Daylighting Rules of Thumb and a Comparison of Different Floor Depth under Overcast and Intermediate Sky Without Sun

M. F. M. A. Sadin, N. L. N. Ibrahim, K. Sopian, E. Salleh

***Abstract*—**Daylighting rules of thumb are simple and comprehensive principles, which can be readily applied in the design process to predict or achieve daylight conditions deemed appropriate for an interior. They have been expressed in a variety of modes in architectural and can be divided into categories based on the parameters which constitute them. One of the categories is floor depth. This paper presents the impact of different floor depth on daylighting performance of the simulated office room using 1 meter shading device under overcast sky and intermediate sky without sun. Several parameters such as shading device, ceiling height, and material reflectance have been appointed. Models then were simulated and analyzed using an application of IES_VE software called RADIANCE. Existing daylighting rules of thumb has been modified and thus create new formula for Kuala Lumpur sky based on the smallest academic office as a lecturer room in public university. All these successfully resulted equations can be considered as simple formulas that can ease everybody to estimate daylighting based on parameters mentioned above.

***Keywords*—** daylighting, floor depth, radiance, rules of thumb.

I. Introduction

There are many reasons for the renewed interest in daylighting, with the increasing cost of fossil fuels and the realization that sources of electricity have a finite life, being quoted as most cogent; but perhaps even more important are the less tangible aspects of daylighting which relate more to the human spirit and the need for a quality of life [1]. Daylight, by displacing electric light use, reduces carbon dioxide emission and, in turn, the greenhouse effect [2].

Daylighting became a minor architecture issue because of the availability of efficient electric light sources, cheap, abundant electricity and the perceived superiority of electric lighting [3]. Daylighting should be adopted to overcome the excessive use of electrical energy in office space .There are many benefits for using natural light, for examples reduction in electrical energy consumption and a better indoor quality as often been quoted in the literature.

The use of artificial lighting not only consumed energy but also produced waste heat inside the building that eventually contributed to the heating or cooling load [4]. The use of natural light has been seen as important in improving the environmental quality and energy efficiency of buildings [5].

II. Daylighting Rules of Thumb and Floor Depth

The Cambridge International Dictionary of English defines *Rules of thumb* as a practical and approximate way of doing or measuring something [6]. Or in other word, rule of thumb in daylighting is an attempt towards simplification of a complex reality. According to [7], rules of thumb have been regarded by some authors as a form of knowledge which has no theoretical reasoning and is therefore unreliable. This perception can be dispelled by adapting a typological approach in dealing with rules of thumb in daylighting. Daylighting rules of thumb can be scientifically examined if their typological limitations are determined and addressed [8]. One of these is floor depth.

A limiting depth of not more than 4 meters for unilateral sidelit room has been proposed by [9] and [10]. According to [9], suggests a limiting depth of 4 meters for office space with a normal ceiling height as a condition for achieving a 2% daylight factor at the back of the room. A slightly higher limiting depth of 4.5 meters for a ‘primarily daylight’ or a ‘fully daylit’ zone was proposed by [11] and [3] for non-residential buildings. According to [11], this distance allows the space to be fully daylit and especially suitable for clerical work. It was [12] and [13] who prescribe sufficient daylight penetration into room of about 4 to 6 meters from window could possibly be considering partially daylit area between the limiting dimensions. Reference [14] claims that a typical office building could provide full illumination to task areas between 3.5 to 4.5 meters from window and partial illumination to areas not more than 7.5 to 9 meters from window. In general, beyond 6 meters from a window, the area can be considered as ‘partially daylit’ which means the area could still be daylit but it may have to rely on artificial light for a considerable period

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during daytime.

III. EXTERNAL SHADING DEVICES AND BENEFITS

In office buildings, an appropriate selection of solar shading devices can control indoor illumination from daylight, solar heat gains, and glare while maintaining view out through windows, thus saving lighting and thermal energy while maintaining visual comfort [15]. In another study by [16], it was discovered that an effective passive design strategy to control solar heat gain in buildings is the application of external shading devices, which can reduce solar heat gain more effectively than interior devices. According to [17], 1 meter shading device is the most suitable choice that meets the criteria for daylighting inside the room.

