Summary The paper describes a simple design tool for architects to estimate daylight performance of high-rise residential buildings in high-density urban sites during the early design stage. The tool is based on a modified version of the original split flux formulae. The tool resolves the formulae to a set of tables relating vertical obstruction angles with horizontal obstruction angles. Given the geometrical properties and the required daylight performances, architect could work out, at the early design and planning stage, the design configuration of the building block itself, the spacing between building blocks, and the sizes of windows required. Working examples demonstrate how the tool might be used in design.

A simplified Daylighting design tool for high-density urban residential buildings

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List of symbols

t	Overall transmittance of the glazing, taking into account diffuse glass transmittance and dirt factor
A_w	Glazing area
A	Total internal surface area: floor, walls, ceiling, windows
A_{fw}	Area of the floor and wall surfaces below the centre-height of the windows, excluding the window wall surfaces
A_{cw}	Area of the ceiling and wall surfaces above the centre-height of the windows, excluding the window wall surfaces
A_f	Total floor area
ρ_{fw}	Mean reflectance of the floor and wall surfaces below the centre height of the windows, excluding the window
ρ_{cw}	Mean reflectance of the ceiling and wall surfaces above the centre height of the windows, excluding the window
ρ	Mean internal reflectance: floor, walls, ceiling, windows
ρ_b	Mean reflectance of obstructing buildings
ρ_g	Mean ground reflectance (The area of effective ground extends from the building some 3 to 3.5 times the height of the ceiling above ground
ρ_c	Mean reflectance of ceiling
ρ_w	Mean reflectance of all internal walls and windows
ρ_f	Mean reflectance of floor
H	Ceiling height
W	Width of the floor area measured parallel to the window
L	Depth of the floor area measured from the window plane
W_H	Height of window head from floor
W_S	Height of window sill from floor
W_w	Width of window
$DF_{average}$	The ratio of average interior illuminance (a spatial average over the working plane) to external horizontal illuminance under standard overcast sky conditions

1 Introduction

Urban Hong Kong has perhaps the highest building density of any cities in the world. It has a population to land density of 175,000 inhabitants per square kilometer, and a development density of

2500-3000 inhabitants per hectare for residential sites. Under these circumstances, providing adequate daylight in dwellings, especially at the lower floors, is extremely difficult.

The building regulations of Hong Kong stipulate a minimum distance between building blocks based on a minimum prescribed plane of 71.5°. The minimum prescribed plane is defined as the rectangular horizontal space, in front of the window, uncovered and unobstructed, and extend from the face of the window so that its length is at least 1/3 the height of the building measured from the sill of the window concerned. The width of the space equals to the width of the window. The regulation also requires that habitable spaces be provided with window area not less than 10% of the floor area. Buildings built to these regulations were deemed to be satisfactory for lighting and ventilation. The regulations have been in force since 1959.[1] For example, for a building measured 100 meters high from the sill of the window concern, the window must face into an uncovered space open to the sky of dimension not less than 33.3 meters multiply by the width of the window or 2.3m whichever is more. That is to say, the building opposite should be 33.3 meters away.

As buildings get taller and as the limits are reached, there has been little study to provide quantitative data to guide the daylight performance of a design proposal. Moreover, existing methods, including computer simulation, are neither easy for the designer to use, nor validated for the unique urban conditions of Hong Kong.

This paper introduces a simple design method based on tabulated tables relating $DF_{average}$ with vertical obstruction (θ_L), horizontal obstructions ($\phi_L + \phi_R$) and window glazing area (A_w). This geometry-based method aims to assist designers during their early design stage. Given the $DF_{average}$ requirement, the tables provide the designer freedom to manipulate various design parameters to satisfy the required performance. Examples in the paper illustrate how the method might be used in design. The key advantage of the method is in its speed of use.

Mega-cities and high density living is rapidly becoming a norm in Asian cities. With slight modifications of the parameters, the method could be used for similar high-density sites in other locations.

2 Predicting $DF_{average}$ using CIBSE Average Daylight Factor Method

Natural lighting of an interior space, lit by side windows, is influenced not only by the illumination indoor, but also by how it relates to the illumination outdoor. The ratio, expressed in percentage, between the illuminance at a point indoors and the horizontal illuminance under an unobstructed hemisphere of sky outside is known as the daylight factor.

Point by point calculation of daylight factor is time consuming and could only be used once the window size, shape and position are known. Design for average daylight factor is a simpler basis of site planning, window and space design during the early stages of the design process. [2] Average daylight factor is defined as the ratio of average interior illuminance (a spatial average over the working plane) to external horizontal illuminance under standard overcast sky conditions. A simplified version of the formula, [3] as in CIBSE Applications Manual – Window Design, may be written as follow:

$$DF_{average} = \frac{tA_w\theta}{A(1-\rho^2)} \quad (\%) \qquad (1)$$

where θ is the angle subtended, in the vertical plane normal to the window, by sky visible from the centre of the window, as illustrated in Figure 1. The equation may be rewritten to estimate the area of glazing required for a desirable level of average daylight factor:

$$A_w = \frac{DF_{average} A(1-\rho^2)}{t\theta} \quad (\text{m}^2) \qquad (2)$$

The equation takes into account obstructions which form a horizontal band. It was claimed that the equation gives a standard error of ±10% of the measured values under certain controlled conditions. [4] Based on the equations and the following values typical of spaces in high rise high density housing:

t=0.76, H=2.5, L=2H, W=1.2H, ρ_c =0.8, ρ_w =0.6, ρ_f =0.2, Table 1 gives the $DF_{average}$ achievable when the window area is known. Table 2 gives the window area required when the $DF_{average}$ is specified.

