

Effect of Perimeter Balconies on Daylighting in Atria

Gon Kim

Ph.D. Professor, Div. of Architecture, College of Engineering
Kangwon National University

ABSTRACT: Designers who predict daylighting performance usually assume that the space is empty and uncluttered. A careful understanding of the light reduction due to major architectural obstructions is necessary not just for providing optimal light level for intended tasks but for safety in the spaces. In the initial stage of the daylighting design process, the effect and light attenuation caused by major interior obstructions should be carefully considered in order to determine whether the light condition in spaces is adequate for the required tasks in a quantitative and qualitative manner. Atrium design must typically confront several specific issues concerning aesthetics, thermal conditioning, and lighting. From the viewpoint of the daylighting, the atrium concept allows the exploitation of daylighting by bringing natural light into the center of the buildings, thus enhancing a more even distribution of daylight. The configuration of perimeter balconies, however, are determined on the basis of the purpose of the perimeter space and the use of the building, which may defeat the primary daylighting advantages inherent in the atrium concept. The authors have developed insights and design guidance regarding the critical daylighting performance factors by evaluating the relative effect of various perimeter balcony configurations on illumination level and its distribution with different atrium geometries and wall reflectances. For these, parametric measurements of illumination level with a scale model of a four-sided atrium building and various perimeter balcony configurations have been conducted under diffuse sky conditions within the sky simulator at Texas A&M University. This paper represents the atrium performance results in terms of Daylight Factor, well index, balcony well index, the configuration of perimeter balcony, and perimeter reflectance; and the results are compared with basecase atria without any perimeter balcony.

Keywords: daylighting, balcony, atrium, light well, skylight

1. INTRODUCTION

Light is necessary in order for people to accomplish daily tasks. In addition, light also helps to define space through visual perception, and daylight has attributes that make its use in defining space, form, color, and texture, particularly pleasing. Before the 1973 energy crisis, the provision of daylight in structures had largely been considered an amenity rather than a

necessity. Numerous studies have conclusively demonstrated a marked preference for daylight over any other form of lighting [Boyce, 1973 and Tregenza et al., 1974]. Usually, exterior illuminance for daylight consists of three components: diffuse sky component, direct radiation component, and reflected component [Gillette et al., 1988]. The direct component, light coming directly from the sun, is composed of directional, parallel rays. Its

intensity may be as high as 9,000 footcandles (fc), depending on the time of day, year and the angle of incidence. Diffuse skylighting, reflected from clouds, dust, etc., is composed of weaker rays coming from all directions and is traditionally the major source for daylighting. Its intensity varies from 100 to 3,000 fc, depending on the degree of overcast and solar altitude. Sunlight reflected from the ground constitutes only 10 to 15 % of the total daylighting reaching a window, but light ground surfaces increase this amount. Natural outdoor light intensity, therefore, may be many times the level required inside. The interior of a building might need illuminance of 50 fc, and exterior natural light levels might be 20 times that amount on a cloudy day or 100 times on a sunny day. Accordingly, daylighting remains one of the most interesting and potentially significant strategies for reducing commercial building energy use. In brief, the most important benefit of the application of daylighting in a commercial building may be not only increased occupant satisfaction but reduced energy consumption as well.

The objective of this research is to develop design guidelines regarding the critical daylighting performance factors with perimeter balconies at atrium design. The paper discusses and evaluates the relative effect of perimeter balcony on illumination levels at atrium spaces with different atrium configuration. It also addresses the effect of balcony edge guardrail configuration and the amount of light attenuation caused by perimeter balconies. For these, extensive parametric measurements of illuminance level with a scale model of a four-sided atrium building have been conducted as a function of atrium configuration under diffuse sky condition within the sky simulator at Texas A&M University. This paper represents the atrium performance results in terms of Daylight Factor, well index, balcony well index and the configuration of perimeter balcony; and the

results are compared with basecase atria without any perimeter balcony.

This research examines only a simple four-sided atrium with typical balcony configurations and interior surface reflectances as the critical variables and focuses only on the daylighting performance in atrium spaces. Consequently, the results of the research are limited to illuminance characteristics and do not directly address annual energy saving due to daylighting. Finally, this research focuses only on the daylighting in the atrium space itself, and provides no evaluation of the surrounding spaces.

