DAYLIGHTING RULE OF THUMB AND TYPOLOGY

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ABSTRACT

Rule of thumb in daylighting has been responsible for generating typologies of building forms and elements. However, not all of these typologies perform well in daylighting. This article briefly reviews the concept of typology in architecture and proposes its application in daylighting study. Based upon the literature and recent researches in daylighting typology, the authors argue for the use of typological approach as means for analyzing and generating rule of thumb in daylighting. Simulations are conducted using Lumen Micro 8 and AGi32 softwares. The findings are suggestive that the typological approach adapted in the simulations can contribute towards development of a new rule of thumb in daylighting.

Keywords: Daylighting, Typology, Daylighting Performance

1. INTRODUCTION

Rule of thumb exists in most disciplines particularly those that involve the application of knowledge related to complex phenomena such as daylight, and also where absolute precision may not be required. Rule of thumb provides "a broadly accurate guide or principle, based upon experience or practice rather than theory" (Procter, 1995) and derive its significance from having been repeatedly used and found to be working. In daylighting, rule of thumb is usually expressed in terms of limiting room parameters and parametric ratios influential in illuminance performance such as room depth to window head height ratio, room depth to ceiling height ratio, window area to floor area ratio and window area to wall area ratio (Nik Ibrahim and Hayman, 2002). This rule of thumb in daylighting actually influences building forms and typologies. For example, when limiting building depth rule of thumb in daylighting had been responsible for generating distinct building typologies as demonstrated by Steven Holl in *The Alphabetical City* (Holl, 1980).

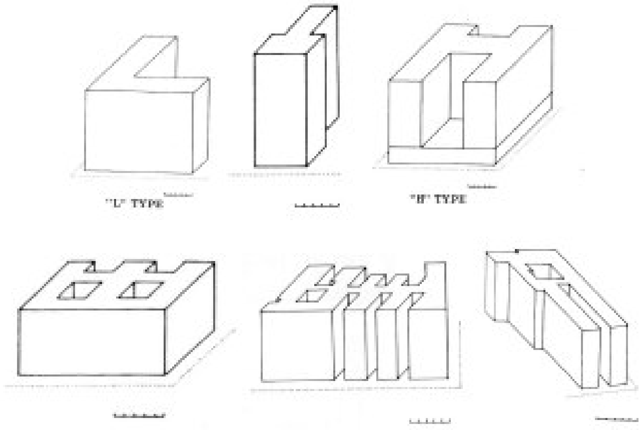


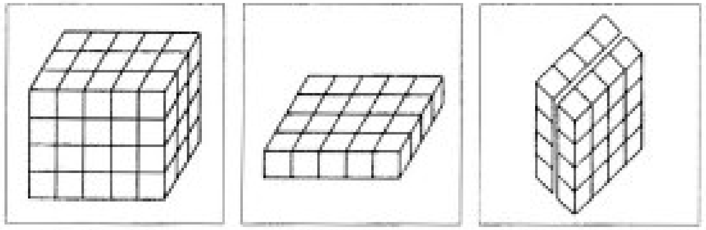
Figure 1: Several general building forms in alphabetical configurations generated by limiting floor depth rules of thumb for daylighting (Source: Holl, 1980).

In architecture, typology has been established as a fundamental aspect of the discipline.

The simulation studies carried out using Lumen Micro 8 and AGi-32 softwares to analyse daylighting rule of thumb has adapted the typological approach. A brief review of architectural typological concepts is provided prior to discussing the simulation methods and results. These fundamental concepts are used to inform the typological approach applied in the simulations.

2. DAYLIGHTING TYPOLOGY

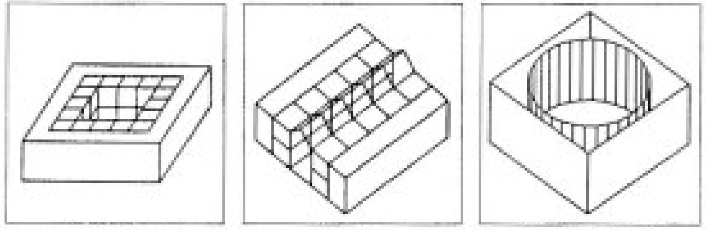
The idea of daylit building typologies has been put forward numerous times in architectural discourses. The most recent and substantial by Baker et al. (1993) concerns itself with the complete range of possibilities from urban planning, building form, room configuration to window type (see Figure 2).



