Daylight Rules-of-Thumb Experimentally Examined

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Abstract

The paper aims to help architecture and architectural engineering students in the early design stages to accurately determine the optimum glass ratio for different building types in different climates. Currently, the design profession depends on old outdated rules-of-thumb to estimate the area of windows that allows good utilization of daylight. These rules-of-thumb are the (1) 2.5 rule, (2) one tenth rule, and (3) 15/30 rule. None of these rules-of-thumb is tailored to a specific building type fitted with a specific glass type in a specific climate. Their use most likely results in downsizing or oversizing windows for the visual task performed in the space. Indeed, rules-of-thumb are meant to be simple in order to be user-friendly, however, in this case, they are rather simplistic and ignore many crucial factors that influence the performance of daylighting systems. The author performed a series of experimental studies in which he tested several physical models under an artificial sky dome in order to obtain accurate results due to the use of the rules-of-thumb under consideration. The results are presented in an easy format, i.e., easy-to-read tables and charts.

Keywords: Daylighting, schematic design, design-assisting tools, energy efficiency

Introduction

State of daylighting design in the profession and academia

Currently, in a typical case, the design of daylighting systems in buildings is often overlooked by both architects and architectural engineers. During the design process, neither architects nor engineers pay enough attention to the design of daylighting systems. Engineers design electric lighting systems but not daylighting. Unless a lighting simulation computer program is utilized, no scientific prediction of the performance of daylighting systems takes place. Very few engineers are trained to use daylighting design computer programs. The majority of the commonly-used methods and design-assisting tools to design daylighting systems do not provide meaningful feedback on performance. This is the case in both academia and practice. A solution is needed to improve energy efficiency and advance sustainable design.

In academia, students tend to learn from precedents of successful designs of daylighting systems. When students are asked to rigorously design daylighting systems, they normally utilize rules of thumb, which are suited for the schematic design phase. Quantitative rules of thumb often used in design studios are: the rule of 2.5, the 15/30 rule, and the one tenth rule (Moore, 1993). In academia and practice alike, because of the current lack of the evaluation of the performance of daylighting systems, these systems tend to be conceived as a visual phenomenon that relates more to the architectural aesthetics rather than the engineering of buildings (Mansy, 2004).

Ramifications of inaccuracy

Dependence on such inaccurate design-assisting tools, such as the above-mentioned rules-of-thumb, results in losing a valuable opportunity for making buildings more energy efficient. Furthermore, these buildings also lose the opportunity of being more pleasant to their occupants. Lost benefits of good design of daylighting may include some or all of the following:

- The opportunity of saving light energy since daylight is considered to be a free renewable source of light. Furthermore, daylight is most available around noon time during which electricity may be at its highest rate due to the energy demand charge during peak hours.
- The opportunity of reducing cooling load since daylight is a cool source of light that has higher efficacy (measured in lumens/watt) compared to artificial light sources.
- The opportunity of being environment-friendly since utilization of daylight in buildings, unlike electric light, does not produce any environmental pollution.
- The opportunity of utilizing the highest quality of light (daylight) with the best color rendition.
- The opportunity of better integration between the indoor environment and the outdoors that makes more pleasant spaces.
- The opportunity for potentially higher occupant productivity due to high quality of light and improved views to the outdoors (New Buildings Institute, 2003).

Sources of Inaccuracy of Rules-of-Thumb

Indeed, the rules-of-thumb are seen as the simplest and easiest design-assisting type of tools to use. However, they may be misleading. In case of rules-of-thumb for daylighting design, they are not accustomed to a specific building type, visual task, glass type, or a specific climate. Availability of daylight, both in terms of light intensity and duration per time, experience wide variations in different climates due to sun position and cloud cover. Rules-of-thumb for daylighting design ignore the following factors:

- Building location which, in return, determines the apparent sun movement (daily and seasonal) and the available intensity of daylight.
- Sky condition that may range from clear sky (no cloud cover) to overcast sky (100% cloud cover).
- Ground reflection that may affect the reflected light components off the ground into bottom floors of the building.
- Space orientation which determines which side of the sky dome the space may receive light from. For example, is the space facing the bright south sky or the less bright north sky (assuming a location in the Northern Hemisphere)?
- Glass ratio, which is the area of glazed windows to the gross area of the exterior wall.
- The visual task performed in the space, since different visual tasks require different intensities of light on the work-plane.

All of the above-mentioned factors affect the performance of daylighting systems in buildings because they affect (1) sky brightness that is the source of daylight, size of windows through which natural light enters the space, and the desirable intensity of light inside the space.