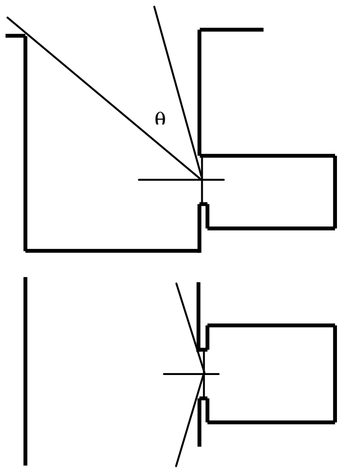


Figure 1 Definition of θ: the angle subtended, in the vertical plane normal to the window, by sky visible from the centre of the window. The CIBSE – Average Daylight Factor Method assumes a continuous obstruction on plan

Table 1 DF $_{average}$ achievable given various window area (m^2).

θ	A_w=10% A_f	A_w =20% A_f	A_w =30% A_f	A_w =40% A_f
20°	0.5	0.9	1.4	1.9
30°	0.7	1.4	2.1	2.8
40°	0.9	1.9	2.8	3.8
50°	1.2	2.4	3.5	4.7
60°	1.4	2.8	4.3	5.7
70°	1.7	3.3	5.0	6.6
80°	1.9	3.8	5.7	7.6

Table 2 Percentage of window area (A_w) to the floor area (A_f) required for the $DF_{average}$

θ	$DF_{average}$ = 1%	$DF_{average}$ = 1.5%	$DF_{average}$ = 2%
20°	21.2%	31.8%	42.3%
30°	14.1%	21.2%	28.2%
40°	10.6%	15.9%	21.2%
50°	8.5%	12.7%	16.9%
60°	7.1%	10.6%	14.1%
70°	6.0%	9.1%	12.1%
80°	5.3%	7.9%	10.6%

The CIBSE – Average Daylight Factor method has been used to design terrace type or slab-like building blocks where external obstructions could be estimated based on a horizontal band. They have also been used to estimate high rise block type office designs in Hong Kong.(5) As an illustration, typical of high density urban residential development in Hong Kong, given A_w=10% of A_f and θ=20°, $DF_{average}$ is estimated to be 0.5% using Table 1. To yield a satisfactory daylight performance, referring to the Table 2, a 21% A_w/A_f ratio is needed for bedroom (1% $DF_{average}$), and a 32% A_w/A_f ratio is needed for living spaces (1.5% $DF_{average}$).

3 Predicting $DF_{average}$ using the Modified Split Flux Formulae

To better estimate $DF_{average}$ under more complicated shapes of external obstructions, for example, windows located at the corner of a L-shape reveal, a slightly more complicated method, based on the original form of the split flux formulae may be needed.[6] [7] The equations can be written as follow:

$$IRC_{mean} = t\frac{A_w}{A}\frac{C\rho_{fw} + D\rho_{cw}\rho_g}{1-\rho} \ (\%) \tag{3}$$

$$DF_{average} = tA_w\frac{C}{A_{fw}} + IRC_{mean} \ (\%) \tag{4}$$

The coefficients C and D define the relative illuminances of the window by flux incident from above and from below the horizontal. To cope with large external obstructions commonly found in high-density urban environment, the following formulae proposed by Tregenza [8] were adopted:

$$C = \frac{9}{7\pi}f(1+\frac{\rho_b}{\pi(1-\rho_o)}g)\times 100\% \tag{5}$$

$$D = \frac{E_g}{2E_h}\times 100\% \tag{6}$$

where

$$f = \frac{1}{3}(\sin\phi_L + \sin\phi_R)\times(\frac{\theta_H - \theta_L}{2} + \frac{\sin 2\theta_H - \sin 2\theta_L}{4} - \frac{2\cos^3\theta_H - 2\cos^3\theta_L}{3}) \tag{7}$$

and

$$g = \frac{\pi}{2} - (\sin\phi_L + \sin\phi_R)\times(\frac{\theta_H - \theta_L}{2} + \frac{\sin 2\theta_H - \sin 2\theta_L}{4}) \tag{8}$$

Since ρ_g is low and is generally assumed to be 0.2, it is not worthwhile to determine E_g/E_h to high degree of accuracy. A value of 0.2 is a reasonable assumption based on the highly obstructed external environment of Hong Kong. Thus D could be conservatively approximated to 10%.

Implicit in the formulae is that the luminance of the obstructions becomes less as more of the sky is obscured. Based on the equations and the following values: t=0.76, H=2.5, L=2.4H, W=1.2H, ρ_c =0.8, ρ_w =0.6, ρ_f =0.2, ρ_b=0.2, ρ_g =0.2, θ_H =90°, $\phi_L+\phi_R$=180°, Table 3 gives $DF_{average}$ achievable with various window areas. Table 4 shows the difference between the two methods of calculation.

Table 3 $DF_{average}$ achievable for various window areas (m^2).