2. DAYLIGHT IN ATRIUMS

2.1 Characteristics of Atrium Buildings

The atrium, which is a particular form of courtyard, was a social center of the ancient Greek and Roman house. In 19th century, the development of iron and glass technology created new possibilities for courtyards. Although there are many reasons for the current revival of atrium buildings, none is more significant than the inherent energy potential of this spatial type. Ever-increasing fuel costs and the impending scarcity of energy will continue to elevate energy conservation as a design requirement. An atrium contributes to passive heating and is useful in an overall ventilation and cooling strategy, and always makes daylight more available to the spaces that surround it. From the viewpoint of daylighting, an atrium allows uniform illuminance over very large interior space and admits much more light can be received than from vertical windows.

The daylighting performance in atria depends on a critical assessment of lighting design criteria-- in particular, determining the intensity and distribution of available daylight to meet design criteria. The daylight that reaches a task location is influenced by several major design features, each of which can be controlled to some

degree. The atrium consists of all building surfaces facing the atrium space as well as interior obstructions (for example, vegetation and stairwells), the length/height/width ratios, and wall surface type and reflectance that affect the amount of light available at the base of the atrium [Boyer, 1988, 1990]. In the initial design stage of atria, more empirical data are needed to predict the daylighting performance of specific atrium spaces because there are a large number of important variables to consider.

2.2 Design Criteria: Illuminance level

The atrium itself should provide sufficient illuminance for pedestrian circulation, casual tasks, and, frequently, for plants or trees. According to the American IES Standards, 5 to 20 fc (50 to 200 lux) is sufficient [Stein et al, 1992]. Boyer (1988) has also suggested in his empirical research that acceptable light levels can be as low as 10 to 20 fc (100 to 200 lux) in the circulation areas. Most spaces within an atrium, especially those which sustain plant life, will easily meet or surpass 100 percent of this lighting requirement during daytime hours through the use of daylighting. Office spaces, however, require illumination levels of 20 to 100 fc (200 to 1000 lux), and it is common to find offices located around the lighting source for significant annual energy savings. Lighting distribution is correlated with visual comfort. Natural light levels may be excessive immediately adjacent to a window but inadequate at the back of the space. An atrium design for daylighting must incorporate features to distribute natural light evenly.

3. DATA ACQUISITION

3.1 Well Index

The behavior of light in atrium spaces depends mainly on the configuration of the atria and it can be expressed in terms of the

Well Index. [Serres,1990] The well index is similar to the cavity ratio in interior electric lighting calculations and has been applied to daylighting performance methods to evaluate the well efficacy of the skylighted space.

$$\text{Well Index} = \frac{\text{Atrium height} \times (\text{Width} + \text{Length})}{2 \times \text{Atrium length} \times \text{Atrium width}} \quad (\text{Serres and Murdoch, 1990})$$

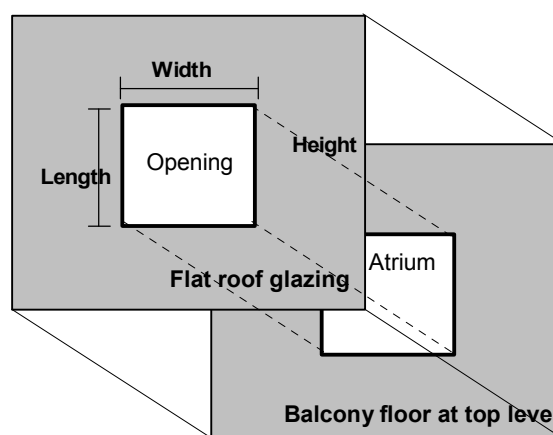


Figure 1: Well index in atriums

If there is no balcony in an atrium, the conventional concept of well index can be used successfully to categorize the various configurations of atria and their daylighting performances. But the building well index can not necessarily be used with perimeter balconies because each balcony floor might function as overhang of a roof glazing system to the floor below. For this configuration, new term, namely, balcony well index or effective well index is introduced which is specified by balcony well width (W'), balcony well length (L'), and atrium height (H'); and defined as.

