0</td>
<td>Linear</td>
<td>85.0</td>
<td>30.0</td>
</tr>
<tr>
<td></td>
<td>Square</td>
<td>86.0</td>
<td>29.0</td>
</tr>
<tr>
<td>50.0</td>
<td>Linear</td>
<td>—</td>
<td>18.0</td>
</tr>
<tr>
<td></td>
<td>Square</td>
<td>—</td>
<td>19.0</td>
</tr>
<tr>
<td>37.5</td>
<td>Linear</td>
<td>37.0</td>
<td>15.0</td>
</tr>
<tr>
<td></td>
<td>Square</td>
<td>36.0</td>
<td>14.0</td>
</tr>
</tbody>
</table>

Table 2. Calculated effective reflectance of the internal atrium walls (%)

<table>
<thead>
<tr>
<th>Type of atrium</th>
<th>Solid area of the walls (%)</th>
<th>Reflectance of the solid area of the walls (%)</th>
<th>25</th>
<th>40</th>
<th>90</th>
</tr>
</thead>
<tbody>
<tr>
<td>Two-story</td>
<td>60.0</td>
<td>21.0</td>
<td>—</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td></td>
<td>30.0</td>
<td>18.0</td>
<td>—</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>Four-story</td>
<td>66.7</td>
<td>20.8</td>
<td>31.7</td>
<td>65.0</td>
<td>—</td>
</tr>
<tr>
<td></td>
<td>27.8</td>
<td>17.8</td>
<td>22.0</td>
<td>35.0</td>
<td>—</td>
</tr>
<tr>
<td>Two-story</td>
<td>60.0</td>
<td>21.0</td>
<td>34.0</td>
<td>64.0</td>
<td>—</td>
</tr>
<tr>
<td></td>
<td>30.0</td>
<td>18.0</td>
<td>—</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>Four-story</td>
<td>66.7</td>
<td>20.8</td>
<td>31.7</td>
<td>65.0</td>
<td>—</td>
</tr>
<tr>
<td></td>
<td>27.8</td>
<td>17.8</td>
<td>—</td>
<td>—</td>
<td>—</td>
</tr>
</tbody>
</table>

shows the values of the effective reflectance as a function of the solid area of the walls and its reflectance. It illustrates that the effective reflectance tested varied from 17.8% (for a solid wall with a 25% reflectance and an area of 27.8%) to 66.7% (for a solid wall with a reflectance of 90% and an area of 66.7%).

**Optimum Transmittance at Low Effective Reflectance**

The average horizontal DF at the atrium floor increased with the top-glazing system transmittance. Figure 3 shows the variation of the horizontal DF with an effective reflectance of the walls around 20.0% , as a function of the WI, and the top-glazing system transmittance. The Figure shows that the optimum top-transmittance meeting target DF decreased with the WI. For a clear sky, the target DF of 10% for a WI of 0.90 and 1.35 was achieved with a top-glazing transmittance of 25% and 70% respectively. In terms of the percentage of the total projected area of the top-fenestration, these transmittance values would translate into a vertical south-facing top-glazing system with an area of 80% of the total projected roof area (transmittance of 25%), and a horizontal top-glazing system with an area of about 80% of the total projected roof area (transmittance of 70%).

**Effect of Solid Area and Reflectance of the Atrium Walls**

The increase of the solid area of the atrium walls and its reflectance for a given WI increased the average horizontal DF. However, the magnitude of their impact was different. Figure 4 shows the effect of the solid atrium wall area and its reflectance on the average horizontal factor of a four-story square atrium. The effect of the wall area at low reflectance was insignificant while the solid wall area almost tripled (from 28% to 67% of total wall area). The horizontal DF increased to only a maximum of 5% of its value. However, this effect was far more pronounced at higher reflectance. The average horizontal DF increased about 35% to 4% of its value when the reflectance of the solid area increased from 25% to 90% in square four-story atria ( WI equal to 1.35). This magnitude further increased with the decrease of the WI, to reach 50% in the case of the four-story linear atrium (WI equal to 0.9). This has a direct implication on the optimum transmittance of the top-fenestration. It is important to mention that a significant increase in horizontal DF occurred only when the reflectance of the solid area was higher than 40%.

The increase of the reflectance of the solid atrium walls increased the horizontal DF at the atrium floor. The effect of the increase of the reflectance was far more significant with higher solid wall area. However, the reflectance was not linearly proportional to the horizontal DF. The horizontal DF increased about an average of 2% of its value when the reflectance of 20.8% increased about 30% (up to 31.7%). However, the horizontal DF increased about 40% to 60% of its value when the reflectance increased about 100%, suggesting that the increase of 1 unit of reflectance above 30% was more significant than that below 30%.

**Effect of the Effective Reflectance on the Optimum Transmittance**

The increase of the effective reflectance of the atrium walls decreased the optimum top-glazing transmittance needed to meet illumination criteria. With a WI of 1.35 (square four-story atrium), the optimum transmittance was about 42% with an effective
Figure 3. Variation of the horizontal DF as a function of the WI, transmittance, and sky conditions.