θ	A_w =10% A_f	A_w =20% A_f	A_w =30% A_f	A_w =40% A_f
20°	0.1	0.2	0.3	0.3
30°	0.2	0.4	0.6	0.9
40°	0.4	0.9	1.3	1.7
50°	0.7	1.5	2.2	2.9
60°	1.1	2.2	3.3	4.4
70°	1.5	2.9	4.4	5.8
80°	1.8	3.6	5.4	7.1

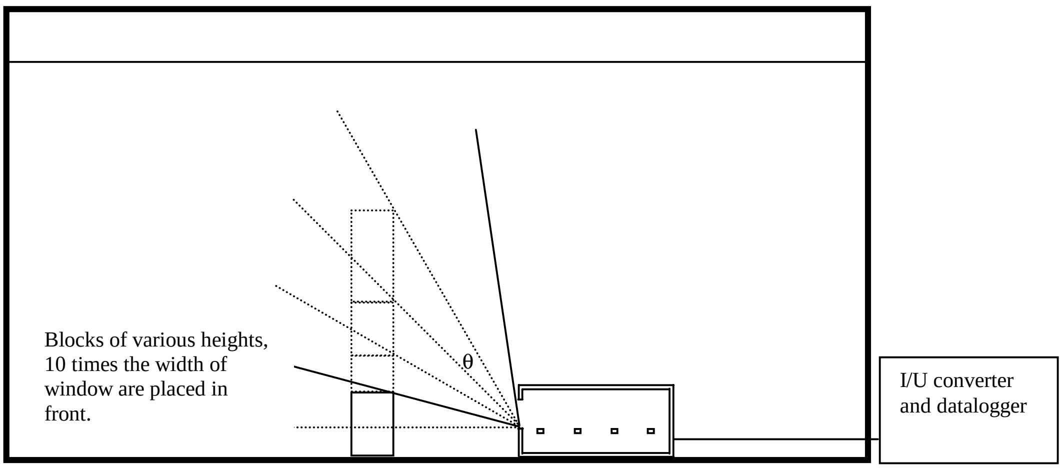
Table 4 Difference between the Average DF method in CIBSE Applications Manual and the Modified Split flux formulae.

θ	A_w =10% A_f	A_w =20% A_f	A_w =30% A_f	A_w =40% A_f
20°	400.0%	350.0%	366.7%	533.3%
30°	250.0%	250.0%	250.0%	211.1%
40°	125.0%	111.1%	115.4%	123.5%
50°	71.4%	60.0%	59.1%	62.1%
60°	27.3%	27.3%	30.3%	29.5%
70°	13.3%	13.8%	13.6%	13.8%
80°	5.6%	5.6%	5.6%	7.0%

Referring to Table 4, it is apparent that beyond an obstruction angle of 30° from the horizontal, when θ<60°, results obtained by using Average DF method in CIBSE Applications Manual and the Modified Split flux formulae deviate by more than 30%. Using the same example illustrated before, based on the Modified Split flux formulae, given A_w=10% A_f and θ=20°, a 21% window to floor ratio would give 0.2% $DF_{average}$, and when A_w=32% A_f, it would give 0.3% $DF_{average}$.

4 Validation studies

To establish which of these two methods of calculation is more suitable for use in a highly obstructed urban environment, a test model, typical of a living room in Hong Kong, with the following characteristics, is studied using a 1.5m x 1.5m x 0.75m high mirror box artificial (overcast) sky: W_H=2.0, W_S =1.0, W_w =2.0, H=2.5, L=2.4H, W=1.2H, ρ_c =0.8, ρ_w =0.6, ρ_f =0.2, ρ_b=0.2, ρ_g =0.2, θ_H =90°, $\phi_L+\phi_{R=}$180. A 4 x 8 grid is drawn, each represents an area equal to 0.75m x 0.75m. 11 mini-photocells (7mm deep, from PRC Krochmann GmbH) were fixed inside the wooden model (1:20) and supported by small wooden posts to represent the height of 1m above floor, as shown in Figure 2 & 3. The photocells were connected to an I/U converter and a datalogger for scanning the 11 channels automatically. Level spirits were used to ensure that all photocells were facing horizontally. Various blocks (ρ_b=0.2) representing external obstruction for θ = 20° to 80° were placed in front of the window opening. Illuminance levels of the unobstructed artificial sky were measured before and after the experiment. Values obtained with photocells 1-8 were averaged to obtain DF $_{average.}$ Photocells 9-11 were used to cross check the other photocells. Calculated Results and measured results under various obstruction angles are presented in Table 5. Relative errors between measured results and calculated results are presented in Table 6.



Section of the model inside the artificial sky

Figure 2 The experimental set up into the Artificial Sky.

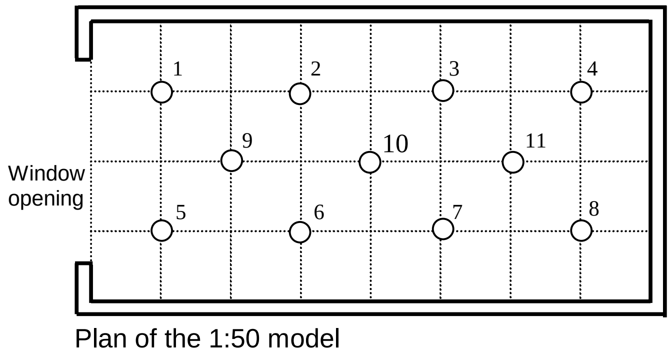


Figure 3 Positions of Photocells in the test model.

Table 5 DF $_{average}$ of Calculated and Measured results of the test model under overcast sky conditions.

θ	CIBSE DF $_{average}$ Method	Modified Split flux Method	Measured results
20°	0.65%	0.11%	0.09%.
30°	0.98%	0.28%	0.31%
40°	1.31%	0.56%	0.62%
50°	1.63%	0.95%	1.01%
60°	1.96%	1.41%	1.53%
70°	2.29%	1.89%	2.1%
80°	2.61%	2.31%	2.4%

Table 6 Relative errors between Measured results and the two prediction methods.