$$\text{Balcony Well Index (WI')} = \frac{\text{Atrium Height} \times \text{Balcony Well (Width + Length)}}{2 \times \text{Balcony Well Length} \times \text{Balcony Well Width}}$$

3.2 Perimeter balcony

Perimeter balconies have been used not only for circulation areas such as a walk path but also for classrooms or shopping

spaces depending on the use of the atrium building. The configuration of the perimeter balcony varies with the building size and its use. Thus, it is difficult to generalize from a small set of balcony configuration to the wide range of balcony configurations to the real world. The height of the edge guardrail is typically 3 through 4 feet for safety and its color is not far from the overall interior color if it is solid.

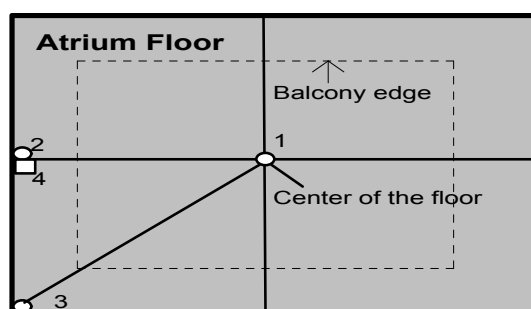


Figure 2: Configurations of perimeter balconies

3.3 Daylight factor

As a primary index to represent the data from the experiment, the *Daylight Factor* (DF) is defined as the percentage of the outdoor light that is available indoors. This evaluation method was developed in England, where the solid overcast sky condition is predominant for much of the year. The Daylight factor (DF) is mathematically defined as

$$DF = \frac{\text{indoor illuminance from daylight at a given point}}{\text{unobstructed exterior horizontal illuminance}} \times 100 (\%)$$

The ratio between the minimum and average DF should not be less than 3%, and the minimum DF in any portion of a space should not drop below 0.5%, which is sufficient for circulation.

3.4 Model construction

For this experiment, a scale model (1/2"=1') of a four sided square atrium in a 5 story building has been constructed so that the wall, interior reflectance, the

balcony configuration and its height can be readily changed. (Figure 3) In order to easily adjust the well index values of atrium spaces, a total of twenty rectangular box-shaped modules measuring 40"(L) x 6"(W) x 6"(H) were made. These modules represent actual dimensions of 80'(L) x 12'(W) x 12'(H) in 1/2"=1' scale. In SI unit, they represent 1m x 0.15m x 0.15m in model and 24m x 3.6m x 3.6m in actual dimension. In this scale, the height from the atrium floor level to the top of the photometric sensor, which measures 1.5 inch (3 ft) including the thickness of the base mount for photocell, represents the general workplane height.

In order to consider the effects of specula surfaces inside the atrium, one of the four long-sided surfaces of a module has window area treated by 1/16 in clear plastic sheet measuring 3 in (6 ft) in height leaving solid walls of 1.5 in (3 ft) in height at the top and bottom of the open area. This strategy will be one of the clear advantages of scale model study over computer simulation programs that almost always ignore the effects of specula surfaces inside the atrium.

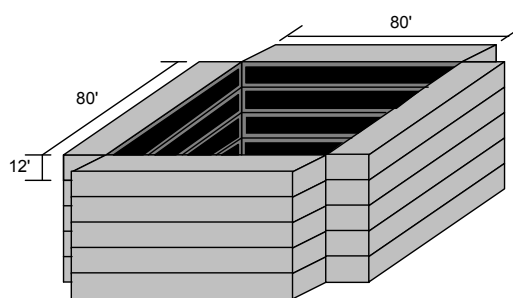
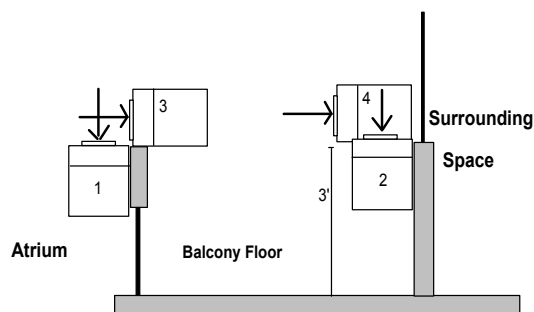


Figure 3: Axonometric view of scale model of the atrium

Since this research concentrates on the daylighting in the atrium space itself, the inside surfaces of the modules were painted flat-black so that light transmitted into the box modules through the open sides cannot be reflected back to the atrium space.