F1 - Deep Plans

F2 - One Level Factory/Warehouse

F3 - Unilateral/Bilateral Slabs



F4 - Courtyard

F5 - Atria

F6 - Double Shell Buildings

Figure 2: Daylighting typologies at 'building level' (Source: Baker et al., 1993).

Baker, Fanchiotti and Steemers (1993) propose a method of gathering a typological grammar from daylit buildings to aid designers composing these elements and forms. This design approach calls for the adaptive use of architectural precedents in daylighting practice and involves ideas expressed in visual terms such as drawings of building plans, elevations, sections, etc. The approach derives both from the typological culture of architectural composition found within the treatises of architectural theories, and from "shape grammar" developed by March and Stiny (1985) which involves two major aspects: i) the repertoire of types described by means of the "morphological box", and ii) the rules for selecting, placing and transforming these types. Daylit building types are organised in a hierarchical way by dividing the parameters into three levels: i) the room, ii) the building and iii) the site (surrounding built environment).

The proposed "morphological box" offers the possibility of decomposing the existing day-lit buildings into elements which become the "variations" within the defined "parameters". The "morphological box" serves as a means for generating new combinations of existing concepts by allowing combination of "parameters" and "variations" which can be derived from the day-lit building typology. Thus, a great number of design solutions can be generated (Baker et al., 1993). This typological approach in daylighting bridges the gap between building science researches and traditional design methods in architecture. However, this tool does not provide simple calculation methods or rule of thumb for daylighting.

3. DAYLIGHTING RULE OF THUMB AS 'ARCHETYPE'

Discussions in architectural typology often lead to the idea of 'archetype'. Archetype as put forward by De Quincy (1977), Vidler (1977), Moneo (1978), Johnson (1994), Brill (1994), Argan (1996) and Scheekloth and Franck (1994) generally refers to the primal and universal guiding principle of types. This principle is not *a priori* or a set of fixed ideas. According to Argan (1996), archetype is the outcome of a process of reducing complex formal variants to a common root form. It is the interior structure of form or a principle which contains the possibility of infinite variations.

Daylighting rule of thumb in experienced practitioners' hands could be seen to operate on such level. An example of an archetypal rule of thumb was proposed by Vitruvius (See Figure 3) to determine the amount of potential light is a follow:

"On the side from which the light should be obtained, let a line be stretched from the top of the wall that seems to obstruct the light to the point at which it ought to be introduced, and if a considerable space of open sky can be seen when one looks up above the line, there will be no obstruction to the light in that situation." (Rowland, 1999: p. 262).

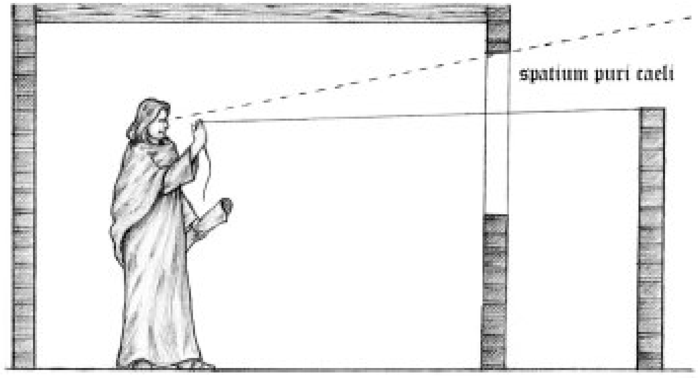


Figure 3: A sketch showing the application of Vitruvius's rule of thumb to assess the amount of open sky, spatium puri caeli, which could illuminate the interior space. (Source: Nik Lukman et al., 2008).

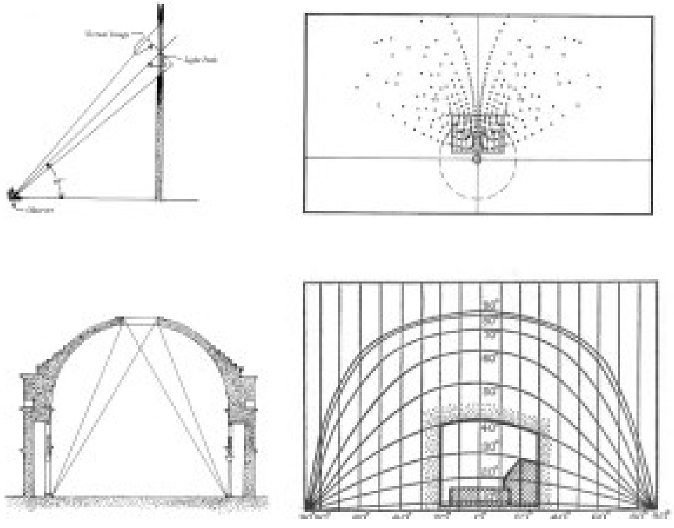


Figure 4: Visible sky rule (top & bottom left), Waldram Diagram (bottom right) and Pilkington Dot Diagram (top right). (Sources: Mark (1990); IES (1972) and Hopkinson, Petherbridge and Longmore (1966).