The 2.5 Rule Examined

The rule of 2.5 assumes that, for office tasks, side-lighting (windows) can provide effective illumination for depths up to approximately 2. 5 times the height of the window head above the work-plane (Allen et al, 2002). According to the Illuminating Engineering Society (IES) publications, this rule is most applicable where (1) clear glazing is used; (2) the window width equals half of the exterior perimeter length; (3) sky conditions are either overcast or the room is facing north, or controllable blinds are provided; (4) light reflectance of interior ceiling and walls is relatively high; and (5) there is no major light obstruction in the outdoor (IES, 1924). Given these five conditions for the applicability of the 2.5 rule, the author performed experimental testing to examine the accuracy of this rule-of-thumb as explained in the next section.

The experiment

The experiment was to build a scale physical model of a simple space that satisfies all five conditions of the 2.5 rule and test this model under the artificial sky dome that accurately simulates the overcast sky condition. Figure 1 shows the brightness distribution of the standard overcast sky. Figure 2 shows the model being tested under the artificial sky dome in the daylighting lab of the School of Architecture, Oklahoma State University. In order to examine the relationship suggested by the 2.5 rule, the author tested a series of physical models with different heights of the head of the window as measured above the floor, which are (1) 2.4 m (eight feet), (2) 2.7 m (nine feet), (3) 3.0 m (ten feet), (4) 3.3 m (eleven feet), and (5) 3.6 m (twelve feet) above the floor. Upon testing, the author obtained the values of the daylight factor inside the model at the height of the workplane that is 75 cm (30 inches) above the floor. Table 1 shows the results of testing the physical model under standard overcast sky condition as simulated by the artificial sky dome.

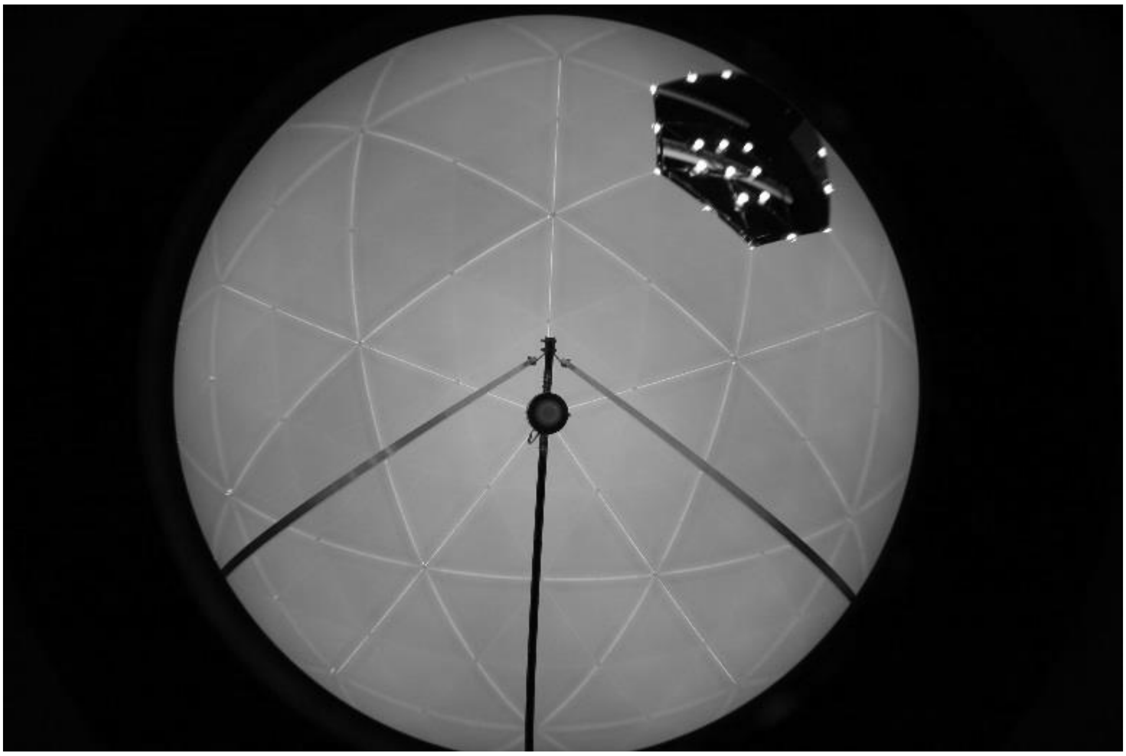

Fig. 1. Brightness distribution of the standard overcast sky as simulated by the artificial sky dome.