3.5 Measurement

The large sky simulator for daylighting research refurbished at Texas A&M University in 1985 allows adjustments to simulate conditions of an overcast sky, uniform sky and various clear sky luminance distributions. The performance characteristics of the sky simulator have been reported by Boyer and Degelman (1989). The size of the facility is a 28-foot (8.5m) diameter with a clear height of 12 feet (2.3m) so that all types of large-scale buildings which may be up to 5 feet (1.5m) can be placed. For this experiment, IDAS (Illuminance Data Acquisition System: Model No. LI-210SZ) made by FOWLKES Engineering Company was used.



Atrium floor level	1, 2, 3: Horizontal illuminance
Balcony floor level	4: Vertical illuminance under balcony
	1: Horizontal illuminance on balcony
	2: Horizontal illuminance on back to surrounding space
	3: Vertical illuminance on balcony
	4: Vertical illuminance on back to surrounding space

Figure 4: Locations of measurement

The measurement of the differences in the horizontal and vertical illumination values between the balcony edge (position 1,3) and close to the surrounding wall (position 2,4) is of importance in ascertaining not only the light attenuation caused by the floor of the above balcony but also the light gain by different balcony edge configuration. (Figure 4) Also in these measurements, the vertical illumination level close to the adjacent surrounding wall

is more meaningful to a lighting designer since it works as a light source to the adjacent spaces.

It is absolutely necessary that certain reference illuminance of exterior conditions be determined and measured at the beginning, during, and the end of model daylighting tests. This provides a basis on which to compare various tests and to give an indication of the changing conditions of the sky. Only exterior horizontal illuminance measurement is necessary when the model has horizontal openings (e.g., skylights) like this experimental model. This measurement provides an indication of the total light from the sky that is available to pass into a horizontal opening such as a canopy system in atria.

4. ANALYSIS ON DAYLIGHTING

4.1 Well Index Effect

The differences in Daylight Factors between different well indices are considerable since the daylighting performance is basically a function of the amount of daylight penetration and the height of the atrium.

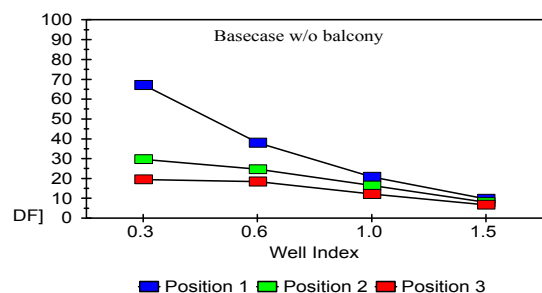


Figure 5: Well index and Daylight Factor without balcony

Figure 5 illustrates the resultant Daylight Factors in four well configurations without balcony when the wall reflectance is 90%. The significance of well configuration should be addressed in more detail

combined with effect of different balcony configurations. To measure the relative effect of well index, 4 different well configurations have been compared with 3 different balcony depth in case of 90% wall reflectance.

Figure 6 represents the effect of different well indices with each balcony configuration. Regardless of the depth of the perimeter balcony, the variation in Daylight Factor on the center point of atrium floor seemed to vary with approximately 50 through 30%.