IV. DAYLIGHT FACTOR

The use of the daylight factor has persisted to the present day. The daylight factor has an important characteristic which is a good indicator of the overall appearance of a room. This is because the brightness appearance of a place depends at least as much on the relative luminance of surfaces within the field of vision as on absolute values. By definition, the daylight factor is a measure of the contrast between inside and outside [18]. Daylight factor defined as the proportion of the unobstructed external daylight illuminance that reaches a point inside the room. That is, if the room is removed, the point of interest would receive all the available daylight. That point would be having the daylight factor of 100% [19].The standard also outlined illuminance levels recommendations for various applications and the recommended daylight factor (DF) for an effective daylight-lit office space is 1.5%. In Table I, daylight levels with the associated visual tasks are outlined in more detail by [20].

IESNA and CIBSE has recommended of 100 – 200 lux for minimum working space illuminance where visual tasks are only occasionally performed [21].

Table I: Amount of daylight levels for adequate visual performance

Visual Tasks	Illumination Levels (Lux)	Daylight Factor (%) (based on overcast sky which provides 5000 lux on horizontal plane)
Casual reading, ordinary factory bench work, etc.	75 – 100	1.5 – 2
Prolonged reading, school and office work, etc.	100 – 150	2 – 3
Sewing, typing and other difficult visual work.	150 – 250	3 – 5
Very fine work or in poor contrast	250 – 500	5 – 10

V. EXPERIMENTAL PROCEDURE

For the purpose of investigating the effects of different length of floor depth on daylighting and rules of thumb, this study use a series or simulations by an energy analysis program, IES_VE. A model designed based on the smallest academic office room (a lecturer room) in National University of Malaysia was simulated. The room size is approximately 3.5m wide and 2.6m high with a full width window facing north. The window glass transmittance is set at 0.9 (being a normal clear glazed window). This room use 1m horizontal shading device. The variable parameter in this experiment is floor depth, which ranged from 3m to 10m with gradual 1m interval. Interior room surfaces reflectance in the simulation has been designated as 0.3 for floor surface reflectance, 0.6 for wall surface reflectance and 0.8 for ceiling surface reflectance. This is based on [22], the reflection surface recommended for general systems are from 0.7 to 0.9 for ceiling finishes, from 0.4 to 0.7 for wall finishes and from 0.1 to 0.4 for floor finishes. Approximately, this is similar to reflectance criteria for best visual comfort in office interior proposed by [23]. The daylight illuminance was measured at the work plane 0.85m above the floor surface. Refer to Fig. 1 for the section diagram.

The original Littlefair's formula was used to calculate daylight factors which were then correlated to the simulation's daylight factors obtained under an overcast sky. Meanwhile, an intermediate sky without sun type is the one that suitable for Malaysia sky. The original Littlefair's daylight factor formula [24] is shown below:

$$DF_{avg} = \frac{\tau_w A_g \theta}{A_s\,(1-R^2)} \tag{1}$$

DF_{avg}	average daylight factor
A_g	window glazing area (m^2)
τ_w	transmission of window glazing
θ	sky angle measured at the center of the window in degrees
A_s	total area of the room surfaces ceiling, floor, walls and window (m^2)
R	the average reflectance. For fairly light colored rooms such as in the case studies, a value of 0.5 is normal

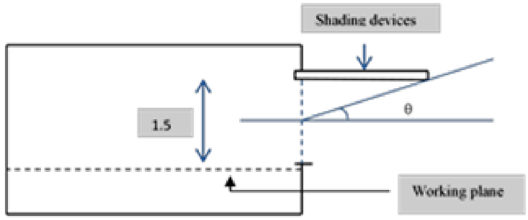

Fig. 1 showing the section diagram of the simulated room model

VI. RESULT AND DISCUSSION

Fig. 2(a) and 3(b) show that illuminance at the back of the rooms were generally lower than rear due to increase room depth. Maximum illuminance obtained under overcast sky was higher than the one which was under intermediate sky without sun. Furthermore, centreline illuminance of not less than 100 lux can be maintained under overcast sky at limiting depth 3 meter meanwhile 2.5 meter for intermediate sky without sun.