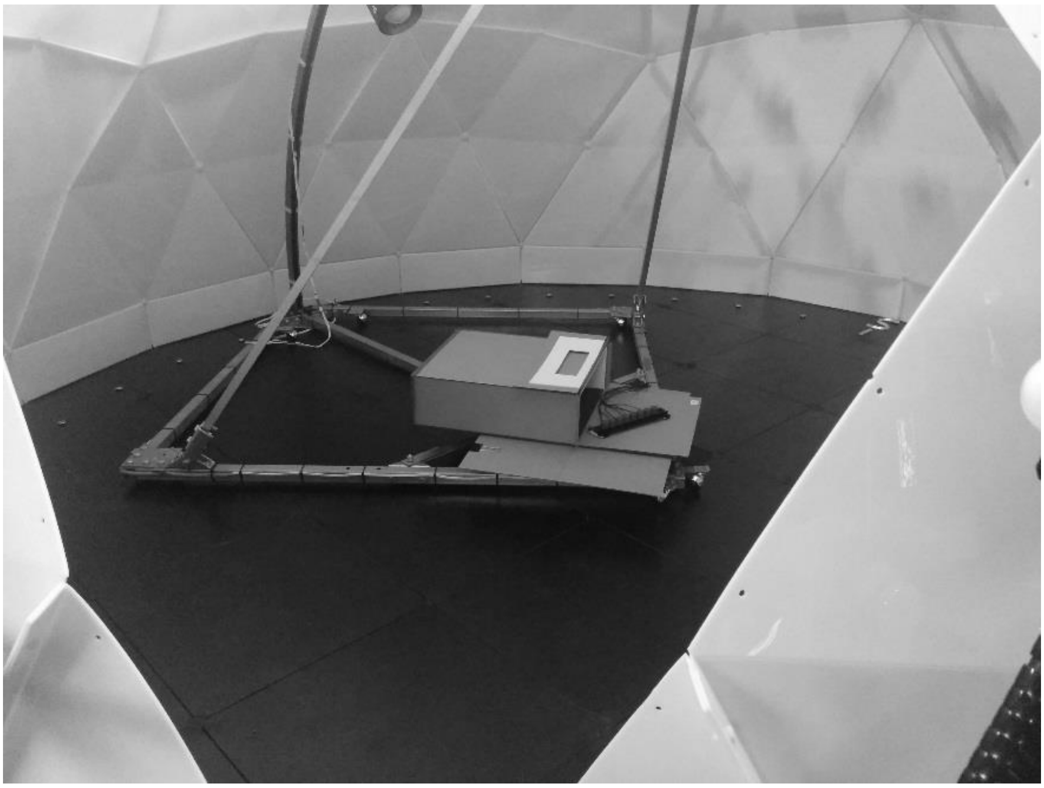

Fig. 2. The physical scale model when tested under the artificial sky dome.

Table 1. DF values obtained from testing the physical model under overcast sky.

Depth into space in meters	Height of Window				
	H = 2.40 m	H = 2.70 m	H = 3.00 m	H = 3.30 m	H = 3.60 m
	h = 1.65 m	h = 1.95 m	h = 2.25 m	h = 2.55 m	h = 2.85 m
	Glass Ratio				
	23%	**27%**	**31%**	**35%**	**39%**
0.30 m	20.42%	24.17%	27.16%	28.52%	30.49%
1.10 m	12.19%	14.80%	18.09%	19.39%	22.09%
1.90 m	7.15%	9.47%	12.15%	12.96%	15.37%
2.70 m	5.67%	6.79%	9.16%	10.79%	7.90%
3.50 m	**3.79%**	4.63%	6.08%	7.11%	8.33%
4.30 m	**2.97%**	**3.63%**	4.68%	5.20%	6.12%
5.10 m	2.46%	**3.07%**	**3.90%**	3.91%	5.06%
5.90 m	2.07%	2.58%	**3.27%**	**4.37%**	4.56%
6.70 m	1.73%	2.11%	2.62%	**3.09%**	**3.51%**
7.50 m	1.57%	1.80%	2.29%	2.70%	**3.06%**
8.30 m	1.30%	1.61%	2.01%	2.28%	2.73%
9.10 m	1.35%	1.49%	1.95%	2.42%	2.79%
9.90 m	1.22%	1.36%	1.73%	2.01%	2.29%
10.70 m	1.14%	1.36%	1.66%	1.84%	2.14%
11.50 m	1.16%	1.39%	1.72%	1.90%	2.14%
12.30 m	1.24%	1.47%	1.70%	1.98%	2.30%
Minimum DF	**1.24%**	**1.47%**	**1.70%**	**1.98%**	**2.30%**