In simple terms, the amount of daylight receivable at a point inside a building according to Vitruvius was equivalent to the area of sky visible from the spot (Rowland, 1999). Similar rule of thumb seemed to have been implemented in the design of the Pantheon (Mark, 1990) and its effectiveness has been proven by recent field measurements by the European Commission (Fontoynont, 1999). This ancient rule is also at the core of modern and complex daylighting tools such as the Waldram Diagram (Hopkinson, Petherbridge and Longmore, 1966) and the Pilkington Dot Diagram (Hopkinson, Petherbridge and Longmore, 1966). In actuality, these scientific daylighting tools are in fact 'rules of thumb' of more sophisticated nature (Nik Lukman, 2002). This daylighting rule of thumb therefore approaches the status of an 'archetype'.

Could daylighting rule of thumb in general then be associated with the notion of archetype—the universal and primal principle? Archetype eludes absolute form and so do most rules of thumb in daylighting. Assumptions and contextual condition behind daylighting rule of thumb are seldom fully clarified. Is there a higher reason behind this negligence beyond the presumed lost information? An important characteristic of daylighting rule of thumb is that it is not an absolute principle but rather a working base or guide upon which further test could be conducted to suit a specific project requirement. Therefore, rule of thumb in daylighting transcends any particular built form. The forms that can be generated by a daylighting rule of thumb are multivalent as demonstrated by Steven Holl (Figure 1) to suit specific requirement and sites regulation (Holl, 1980).

4. TYPOLOGICAL CONCEPTS BEHIND DAYLIGHTING SIMULATIONS

Functional typology in architecture borrowed its concept from the classification system of 18th century Natural History. A significant change was initiated in the natural science in 1796 when Georges Cuvier (Steadman, 1979), a zoologist, introduced his classification system consisted of two functional anatomical rules; the 'correlation of parts' and the 'subordination of characters'. The former involves the interdependence between various functions of organs or body systems and the latter implies the hierarchical function of organs or bodily systems (Steadman, 1979). The simulations carried out in daylighting had addressed the 'correlation of parts' or the interdependence between functional daylighting elements such as window head height, glazing area, interior surface reflectance, floor area etc. To demonstrate the idea of 'subordination of characters' or the hierarchical function of these elements, these simulation series were put together starting from the most fundamental elements such as window size and its ratio to floor area to less fundamental aspects such as varying ceiling heights. Foucault has highlighted that Cuvier's (Foucault, 1970) systematic and functional approach had caused the visible, formal, external properties of organism to cease being the main criteria for classification of species. Instead, the 'invisible' functional properties became the important criteria for categorization in which case classification was based upon similarities of functioning internal organs or systems (Foucault, 1970). This turn of emphasis towards function in relatedness of parts in classification later influenced typological categorization in architecture. In the simulations conducted, typological room series were formed based on this functional aspect in order to test existing rule of thumb in daylighting.

18th century classification techniques in natural science and typological method in architecture both involved organizational process to form a continuous series with detailed gradations which imply the possibility for transformations and combinations. Typological classification in this sense could actually generate design principles for new forms through this transformational procedure (Steadman, 1979). This generative role of typological approach has been reinforced more recently by writers such as Moneo (1978), Crowe (1984), Vidler (1996) and Schneekloth and Franck (1994). Such typological organization was adapted in the simulation series carried out to study daylighting rule of thumb. Gradual transformation was introduced in each simulation series so that detailed gradations of daylighting performances could be obtained. For an example in TS-2, the transformation consisted of gradual room depth increments which subsequently influenced daylighting performances. The detailed gradations in all simulation series (TS1 to TS13c) had allowed modification and formation of new rules of thumb in daylighting based on specific types of rooms.