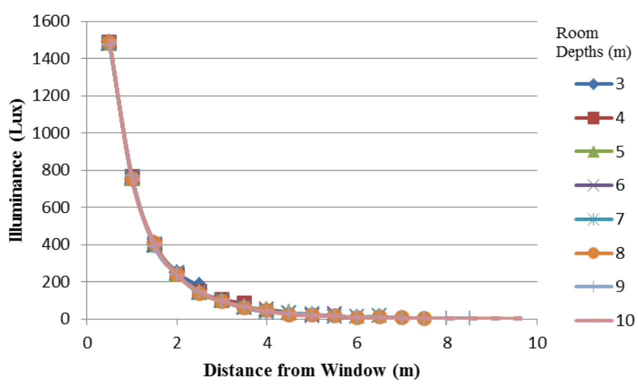

Fig. 2(a) showing centreline illuminance of floor depth under overcast sky

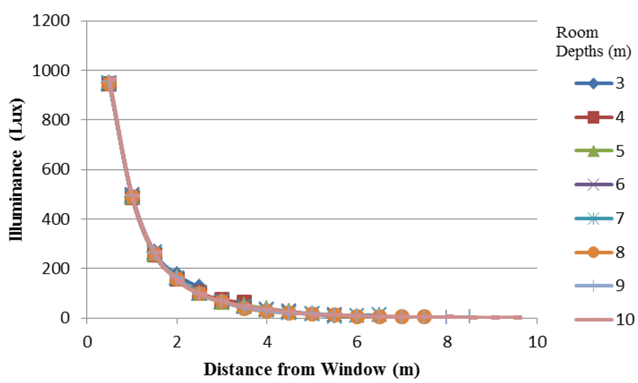

Fig. 2(b) showing centreline illuminance of floor depth under intermediate sky without sun

Fig. 3(a) and 3(b) show that average illuminance increased inside rooms with a larger percentage of window area to floor area. Average illuminance of about 380 lux was achieved inside a room with a window to floor area ratio of 20% under overcast sky and about 240 lux for same ratio under intermediate sky without sun. The linear correlation between average illuminance and the percentages of window area to floor area as shown below:

$$E_{avg} \approx 20\, A_w/A_f \quad \text{(overcast sky)} \tag{2}$$

E_{avg} average illuminance
A_w window area (m^2)
A_f floor area (m^2)

$$E_{avg} \approx 10 A_w/A_f \quad \text{(intermediate sky without sun)} \tag{3}$$

E_{avg} average illuminance
A_w window area (m^2)
A_f floor area (m^2)

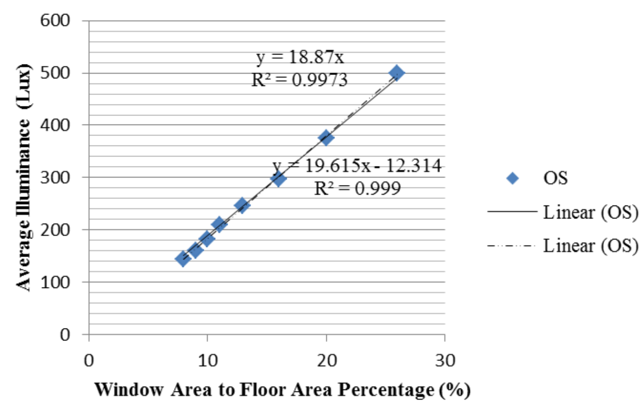

Fig. 3(a) showing average illuminance vs. window area to floor area under overcast sky