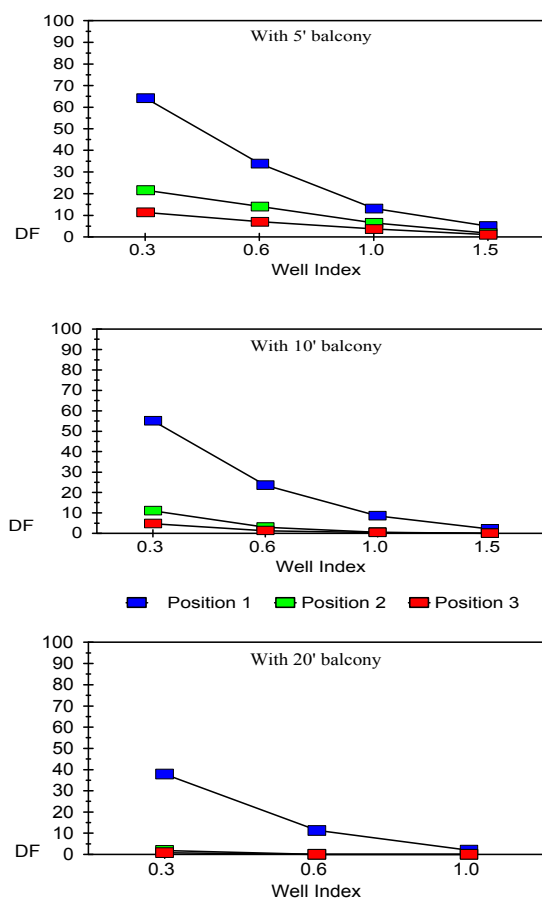


Figure 6: Well index and Daylight Factor with balcony

For other positions covered by balcony floor, however, the amount of reduction is more considerable when the well index becomes higher. It is believed that the balcony floors intercept the desirable light into atrium floor. Accordingly, high well

indexed atrium with perimeter balcony may have some problem to achieve adequate light level and even distribution.

4.2 Balcony Depth and Building Well Index Effects

Balcony depth is one of the most fundamental factors in daylighting performance in case that the atrium building has perimeter balconies. As expected, clearly deeper perimeter balcony blocks more light from skylight and the light level and distribution are strongly depended on the depth of the balcony floor.

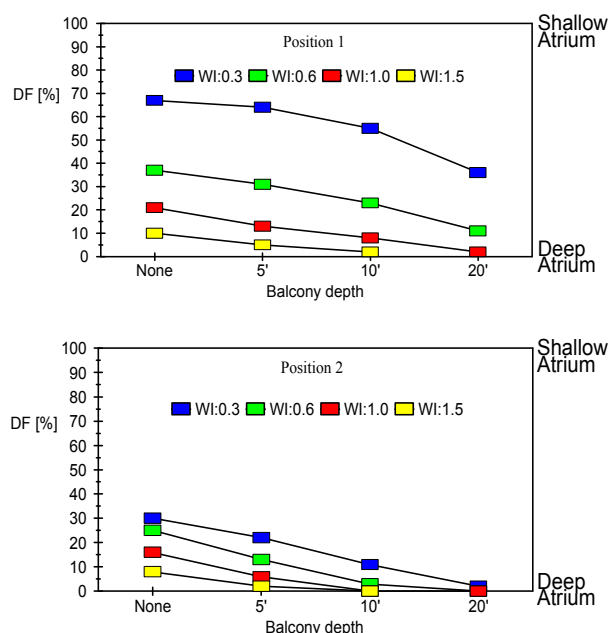


Figure 7: Balcony depth and Daylight Factor without edge

For the position uncovered by balcony near the center of the atrium floor by balcony, adequate illumination level can be achieved for circulation regardless of building well index and balcony depth. On the other hand, the attenuation in illumination level on the position under the balcony floor is considerable, in particular, when the well index becomes higher and balcony floor deeper. (Figure 7)

As with building well index, a higher balcony well index means deeper balcony

floor and indicates lower daylighting performance. As shown in Figure 8, the illumination levels on the center point in the atrium vary proportionally with changing balcony well configuration. Also, in case of same building well index, it seems to be a relationship between balcony well index and lighting level. However, considering the light level on other positions (2, 3) with whole building well indices, illumination levels are not dependent on balcony well index. It is believed that the illumination level on the position under the balcony is affected mainly by the balcony depth.