Typology is not merely classification of types. This argument was put forward by Wojtowicz and Fawcett (1986) who draw a distinction between typology and classification. According to them, 'typology' is a system of grouping types to aid demonstration or investigation by establishing a limited relationship among phenomena. Typology then involves examination of a particular aspect of objects in question while classification is seen as a method related to the problem of order. An example of a typological analysis is the examination of column bases by Ruskin (1907) in *The Stone of Venice* drawn to the same scale irrespective of the bases actual dimension (Figure 5). This typological concept was adapted in the simulations carried out. In each of the simulation series only one parameter was varied at a time in order to aid comparison in daylighting performances. See Figure 6.

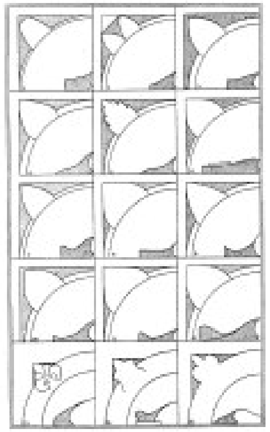


Figure 5: Typological analysis of column bases by John Ruskin in 'The Stone of Venice'. (Ruskin, 1907).

5. DAYLIGHTING SIMULATION STUDIES

The simulation studies to analyse daylighting rule of thumb were carried out using Lumen Micro 8 and AGi-32 lighting softwares. Lumen Micro 8 was used to simulate rooms in an open site (typologies at room level) while AGi-32 was used to simulate rooms with external obstructions (typologies at external level). This arrangement was effective because Lumen Micro 8 could only simulate rooms without external obstructions.

5.1 Simulation Typological Series without External Obstruction (Lumen Micro 8)

Being a standardised commercial product, Lumen Micro 8 software allowed the simulations to be easily repeated to provide typological detailed gradations (or grammars). The software was claimed to have verification tolerance of ± 8% (Jongeward, 1993) and its external illuminance prediction appeared close to field measurements made by Hayman (1996) in Sydney.

The typological series simulated using Lumen Micro 8 involved 143 parametric variances at room level. As this was an exploratory study, a number of assumptions were made to ensure comparability of the data set and testing conditions:

a. A single location was used (35°S 150°E), close to Sydney but away from the known localized asymmetric daylight climate (Hayman, 1996).
b. Standard CIE Overcast and Clear Skies were used as these represent two extreme sky conditions as well as having wide acceptance and applications.
c. External ground reflectance 0.2 and internal reflectance 0.8 for ceiling, 0.5 for walls and 0.2 for floor in line with standard practice (Kaufmann, 1972).
d. Standard glazing transmittance of 0.9 for clear glass.
e. All windows were South-facing to assume minimal daylight condition
f. Testing occurred at noon, mid winter. The advantage was that the available diffuse illuminances from overcast and clear skies were almost similar allowing direct comparisons between the sky conditions.

Simulations were carried out with varying room and window parameters to form distinct typological series. In all typological series, the ceiling height was fixed at 2.4 metres and sill height at 0.8 metres with the exceptions of TS7 and TS9.

TS1: Square rooms of varying floor areas (7.29-324m2) and window widths (full wall widths),
TS2: Narrow rectangular rooms of fixed width (2.7m) and increasing depth (up to 18m),
TS3: Square rooms of varying size and window width to fix the window to floor area ratio at 10%,
TS4: Fixed square room (12.96m2) with varying window size (window to floor areas from 5 to 40%),
TS5: As for TS4 but with a larger room (100m2),
TS6: Fixed square room (30.25m2) with fixed window but varying ceiling heights (2.4 to 8 m),
TS7: Fixed square room (30.25m2) and window but varying window head heights (2.4 to 10 m),
TS8: Fixed square room (30.25m2) and ceiling height (3.6 m) and sill but varying window size,
TS9: Fixed square room (30.25m2), window size and ceiling height but varying sill (0.8 to 2 m),
TS10: Single standard window (1.5m by 0.9m) with varying square room sizes (7.29 -100 m2),