θ	CIBSE DF $_{average}$ Method	Modified Split flux Method
20°	+622.22%	+22.22%
30°	+216.13%	-9.67%
40°	+111.29%	-9.68%
50°	+61.39%	-5.94%
60°	+28.1%	-7.84%
70°	+9.05%	-1.00%
80°	+8.75%	-3.75%

For low obstruction angles (θ < 70°) the CIBSE DF $_{average}$ Method gives reasonable results as compared to the measured results. However, errors accelerate for higher obstruction angles. Results for the modified split flux method agree closely with the measured result. Higher errors are noted for very high obstruction angles. The small numbers involved may have attenuated the errors.

5 A simplified design tool

$DF_{average}$ of buildings located in high-density urban sites could be estimated based on the Tregenza's modified split flux formulae. However, the method is difficult for the design process to be anything but a checking procedure. For this reason, it is necessary to simplify the tool in such a way that would allow designers a quicker way to assess daylight performance of interior spaces during the initial site planning and building block design stage. To achieve that, a set of tables can be developed relating $DF_{average}$ with vertical obstruction (θ_L) and horizontal obstructions ($\phi_L + \phi_R$).

Assuming close proximity of building blocks, as illustrated in Figure 4, the horizontal obstructions ($\phi_L + \phi_R$) could be used to establish $DF_{average}$ achievable when designing the building blocks. The vertical obstruction (θ_L) could then be introduced to guide the design of spacing of blocks. For example, if the window is situated in a reveal and that the ($\phi_L + \phi_R$) angle achievable is only 50°, then based on Table 7 below, given a window size of 30% and a desirable $DF_{average}$ of 1%, the window must not be obstructed more than 40° from the horizontal. This basic information could then be used to design the site layout. The method is particularly useful designing estate style residential buildings typical in Hong Kong and in other Asian cities.

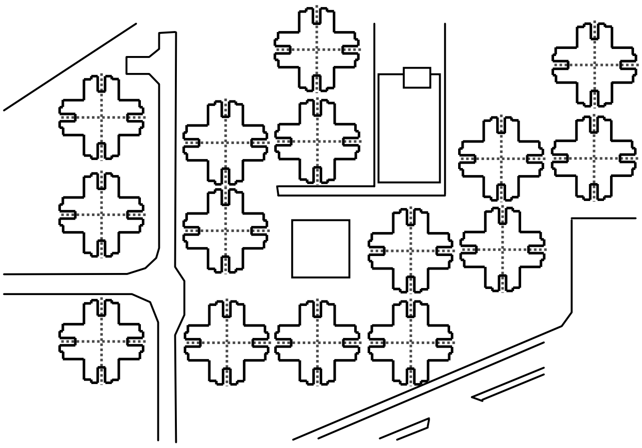


Figure 4 An example of high-rise, high-density residential site plan in Hong Kong. Note that building blocks are spaced based on a prescribed plane of 71.5° for windows of habitable spaces. For example, a distance of 30m will be required if the opposite building is 90m above the horizontal measured 1m from the floor level of the space where the window is located.

Typical of high rise, high density residential plans in Hong Kong, as illustrated in Figure 5, the following assumptions could be made: t=0.76, H=2.5, L=2.4H, W =1.2H, ρ_c =0.8, ρ_w =0.6, ρ_f =0.2, ρ_b=0.2, ρ_g =0.2, θ_H =90°, ϕ_L =ϕ_R , Table 7 give the minimum ($\phi_L + \phi_R$) required to achieve various $DF_{average}$ under different vertical obstruction (θ_L) and window area (A_w).

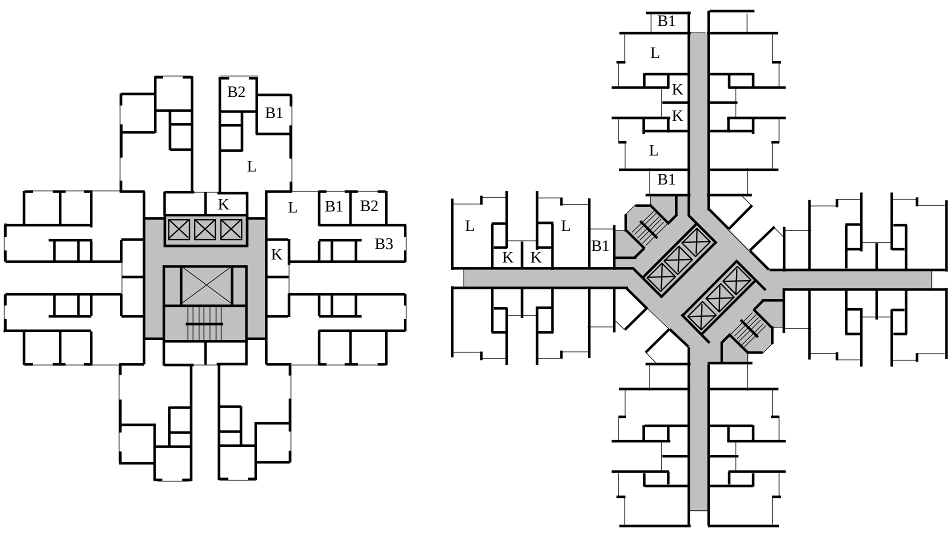


Figure 5 Examples of high-rise, high-density residential plans in Hong Kong: Public Housing on the right and Private Housing on the left. Note the deep re-entrant for the Kitchen and bathroom. Also note the extent of external obstructions of the living and bedrooms by adjacent units.