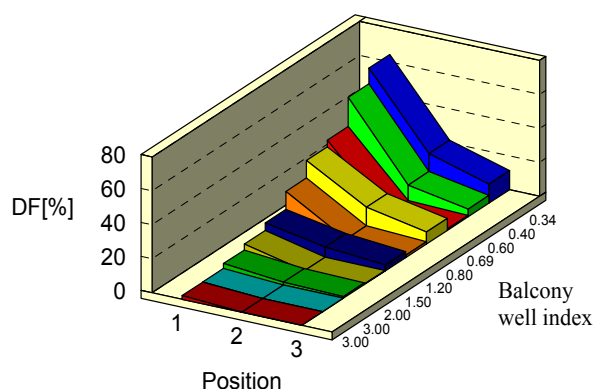


Figure 8: Balcony well index and Daylight Factor

4.3 Light reduction on balcony floor

To determine the amount of light reduction due to balcony floor, horizontal and vertical illuminances have been measured. In particular, the vertical illumination level is very significant since it is a light source to the surrounding surfaces. With changing atrium and balcony configurations, light levels on two different locations- in front of balcony edge and close to window on atrium wall- have been measured and compared. The reduction has been tested on only the top floor of each atrium configuration. The attenuation in horizontal illuminance is mainly also a function of balcony depth although well index has some effect. In the case of 10'

balcony depth, the reduction is around 70% and is 90% with 20' balcony floor.

The effect of balcony depth on the reduction is more serious in dealing with vertical illuminance. It is very interesting that the reduction ratios are negative in certain cases, which means it gains more light to some degree in the location close to the atrium wall. But it is true with only shallow balcony and thus when the balcony becomes deeper than a certain depth (in these data, 10'), the vertical illuminance is reduced considerably. It is due to the sky factor with top glazing system for the top floor level and thus, it may be also only when the top floor has been considered.

5. CONCLUSION

The relative effect of perimeter balconies on illumination level and its distribution in atrium spaces with different well configurations has been tested and discussed. First, as expected, well index and balcony depth are the most significant factors in daylighting performance in atrium spaces with perimeter balconies. For the position not covered by balcony, adequate illumination level can be achieved for circulation regardless of building well index and balcony depth although it may be that involved well indices are relatively low.

On the other hand, light attenuation on the position under balcony floor is considerable, in particular, when the well index becomes higher and balcony floor becomes deeper. Accordingly, high well indexed atrium with perimeter balconies should be carefully designed to provide adequate light level and even distribution. In case of deep balconies in a deep atrium building, intensive supplementary artificial lighting system should be carefully installed with reference to the amount of light attenuation due to the balcony configuration and the geometric characteristics of the atrium. Secondly, as with building well index, a higher balcony well index generally

means deeper balcony floor and thus indicates lower daylighting performance.

The balcony well index can be a useful index to figure out the daylighting performance when spaces uncovered by balcony are concerned. Conversely the lighting levels in the covered spaces are not predicted by using only the balcony well index. Once again, it is believed that the illumination levels on the positions under the balcony are mainly affected by the balcony depth and the positions are not within the balcony well.

ACKNOWLEDGEMENT

This work was supported by grant No. (R01-2006-000-10712-0) from the Basic Research Program of the Korea Science & Engineering Foundation.

REFERENCES

- [1]Bednar, Micheal J., 1986, *The New Atrium*, McGraw-Hill Book Co., New York.
- [2]Boyce, P.R., 1973. Age, illumination, visual performance and preference. *Lighting Research and Technology* Vol. 5(no. 3):125-144.
- [3]Boyer, Lester L. 1990. Preliminary design consideration for daylighting in atria. *15th Passive Solar Conference Proceedings*. American Solar Energy Society, Austin, Texas, March.
- [4]Boyer, Lester L. and Degelman, Larry O., 1989. A large sky simulator for daylighting studies at a Texas University. *Proc. II, International Daylighting Conference*, Long Beach, CA. published by ASHRAE, Atlanta, Georgia
- [5]Evans, Benjamin H., 1981. *Daylight in Architecture*; MacGraw-Hill Book Company, New York.
- [6]Gillette G. and S. Treado, 1988. The daylighting and thermal performance of roof glazing in atrium spaces. *ASHRAE Transaction* Vol. 94, Part I.
- [7]Kim, K. S. and Boyer, Lester L., 1988. Daylight prediction and measurement for three-sided multistory atriums under overcast and clear skies. *ASHRAE Transaction* Vol. 94, Part I.
- [8]Meacock, H. F. and Lambert, G. E. 1930. The efficiency of light wells, London: Department of Scientific and Industrial Research. *Illumination Research Technical Paper*, no. 11.