Figure 4. Effect of the solid area of walls and its reflectance on the horizontal DF of a four-story square atrium under clear sky.
reflectance of 65.0%. This optimum transmittance increased to 75% when the effective reflectance was reduced to 17.8%. This translates into an increase of the area of horizontal top-glazing from 40% to 90% of the total projected roof area. With a WI of 0.5 (two-story linear atrium), the optimum increased from 18 to 30% when the effective reflectance increased from 17.8 to 65%. This translates into an increase of the vertical south-facing top-glazing area from 50 to 100% of the total horizontal projected roof area. These results have a tremendous impact on the amount of heat gain that can be reduced by treatments in the internal walls. More significant these results are most significant for atria located in hot climates.

Effect of Transmittance on the Daylighting Contribution in the Adjacent Spaces

Low Internal Reflectance. The configuration of the top-fenestration and of the atrium walls had an impact on the daylighting distribution of the atrium floor. The vertical DF at each floor decreased with the decrease of the transmittance and/or the increase of the WI. Under low reflectance, the daylighting contribution in the second floor of four-story atria seemed rather low, and suggested the need for sunlight and/or the increase of the internal reflectance of the atrium walls. The average vertical DF at the second floor of linear four-story atria dropped from 12.3% with a top-glazing transmittance of 86% to 2.0% with a transmittance of 30%. In Phoenix, this would translate into a drop of vertical illumination levels from 124 fc to 20 fc. If a target of 50 fc (general office use) was sought in the occupied spaces, the transmittance of 86% would likely contribute useful daylight up to 4 of 8 feet into the adjacent spaces.

Data suggest that atria with WI above 1.0 cannot rely on diffuse natural daylight at the second floor for office work, except if the perimeter was used for circulation. Under clear diffuse sky, the expected vertical average illumination in the atrium with a well index of 1.35 would be 69 fc and 13 fc with a transmittance of 86% and 14%, respectively. For a WI lower than 1.0, the transmittance should be higher than about 75% to allow any useful daylight contribution for office work and similar activities.

Effect of the Effective Reflectance. The increase of the solid area and its reflectance increased the vertical DF. The vertical measurements were taken only for a reflectance of 25% and 40%. As the effective reflectance almost doubled (17.8% to 31.7%), the vertical average DF increased about 35% of its value. This increase is expected to be much higher with higher reflectance. In a four-story square atrium under clear diffuse sky with a transmittance below 37%, the effect of effective reflectance below 22% on the vertical DF was insignificant.

Effect of the Atrium Physical Parameters on the Daylighting Distribution. The daylighting distribution on the atrium floor and the vertical walls was less uniform with the decrease of the transmittance. The increase of the WI decreased the uniformity of daylighting distribution more on the vertical walls than on the atrium floor. As expected, the configuration of the top-fenestration had an effect on the daylighting distribution. For the same projected roof area, horizontal top-fenestration distributes light on the atrium floor more uniformly than vertical south-facing top-fenestration. The ratio of vertical DF at the fourth floor to that at the second floor increased with a decrease of the transmittance, ranging from 2.0 to 7.0. This ratio, affecting the contrast in the atrium, increased with the WI, especially in the south wall of atria with a vertical south-facing top-glazing system.

Validity of the Average DF as an Evaluation Tool.
The nine-point average DF was an appropriate tool for evaluation, when the average DF met the target, at least 90% of the atrium floor area did so. The DF at the center could not have been chosen as a tool for evaluation; when it was equal to the target DF, only about 20% of the floor area met the targeted DF.

DISCUSSION AND ANALYSIS

Summary of Results

The results of the experiment can be summarized as follows:
1. The optimum fenestration for lighting criteria was a function of the solid area of the atrium walls and its reflectance.
2. The increase of the solid area of the atrium walls increased the lighting levels of the atrium floor and the adjacent spaces, but its effect was more significant with higher reflectance.
3. The increase of the effective reflectance increased the daylighting potential in the atrium floor and into the occupied spaces. As a result, the increase of the effective reflectance of the atrium walls lowered the optimum transmittance needed for lighting criteria.
4. The resulting vertical DF at lower floors suggests that low daylighting contribution in the occupied spaces under diffuse sky and sunlight is always needed for transmittance below 86%. This also suggests that the daylighting contribution in the occupied spaces for lower floors of atria with a WI higher than 1.35 is not very significant.
5. The optimum transmittance meeting lighting criteria at the atrium floor decreased with the WI.

Interpretation

The optimum top-fenestration transmittance for effective daylighting could not have been defined independently of the reflective and surface characteristics of the internal walls. This is because the increase of the area of the atrium walls provides more surfaces to reflect light downward. The solid area at low reflectance did not significantly affect the lighting levels since reflectance was close to that simulated for the glazing of the windows (25% vs 15%). The solid area of the walls could have more significant impact at low reflectance if there were no glazing (0% reflectance) in the windows. It is important to note that the reflectance has been tested under diffuse light only. The effect of reflectance on indoor daylight levels under diffuse light was reported lower than that under sunlight at high altitude (Navab and Selkowitz, 1984). Glass (not simulated in the experiment) can also contribute to specular light distribution. The target DF was achieved through several combinations of the transmittance of the top-fenestration, and area and reflectance of the different components of the atrium walls. This suggests that the internal atrium's physical parameters can enhance the daylighting performance of an atrium without having to increase the top-fenestration area, thus reducing heat gain, especially in hot climates.