Table 7 Minimum ($\phi_L + \phi_R$) for spaces achieving 1%, 1.5% and 2% $DF_{average}$

	A_w =10% A_f			A_w =20% A_f			A_w =30% A_f			A_w =40% A_f		
θ_L	1%	1.5%	2%	1%	1.5%	2%	1%	1.5%	2%	1%	1.5%	2%
0°	**54**	**92**	**154**	**30**	**42**	**58**	**18**	**26**	**36**	**12**	**20**	**26**
10°	**64**	**112**	-	**32**	**50**	**68**	**20**	**32**	**42**	**14**	**22**	**30**
20°	**82**	-	-	**38**	**62**	**88**	**24**	**38**	**54**	**18**	**28**	**38**
30°	**126**	-	-	**54**	**88**	**140**	**34**	**54**	**74**	**24**	**36**	**54**
40°	-	-	-	**84**	-	-	**50**	**90**	**146**	**34**	**54**	**80**
50°	-	-	-	-	-	-	**96**	-	-	**70**	**110**	-
60°	-	-	-	-	-	-	-	-	-	-	-	-
70°	-	-	-	-	-	-	-	-	-	-	-	-

Table 7 can be used when external obstructions are roughly symmetrical along the axis normal to the window, as shown in Figure 6. For asymmetrical external obstructions, Table 8 should be used. Values used in Table 8 are same as those used for Table 7, except that ϕ_L (or ϕ_R) is fixed at 0°.

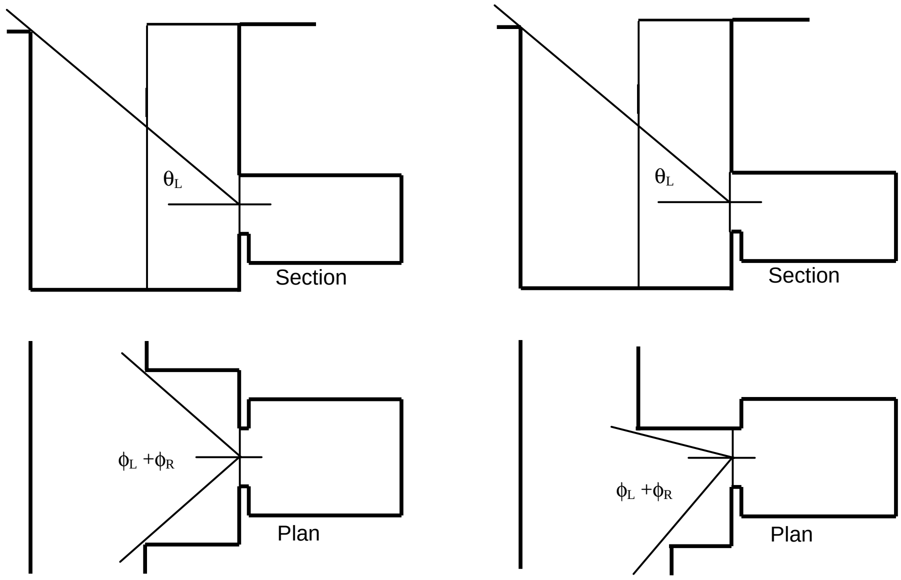


Figure 6 Use Table 7 when horizontal obstructions are symmetrical along the axis normal to the window. Use Table 8 when it is asymmetrical.

Table 8 Minimum ($\phi_L + \phi_R$) for spaces achieving 1%, 1.5% and 2% $DF_{average}$

	A_w =10% A_f			A_w =20% A_f			A_w =30% A_f			A_w =40% A_f		
θ_L	1%	1.5%	2%	1%	1.5%	2%	1%	1.5%	2%	1%	1.5%	2%
0°	**65**	-	-	**27**	**45**	**75**	**17**	**27**	**38**	**12**	**19**	**26**
10°	-	-	-	**32**	**55**	-	**20**	**32**	**46**	**14**	**22**	**31**
20°	-	-	-	**41**	-	-	**25**	**41**	**63**	**17**	**28**	**39**
30°	-	-	-	**62**	-	-	**34**	**62**	-	**23**	**38**	**58**
40°	-	-	-	-	-	-	**57**	-	-	**36**	**69**	-
50°	-	-	-	-	-	-	-	-	-	-	-	-
60°	-	-	-	-	-	-	-	-	-	-	-	-
70°	-	-	-	-	-	-	-	-	-	-	-	-

7 Some observations

The following observation is based on the recommended minimum $DF_{average}$ in BS8206 Part 2 – at least 1% in bedrooms, 1.5% in living rooms and 2% in kitchens. It should be noted that there has been little study to suggest alternative minimum standards acceptable to the local inhabitants. If lower standards are acceptable, Table 5 and 6 could be recomputed to suit.

Based on the Tables developed using the modified split flux formulae, it could be demonstrated that achieving a minimum $DF_{average}$ of 1% when external obstructions exceed 60° is almost impossible. It indicates clearly that current building regulations provisions in Hong Kong allowing external obstruction of up to 71.5° will not produce satisfactorily day lit interiors. This finding should be taken serious by law makers and enforcers.