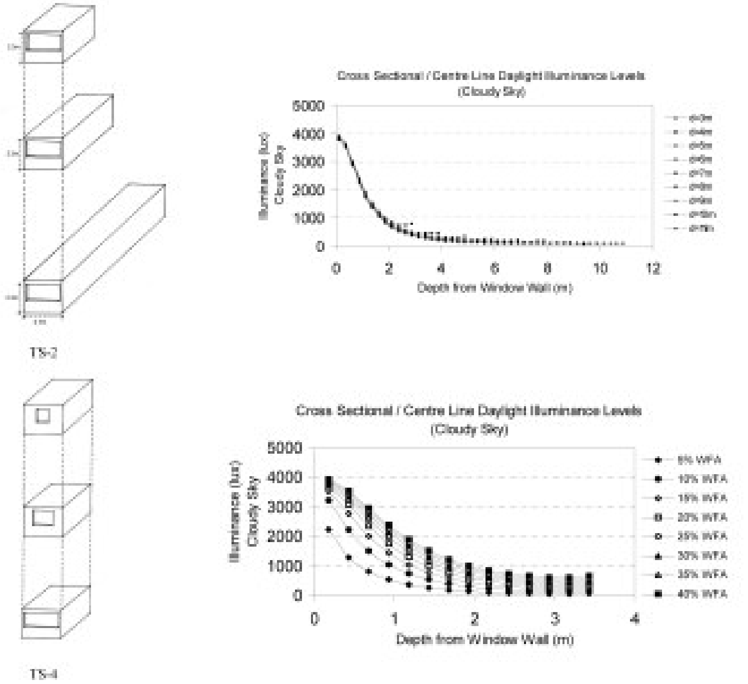


Figure 6: Typological variations /series and daylighting performances (d - room depth, WFA - window to floor area ratio).

Typological method was engaged in the simulations by introducing “variations” within the restrictedly defined room parameters. In other words, only one or two variables were manipulated or changed at a time in each simulation series. These typological variations are shown above. For the economy of this article only two typological series are represented to illustrate parametric gradations of rooms and the individual daylighting performances under overcast sky (Figure 6).

Once a range of simulations was created, these were studied in terms of maximum, minimum and average illuminances, daylight factors in relation to room depth, floor area, window area, window head height under both overcast and clear skies.

5.2 Simulation Typological Series with External Obstructions (AGi-32)

As Lumen Micro 8 could not simulate external obstructions, AGi-32 was utilised for this effect. AGi-32 has been successfully tested against the international standard for accuracy, CIE 171:2006 - Test Cases to Assess the Accuracy of Lighting Computer Programs (DDCI, 2007 June). Eight typological room series with external obstructions were simulated using this lighting software. The rooms ranged from medium to large sizes: 4.5m x 4.5m, 5m x 5m, and 10m x 10m (see Table 1). Each typological series consisted of 17 variations established by different gradations of obstruction angles. Altogether there were 136 parametric variations within these series to test the effects of external obstructions on indoor daylighting performances.

Table 1: Schedule of the Typological Series Showing Room and External Obstruction Parameters Simulated using AGi-32

Typological Series (TS)	Floor Area (m^2)	Ceiling Height (m)	A_g / A_f (%)	Obstruction Surface Reflectance
11a	4.5m x 4.5 m	2.4m	27%	25%
11b	4.5m x 4.5 m	2.4m	27%	0%
12a	5.0m x 5.0m	3.0m	20%	25%
12b	5.0m x 5.0m	3.0m	20%	0%
12c	5.0m x 5.0m	3.0m	20%	25% (ST.11)
13a	10.0m x 10.0m	2.7m	15%	25%
13b	10.0m x 10.0m	2.7m	15%	0%
13c	10.0m x 10.0m	3.0m	15%	25%

The external obstructions were located 2.5m from the window wall in order to give an average influence from ground surface reflectance. The area of ground plane that contributes to internally reflected light has been reported to be approximately from a window head height away from window wall up to a distance of 5 times the window head height (Transgrassoulis, 2001). The typological series also assumed a typical external ground plane reflectance of 0.20 which was automatically generated in AGi-32. Two values of surface reflectances were used for external obstructions (0.25 and 0.00). Obstruction surface reflectance 0.25 represented a typical urban scenario which coincided with surface reflectance of medium coloured bricks and concrete surface (Hopkinson et al., 1966) whereas 0.00 percent represents a worst case scenario. The length of the obstructing external wall was 3 times longer than the width of the room wall and window. This length was chosen after a pilot study to obtain the effect of nearly 'infinite' obstruction length. An obstruction much longer than this dimension took a considerably longer calculation time with no significant effect on the illuminance results. Finally, the external obstruction angles (measured from window sill) were varied from 5° to 80° in 5° increments. Note that in all typological series, AGi-32 surface type 31 was used for external obstructions except in the 12c series.

6. MODIFIED AND NEW RULE OF THUMB IN DAYLIGHTING

To investigate the possibility of new rule of thumb, measurements from all typological series at room level (those simulated using Lumen Micro 8) were analysed as a combined data set using plotting and regression analysis. Strong linear association existed between average illuminance and window to floor area ratios as shown in Figure 7, except for those typological series involving varying window sill height (TS7 & TS9).