Optimum Combination of Top-fenestration and Wall Treatment for Efficient Daylighting

Optimum top-fenestration transmittance for lighting criteria at the atrium floor as a function of solid wall area and its reflectance is shown in Table 3. The data in this table are intended to assist designers to size the optimum design combinations of top-fenestration and wall treatments to achieve target lighting criteria at the atrium floor while reducing the heat gain associated with oversized top-fenestration. In atria with WI higher than 1.00, the lower optimum transmittance was around 30% (e.g., transmittance of vertical south-facing top-glazing system with an area of 100% of total projected area). This result coincides with the on-site daylighting measurements in the Dallas City Hall Building with the vaulted north-facing vertical top-glazing. This atrium with a WI higher than 1.00 had its floor in continuous need of artificial lighting despite side lighting at the first floor (Molinelli and Kim 1987).
The reduction of the transmittance due to wall treatments ranges from 4% (low reflectance solid area) to 35% of its value (highly reflective solid area). The reduction of 35% would reduce a 100% transmissive top-fenestration by about 35% of its area. The maximum reduction of optimum transmittance for average reflectance of 40% was 12%. However, data in Table 3 excludes other lighting effects such as daylighting distribution, and glare. It also excludes other types of atrium wall configurations such as stepped down atria.

### Optimum Lighting at the Atrium Floor vs Daylighting Contribution in the Adjacent Spaces vs Daylighting Distribution

The optimum combinations of top-fenestration wall treatment also affect indoor lighting contrast and daylighting in the occupied spaces. For atria with a WI above 1.00, a top-fenestration transmittance of 40% or higher is really needed for any useful daylighting contribution (for an office) at the second floor under diffuse sky. This coincides with the fact that the minimum transmittance needed for target lighting at the atrium floor was 30%. Choices have to be made according to a primary lighting solution. The first one includes an uneven vertical distribution of the solid area in the atrium, the maximum proportion being at the top. Upper floors of atria need fewer openings since they receive more direct light. Furthermore, a solid area at upper floors is likely to receive light that is either direct or has been reflected only a few times, thus increasing the amount of light being reflected downward (Saxon, 1983). This solution is more important for taller and narrower atria.

The second design solution would be to use reflective elements such as fins and lightrayshelves that would free the facades, while they would still reflect light at the side and the corners of the atrium floor. This would eventually increase the uniformity of light distribution at the atrium floor. These fins and lightrayshelves should be combined with a solid area at the perimeter, otherwise their size would interfere with functional requirements of the atrium floor. The third solution of using stepped-down atria to allow lower floors to receive more direct light seems inappropriate since it increases the depth of lower floors.

<table>
<thead>
<tr>
<th>Well Index</th>
<th>Reflectance (%)</th>
<th>Percentage of solid area in the atrium walls (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>25 40 90</td>
<td>67 90 28</td>
</tr>
<tr>
<td>0.5</td>
<td>30 27 17</td>
<td>25 40 90</td>
</tr>
<tr>
<td>0.75</td>
<td>34 30 20</td>
<td>38 35 32</td>
</tr>
<tr>
<td>0.90</td>
<td>44 37 27</td>
<td>45 42 38</td>
</tr>
<tr>
<td>1.35</td>
<td>67 57 45</td>
<td>70 65 58</td>
</tr>
</tbody>
</table>

The internal treatments of the atrium walls can enhance the lighting criteria at the atrium floor without having to substantially increase the size of the top-fenestration. This alleviates the issue of heat gain resulting from oversized and unshaded top-fenestration, which is an often claimed problem especially in hot climates. The impact of sunlight on the daylighting performance of atria still needs to be investigated. However, the data were based on an appropriate representation of average sky illuminance. Therefore, the data above can be used as rules-of-thumb for atrium design. The thermal performance of atria tested in this study is being investigated to examine the trade-off with the daylighting performance. Further work also includes the calculation of the expected lighting loads of atria.

The recommendation pertaining to the optimum combination of the components of the entire atrium perimeter for efficient daylighting cannot be merely stated, excluding other architectural priorities such as glare, functional requirements, and so on. The first pertinent concern in daylighting an atrium is to determine the daylighting "task" of the space, i.e., whether the role of daylighting is restricted to the atrium floor, or the occupied spaces, or both. This basically will determine the overall transmittance as well as the configuration of the atrium walls. The second concern is to determine the light distribution targeted at the atrium floor and walls: uniform or light-and-shadow play. This should determine the desired configuration of the top-fenestration and the amount of solid area on the walls and its reflectance.

### REFERENCES