Kitchens of residential units in Hong Kong are typically situated in a deep reveal – also known locally as re-entrant. For private housing, an ($\phi_L + \phi_R$) angle of 10° to 15° is not uncommon. Given that window area seldom exceeds 10 to 15% of floor area, a minimum $DF_{average}$ of 2%, as recommended in BS8206 Part 2, could never be achieved. To drastically improve $DF_{average}$ of kitchens, radical changes to the building regulations and building design are needed. Since the kitchen requires high $DF_{average}$ than the living and bedrooms, one could suggest that it be given a more prominent aspect on the external wall. However, this is a design issue and has to be carefully balanced against other considerations.

Given the plan forms commonly used in Hong Kong, as illustrated in Figure 5, an ($\phi_L + \phi_R$) angle of around 90° is achievable for most habitable rooms (living and bedrooms). If the window area (A_w) for these spaces is designed to be around 30% of floor area, then external obstructions of 40° to 50° from the horizontal will be acceptable. This will yield a $DF_{average}$ of 1% to 1.5%. The information could be used to calculate building heights and site development density.

8 Working example I

The typical floor plan of a high rise housing estate has been drawn up as Figure 7. It is anticipated that up to 20 of these block would be built on a square-ish rectangular site. Initial values of $DF_{average}$ and window sizes for each of the main spaces of Unit A are decided. There is no specific daylight performance requirement for the bathroom except that a window is provided. Minimum block spacing is desired, thus referring to Table 7 and 8, values of θ_L and $\phi_L + \phi_R$ can be determined, as in Table 9.

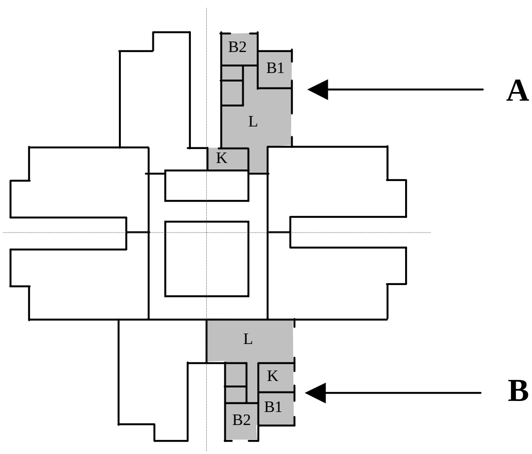


Figure 7 Typical high rise private housing block plan in Hong Kong.

Table 9 Design parameters of the building

	$DF_{average}$	A_w/A_f	θ_L	$\phi_L+\phi_R$
Living	1.5%	20%	30°	62°
Bedroom 1	1%	20%	40°	84°
Bedroom 2	1%	20%	40°	84°
Kitchen	1%	20%	40°	84°

It becomes apparent that to achieve a maximum obstruction angle θ_L of 40°, the living room window has to be increased to 30%. Moreover, the kitchen needs to be brought out of the recess so that $\phi_L+\phi_R$ is not less than 84°. If that could be achieved by redesigning the block plan, as in Unit B, then the spacing between the blocks could easily be determined geometrically. For example, if the building is 15 storey high, then assuming a floor to floor height of 2.7m, the distance between the block should be at least 47m, as in Figure 8. If window of bedroom 2 could be re-orientated to face the same direction as the window of the living, then the distance between the blocks on the Y-axis could be reduced, as in Figure 9. Exactly how close the blocks could be brought together will depend on $\phi_L+\phi_R$ = 84° required for Bedroom 2.

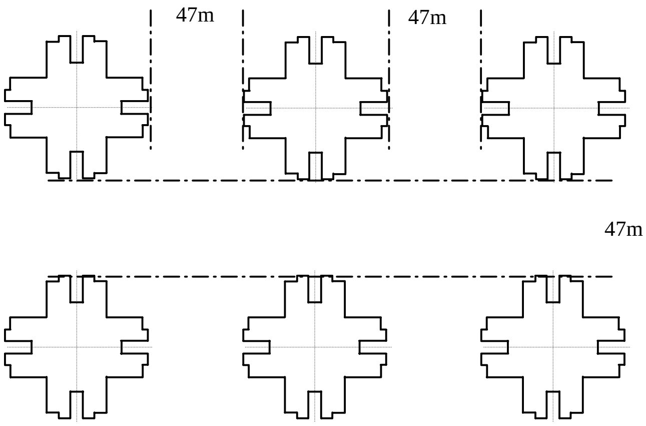


Figure 8 Site layout and block spacing based on an external obstruction of 40° on both axes.

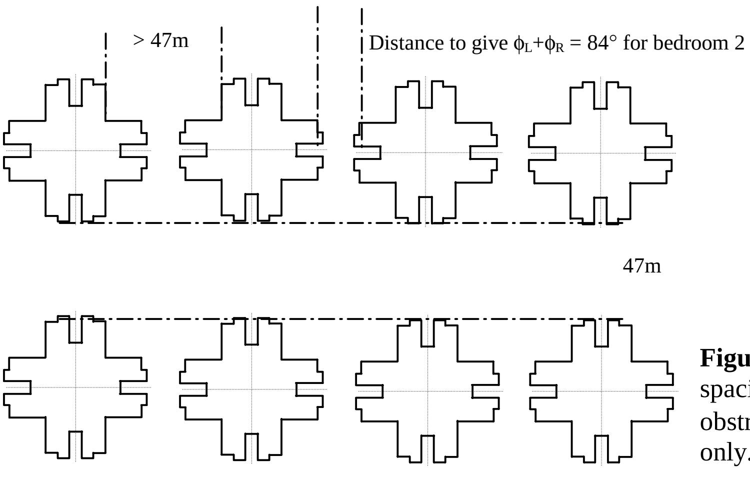


Figure 9 Site layout and block spacing based on an external obstruction of 40° on the X axis only.