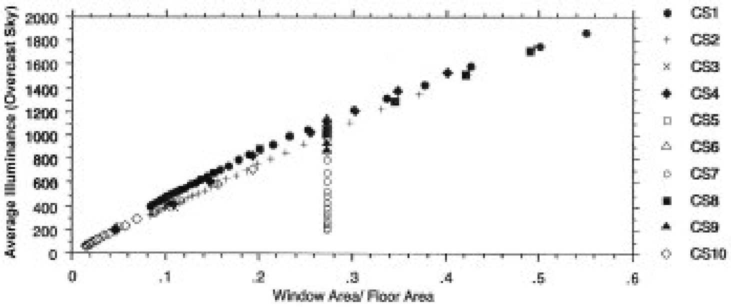


Figure 7: Window to floor area vs. average room illuminance under an overcast sky (TS1 to TS10).

To explore the possibility of using the data set as a test source for existing daylighting design tools, a useful design formula by Littlefair (1996) was selected which equates average daylight factor with a few easily measurable variables of the typological series. The formula:

$$DF_{Avg} = \frac{\tau_w A_g \theta}{A_s (1 - R^2)} \% \qquad \text{(Eq. 1)}$$

DF_{Avg}	average daylight factor
π_w	transmission of glass (0.9 in the studies)
A_g	area of window glazing (m2)
θ	sky angle in degrees measured at centre of window (90° for no obstruction)
A_s	total surface area of room (m2)
R	average reflectance of interior (0.5 is standard reflectances)

This formula is applicable on small to medium sized room types with a maximum depth of 6m in its stated form.

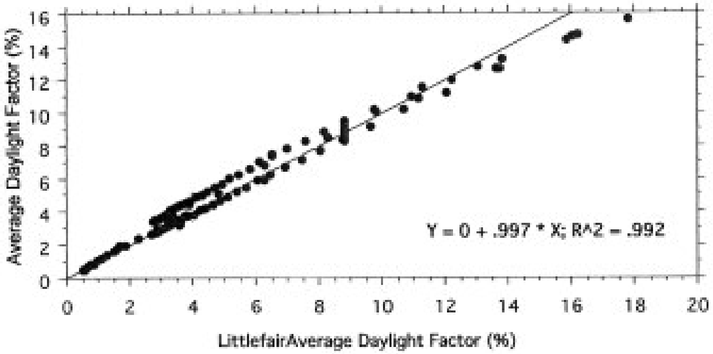


Figure 8: Average Daylight Factor (TS1 to TS10) vs. Daylight Factor from modified Littlefair's formula.

It was immediately evident from the analysis that the formula was applicable to a much wider range of room types but an improvement in performance could be made by substituting room surface area (AS) by a much simpler variable of floor area (Af) for normal sill heights (Figure 8). Thus, a transformation was introduced to existing correlation of room parameters which resulted in the following relationship:

$$DF_{avg} = 0.3 \left(\frac{\tau_w A_g \theta}{A_f (1 - R^2)} \right) \% \qquad \text{(Eq. 2)}$$

A_f	area of floor (m2)

The data set produced by AGi-32 simulations of the typological room series subjected to external obstructions had also generated an almost similar correlation as shown in the equation below:

$$DF_{avg} = 0.28 \left(\frac{\tau_w A_g \theta}{A_f (1 - R^2)} \right) \% \qquad \text{(Eq. 3)}$$

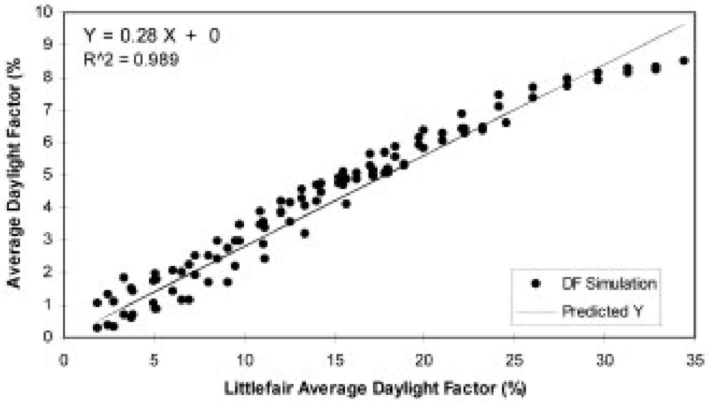


Figure 9: Average Daylight Factor of rooms with external obstructions (TS11a to TS13c) vs. Daylight Factor calculated using the modified Littlefair's formula.