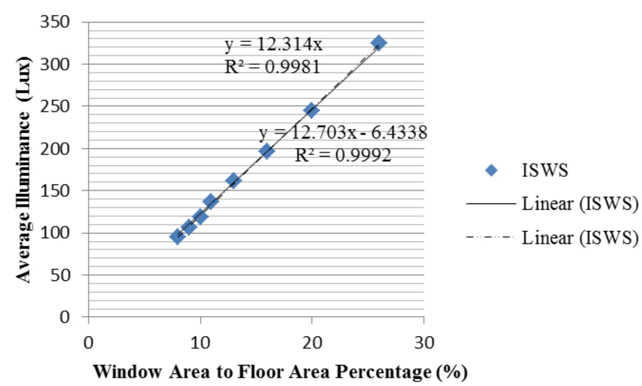

Fig. 3(b) showing average illuminance vs. window area to floor area under intermediate sky without sun

Analyses were carried out to determine further correlations between the simulation daylight factors and the formula daylight factors. However, the Littlefair's daylight factors formula is modified by substituting A_s with A_f as shown in Fig. 4(a) and 4(b). Therefore, the generated correlative equations are much easier to calculate. The objective is for increased usability of the daylighting rules of thumb.

The correlation can be represented by the following rules of thumb:

$$DF_{avg} = 10\ \ Ag/Af\ \ \%\qquad (R^2 = 0.999)\qquad (4)$$

$$DF_{avg} = 7\ \ Ag/Af\ \ \%\qquad (R^2 = 0.999)\qquad (5)$$

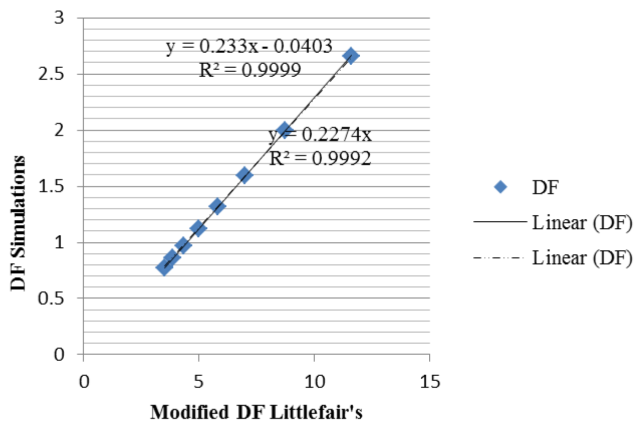

Fig. 4(a) showing simulation daylight factor vs. modified Littlefair daylight factor under overcast sky

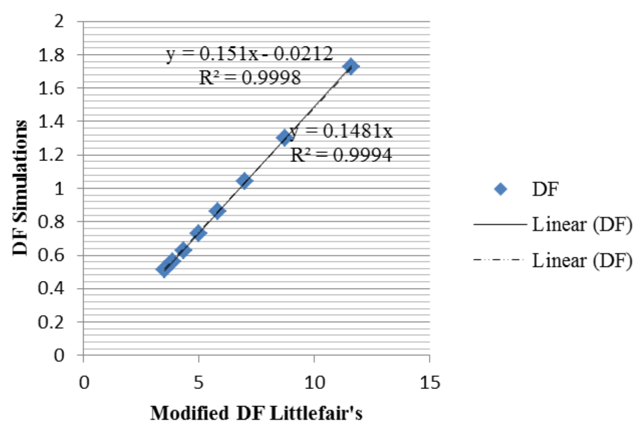

Fig. 4 (b) Simulation daylight factor vs. modified Littlefair daylight factor under intermediate sky without sun

I. CONCLUSION

The simplified equations or rules of thumb produced in this article are applicable for small size office rooms in public university of Malaysia with standard glazing transmittance, standard ceiling high, and 1m shading device under both an overcast sky and intermediate sky without sun. These equations can be considered as rules of thumb to estimate daylighting for a standard office room. These rules of thumb can aid architects in designing sufficiently daylit office space with shading device. The experiments show that small office room, 3.5 meter width with full width window and 1 meter horizontal external shading can provide sufficient interior illuminance for both under overcast sky and intermediate sky without sun.

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