H is the height of the window head above he floor

h is the height of window head above the workplane

Test results & discussion

As evidenced by testing the physical model, effective penetration of daylight into the space is proportional to the height of the window head above the workplane. Note that the staircase-shaped shaded values in Table 1 are the Daylight Factor (DF) values at a depth that is 2.5 times the height of the window head above the workplane. However, the average of these measured values is in the range of 3.0 to 3.5% without taking the glass visible transmittance (VT) or the glass transmittance depreciation into account. Assuming clear glass with VT = 88% and transmittance depreciation (due to accumulation of dirt) = 85%, the effective DF at a depth equals 2.5 h is reduced to 2.43% on average, which is relatively low. When this DF is compared to the recommended intensity of light (illuminance) inside an office space of about 30 fc (IES, 2000), the horizontal illuminance in the outdoor must be about 1,230 fc in order to achieve the recommended illuminance. The critical question here becomes, which location has such average standard illuminance (at solar noon on the two equinoxes)? According to CIE standard # CIE S 011/E: 2003, a standard overcast sky illuminance at solar noon on the two equinoxes of 1,230 fc coincides with locations at 51^{o} NL in the Northern Hemisphere (IES, 2003). In North America, locations at 51^{o}NL are about 100 miles north of the border between the US and Canada. In other words, using this rule-of-thumb for locations within the US results in oversizing of windows.

The One Tenth Rule

The one-tenth rule states that the minimum DF in a daylit space is approximately one tenth of glass ratio, which is defined as the area of the glazed window divided by the gross area of the exterior wall (Moore, 1993). For example if the minimum desired DF is 3%, the glass ratio should be ten-fold, i.e., 30%. In reference to Table 1, the ratio of Glass Ratio to the minimum DF in the tested model is in the order of 18:1 which is much higher than the 10:1 ratio suggested by the one tenth rule. Consequently, ignoring the effect of glass VT, following the one tenth rule results in downsizing of windows. After considering the glass VT, windows would be much smaller than what they should be.

The 15/30 Rule

The 15/30 rule states that illumination level due to daylight is sufficient for office tasks within the first 15 feet from the window, and 50% benefit of daylight happens within the next 15 feet, while areas deeper than 30 feet will receive no benefit of daylight (Moore, 1993). In reference to Table 1, the average DF of points within 15 feet (up to 5.10 m) from the window = 11.02%, while the average DF of points within the next 15 feet (from 5.90 m to 9.90 m) = 2.33%. The ratio between 2.33% DF to 11.02% DF is approximately 21% which is much lower than the 50% suggested by the 15/30 rule.

Conclusion

As evidenced by the experimental test results, all three rules-of-thumb are inaccurate. In light of the fact that the 2.5 rule-of-thumb was first established about a century ago, it is not surprising that it is now outdated. In fact, the recommended illuminance for visual tasks were subject to change several times over the past century, which consequently changed the definition of what constitutes a “sufficient illumination” and “effective penetration”. However, assuming the following conditions:

- Desirable illuminance in office spaces equals 30 fc.
- Windows are fitted with clear glass with visible transmittance (VT) of 0.88
- Window width equals half of the exterior perimeter length.
- The ceiling and walls inside the space are of high light reflectance.
- Overcast sky condition or equivalent
- No external obstruction of the sky

It has been found that the 2.5 rule provides an accurate prediction of illuminance at locations at 51^o NL in the Northern Hemisphere and 51^o SL in the Southern Hemisphere. Consequently, at all locations between latitudes 51^o north and south, illumination levels at locations as deep as 2.5 h into the space will be higher or much higher than what is desired. For the benefit of the design process, this rule-of-thumb needs to be adjusted per location.

As for the one tenth rule-of-thumb, it is far from being accurate. Applying the rule will result in much smaller windows than what is needed. Another source of inaccuracy is that the rule estimates the minimum DF and not the average DF which should be a better indication of the illumination levels in the space.

As for the 15/30 rule-of-thumb, it underestimates illumination levels within the first 15 feet from the window, while overestimating them within the next 15 feet.

The aforementioned conclusion affects student learning outcome in the design studio. Architecture and architectural engineering students are now advised not to rely on simplistic rules-of-thumb in their design. When such simple rules are used, their use is limited only to the very early design stages. For later design phases, students understand the need for a more accurate analysis that takes into account all variables that may affect the performance of daylighting systems. For that, students become more appreciative to the required detailed design that is based on experimental testing of their own models under the artificial sky dome.

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