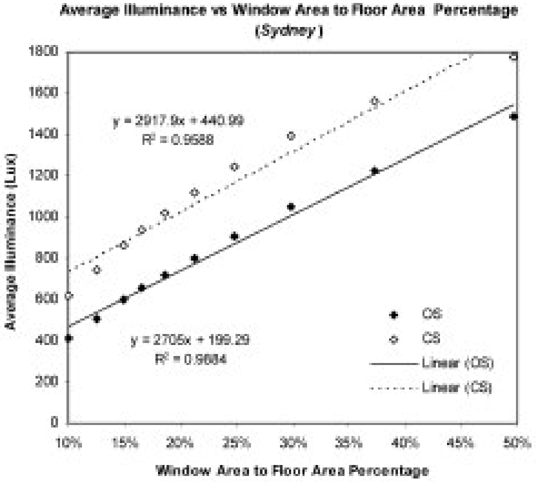
The slightly higher constant in equation 2 might be due to Lumen Micro 8 tendency of giving higher illuminance readings compared to other simulation softwares in the market (Ubbelohde, 1998). However, the difference was insignificant as the constant figure of E3 could be rounded up to 0.3.

Based on Equation 3, a simple rule of thumb could be proposed for rooms with standard interior surface average reflectance (R = 0.5) which are equipped with clear glazed (tw = 0.9) windows and subjected to no external obstruction.

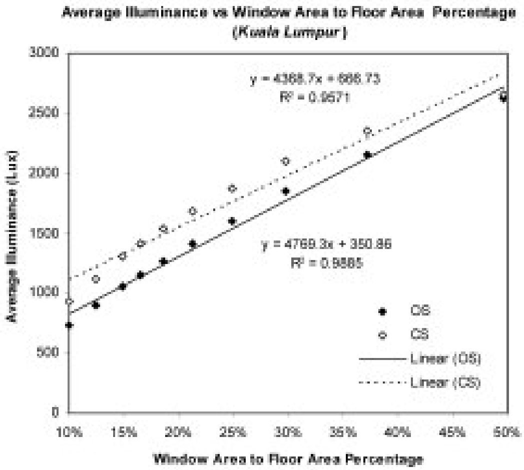
From Equation 3,

$$DF_{avg} = 30\ (A_g/A_f)\ \% \qquad \text{(Eq. 4)}$$

To test the compatibility of this rule of thumb and modified Littlefair's Daylight Factor formula, a limited number of simulations were carried out for Kuala Lumpur geographical location (2.6°N, -101.6°E) using TS1 parametric variables. From Figure 10 (a) and (b), the correlations between average illuminance (under overcast and clear skies) and window area to floor area percentage in Sydney and Kuala Lumpur could be represented by Equations 5 to 8.



(a)



(b)

Figure 10: Average Illuminance under overcast sky (OS) and clear sky (CS) vs. Window Area to Floor Area Percentage for Sydney (a) and Kuala Lumpur (b).

$$E_{avg} = 2705\ A_g/A_f + 199\ \text{(overcast sky, Sydney)} \qquad \text{(Eq. 5)}$$

$$E_{avg} = 4769\ A_g/A_f + 351\ \text{(overcast sky, Kuala Lumpur)} \qquad \text{(Eq.6)}$$

$$E_{avg} = 2918\ A_g/A_f + 441\ \text{(clear sky, Sydney)} \qquad \text{(Eq.7)}$$

$$E_{avg} = 4369\ A_g/A_f + 667\ \text{(clear sky, Kuala Lumpur)} \qquad \text{(Eq.8)}$$

E_{avg} average illuminance (lux)

From Figure 10, if the average illuminance over 1000 lux under overcast sky is considered too bright, then window with glazing ratio to floor area above 15% in Kuala Lumpur may need some form of shading as opposed to the one in Sydney.