9 Working example II

A housing estate based on building blocks using Unit B plan in Figure 7 will be built on a site recently reclaimed from the sea. A small hill sustains a continuous obstruction angle (θ_L) of 20° on the other side of the waterfront. Block B and C are 15 storey high. To take advantage of the see front, block A will be 50 storey high. The architect has positioned the block as in Figure 10. One of the critical units of the arrangement is located at Block C. Take the living space of the unit as an example, to achieve $DF_{average}$ of 1.5%, given $\theta_L = 20°$ and $A_w = 30\% A_f$, $\phi_L + \phi_R$ must be equal to or greater than 41°. Since Block A is tall, it can be assumed that it forms a continuous vertical obstruction to the right of the window. Therefore $\phi_L + \phi_R$ will have to be counted as shown in Figure 10. If the angle is less than 41°, Block B should be moved back to increase the angle.

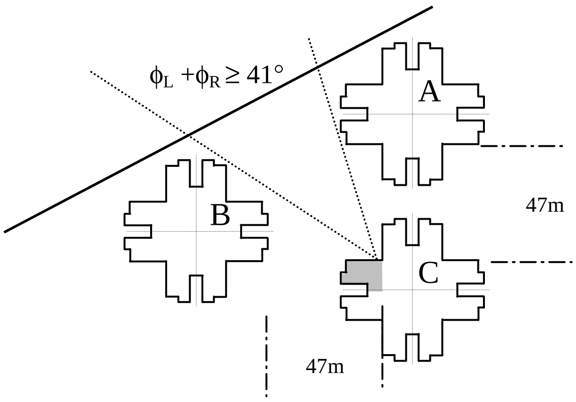


Figure 10 Site layout and block spacing for working example II.

The perpendicular distance from the window of the living room in Block C to the opposite façade on Block C is 47m. Given that Block A is 50 storeys high and a floor-to-floor height of 2.7m, the angle of obstruction is 70.7°. This working example illustrate that it is possible to achieve satisfactory daylight if an open gap is available on one side. However, in this case, it must be ascertain that no building should be placed in front of the gap in such a manner that $\theta_L > 20°$. Otherwise, the gap will have to be widened accordingly. For example, if the hills opposite the waterfront sustains a continuous obstruction angle of 30°, then refer to Table 8, $\phi_L + \phi_R$ must be equal to or greater than 62°.

10 Conclusions

A daylighting design tool based on the four critical variables – $DF_{average}$, vertical obstruction (θ_L), horizontal obstructions ($\phi_L + \phi_R$) and window glazing area (A_w) – has been introduced. The variables were chosen as they could be easily manipulated geometrically during the early design process. The tool has an advantage in that it conveniently links building plan, façade design and site planning in one inter related consideration. Trade offs and options could easily be examined without referring to complicated calculations.

Notwithstanding some of the advantages of the tool, it should be noted that, like all simplified design tools, assumptions and defaults are built into the tables – most of them are explained in the text. The tool should not be used out of context. For more accurate prediction and checking, readers are advised to refer to the fundamentals established in Equations 5 – 8.

The method aims to assist designers designing better day lit interiors. In addition to daylighting, designers are encouraged to consider solar heat gain, thermal, ventilation and acoustics and visual requirements of window design and site planning. [(9)]

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Discussion

TM Chung (Department of Building Services Engineering, Hong Kong Polytechnic University, Hong Kong)

This is a very interesting paper which addresses the current difficulties in designing for daylighting in high-density high-rise residential blocks in Hong Kong. However, there are three points that I would like to discuss with the author.

Firstly, the author should discuss the validity of the CIBSE average daylight factor formula for applications in Hong Kong. Apart from the very limited amount of data used in the original derivation of this average daylight factor formula [1], little work has been done to establish its validity, even in the UK. I also question the validity of this formula for use in the Hong Kong Building Environmental Assessment Method (HK-BEAM)[2]. The author did some measurements in a mirror box artificial sky which showed that the values calculated using CIBSE $DF_{average}$ formula are consistently larger than the measured values and the errors increase (at a fast rate) as the obstruction gets larger. As the experiment was in an artificial (overcast) sky with no specific reference to any location, would the author suggest that the CIBSE $DF_{average}$ formula be used only for small obstructions (i.e. large θ)?

Secondly, the author uses a value of 0.6 for the mean reflectance of all internal walls and windows. Taking into account of the inclusion of windows and furniture (such as a wardrobe) commonly used in Hong Kong, would a lower mean wall reflectance be more appropriate for the "worst" case scenario usually used in the early stages of design?

Thirdly, the author has not defined ρ_o which appears in equation (5) and the value of ρ_o used in the calculations leading to Table 3 is not given. According to Tregenza[3], this is the mean external reflectance and the value can be taken as $\rho_o = m_r \frac{\rho_b + \rho_g}{2}$. Did the author use this expression for ρ_o?

I tried to use this expression when $\rho_o = 0.1$, but the results for $DF_{average}$ I obtained were slightly different from those shown in Table 3.

References:

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Glenn Sweitzer (Department for Building Services Engineering, Hong Kong Polytechnic University, Hong Kong)

The proposal is timely, especially in Hong Kong where more than 90% of the population reportedly live in high-rise housing. In addition, the lighting and ventilation section of the HK Building Regulations is now under review amidst growing support for sustainable practice, including daylighting. Accordingly a simplified daylighting design tool could benefit both design and performance assessments. The proposed tool however appears a not-so-simple method, especially for assessing worst-case exposures. Questions and a suggestion follow.

Is the Daylight Factor method appropriate for assessing overshaded window exposures at the base of residential blocks with almost no access to sky (note that the referenced public Housing Authority examples are not subject to the Hong Kong Building Regulations albeit to even less stringent sky access requirements)?

Neither of the two window sections shown (Figures 1 and 2) includes a shelf, a standard for public Housing Authority units and many private estates, for shading and distributing incoming sunlight and for supporting through-the-wall air conditioners. Given that these shelves further limit available diffuse skylight compared to the window openings shown, should they not be included as part of early design assessment?

For the validation study in the mirror box, were blocks of corresponding height used above as well as opposing the test room? If not, this would greatly increase the vertical and lateral acceptance angles to the sky for the block exposures.

Finally, it is suggested that a revolutionary new tool is needed to adequately assess daylighting for window exposures dominated by high-rise buildings.

Author's response to T M Chung

Firstly, I would like to thank Dr Chung for bringing out some of the more interesting questions the paper has fails to answer. It is obvious that much work needs to be done in the area of daylighting in high-density cities.

The CIBSE average daylight factor formula is basically a revised version of Lynes formula. (1) Crisp and Littlefair's paper only attempted to bring it in line with the more accurate Longmore's formula. (2) The limited experimental data in their paper, apparently collected without any reference to external obstructions, were there only to support the revisions. In Longmore's formula, the luminance of external obstruction is assumed to be constant. However, Tregenza's modified method (3), upon which this paper is based, has built in an allowance for the decrease of luminance of external obstruction as more of the sky is obscured. My limited experimental data seems to support Tregenza's formulation. Moreover, the effect has also been experimentally noted by Lee who has attempted a mathematical function to describe his observation. (4) I would certainly recommend one to be cautious when using the CIBSE formula for high obstructions. However, I am not in a position to validate or to refute the validity of the CIBSE average daylight factor formula in general. To do that, it will require tests to be conducted using model rooms of various dimensions, surface reflectances and external obstructions.

Dr Chung has raised one very important point here. There is a need to verify the accuracy of the formulae under real sky conditions and in real buildings for Hong Kong. On that note, Cannon-Brookes' landmark findings on the use of models for daylight studies could be extended. (5) Moreover, it is necessary to study the characteristics of Hong Kong's sky conditions. A General Class IDMP Station has recently been constructed at the Chinese University of Hong Kong. It will certainly provide the much needed data in this respect.

The use of $\rho_w = 0.6$ is based on an as-built condition commonly found in newly constructed residential buildings. As a performance-base approach to building regulations has recently been hotly debated between the legislators and the design professions, there might be needs for on site daylight verification of un-decorated and un-occupied flats before a Temporary Occupation Permit could be issued. The paper was written in tandem with another study involving changes to Building Regulations. It is on this basis that the paper has adopted the value of 0.6 for the reason of consistency and legality. Dr Chung is right to suggest that a lower value could be used to account for the live-in conditions.

Based on Tregenza formula $\rho_o = m_r \dfrac{\rho_b + \rho_g}{2}$, he has assumed that $m_r = 0.5$. That is to say half of the flux is reflected out of the system. However, for conditions of high obstruction, it is reasonable to assume that more of the flux is inter-reflected. Thus the paper has adopted a value of 0.7 to account for that. And if ρ_b=0.2, ρ_g =0.2, then $\rho_o = 0.14$.

Since the paper was submitted in December 2000, there have been developments. In May 2001, the tool received in principle endorsement by the Buildings Department of the Hong Kong Government. (6) There is now a need to fine-tune the tool so as to incorporate it into the legal framework. In addition, design studies have been conducted to test the tool's ability to address real life problems. It would therefore be interesting to revisit it in a few year's time.

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Author's response to G Sweitzer

Regarding Dr Sweitzer's comment, I am not aware of any reason why the Daylight Factor method is not appropriate or adequate for the task at hand. But I too am keen to see if new and better tools could be formulated. This paper is based largely on current knowledge and some of the limits associated with it. Although Housing Authority housing is in theory not subjected to Hong Kong Building Regulations, in practice, almost all of the housing was designed to satisfy the requirements. I have known of isolated cases where the requirements of the regulations were not met. In those cases, computational studies were made during the design and on site measurements were conducted after the projects were completed. Many different types of window features are in use in Hong Kong and nibs incorporated into the precast panels at floor level (which Dr Sweitzer referred to as shelves) have been used for some windows of recently completed public housing blocks. The question of what window features, be it light shelves, bay windows, sun shades, balconies and so on, should be incorporated was considered when the tool was formulated. It was decided that the external walls containing the window were assumed to be flat. This gives us, so to speak, a clean sheet of paper to begin with. It is possible for some allowances to be made for shelves to be incorporated into the design tool. However, it is impossible to account for all the variations. Instead of building the features into the tool, another approach is to separately assess the implication of light shelves by means of tables of multiplying factors. However, this would make the tool unnecessarily complicated to use. One must be mindful of balancing simplicity against accuracy. As I have mentioned in the paper, the tool aims to give the designer a general idea of how blocks should be arranged. For a more detailed calculation involving design and window features, the best approach is to use the equations. For the validation study, data was obtained without blocks of corresponding height used on top of the test room. The purpose of the experiment was to see which of the two formulae were more suitable for the task at hand. It was not meant to be all inclusive.