From Equations 5 to 8, average illuminance under overcast sky is 1.76 times higher under overcast sky and 1.5 times higher under clear sky inside rooms in Kuala Lumpur than those with similar parameters in Sydney. However, as shown in Figure 11 (a) and (b), Daylight Factor equation for both geographical locations issimilar:

$$DF_{avg} = 24\ A_g/A_f + 1.8 \text{ (Sydney and Kuala Lumpur)} \qquad \text{(Eq. 9)}$$

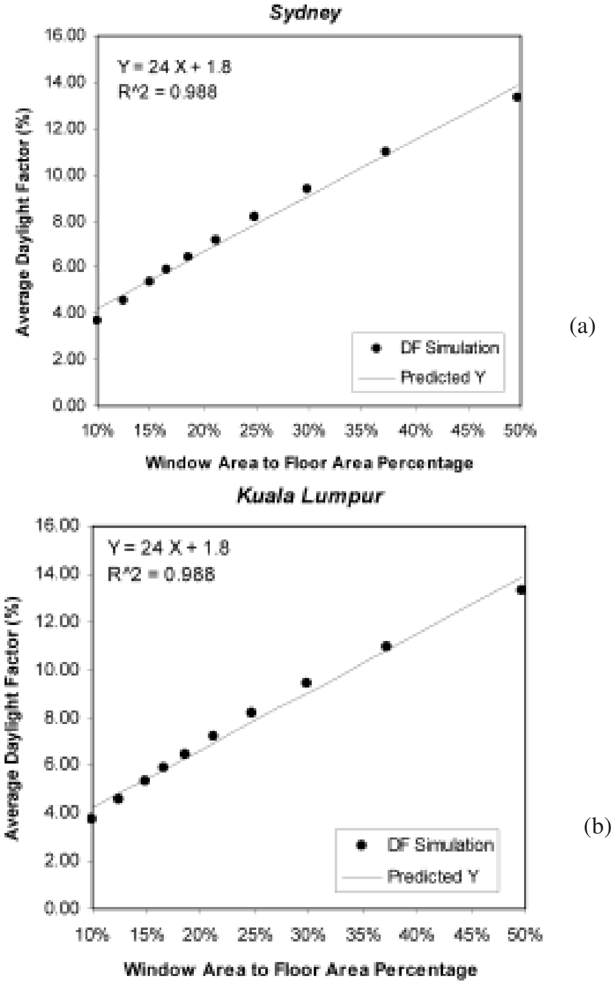


Figure 11: Average Daylight Factor vs. Window Area to Floor Area Percentage for (a) Sydney and (b) Kuala Lumpur.

This analysis indicates that the modified Littlefair's formula (Equation 3) and the rule of thumb (Equation 4) are applicable in Kuala Lumpur, Malaysia. Nevertheless, one should remember that a similar room in Kuala Lumpur could yield higher average illuminance. For example, a room with standard interior surface reflectance of 0.5, window to floor area ratio 25%, window glazing transmittance 0.9 and with 20° clear sky angle could provide Daylight Factor 1.68% in both Sydney and Kuala Lumpur. However, the illuminances on external horizontal planes under overcast sky are 11,156 lux in Sydney and 19,662 lux in Kuala Lumpur. Therefore, the average illuminance inside the rooms in the two geographical locations are 187 lux and 330 lux respectively. So, while the Daylight Factor might be adequate to provide 'daylit appearance' in Kuala Lumpur, it could be less effective in Sydney.

7. CONCLUSIONS

Concepts of architectural typology are adapted in the simulations conducted by analysing and generating daylighting rule of thumb for Sydney which have implications on other geographical locations as well. The simulations carried out allow comparisons of illuminance performances between various typological room series which serve as a means for generating new daylighting rule of thumb with simple formulas. The simulations also help to identify room types where the rule of thumb is not applicable (such as TS7 and TS9). A limited number of simulations were also carried out to generate simplified a Daylight Factor equation for each typology or rule of thumb for application in Kuala Lumpur, Malaysia. However, this rule of thumb does not address the issues of direct sunlight and heat gain which require different typological interventions which are not included within the current scope of simulation work. As the proposed Daylight Factor equations are found to be valid for both Sydney and Kuala Lumpur, we can assume that the rule of thumb could also be applicable in other geographical locations. The assumed universal compatibility of this rule of thumb suggests an 'archetypal presence' but this notion is too extensive to be elaborated in this article.

The current work contributes towards development of simple daylighting formulas or rule of thumb which could serve as aids during schematic architectural design stage. Daylighting calculations have largely been the domain of illuminating engineers. Therefore, by formulating simple Daylighting Factor rule of thumb, this 'computational' knowledge could become more accessible to the general practicing architects. In addition, by assigning typological categories—the traditional mode of architectural classification system—to these daylighting rule of thumb, important parametric assumptions could be strategically clarified. However, further simulations are needed to generate this rule of thumb which could counter the problems of direct sunlight and glare especially in a tropical region. These issues will be addressed in future simulation works which shall take into consideration the climate of Malaysia.

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