

# DAYLIGHT DESIGN AND REGULATION FOR HIGH DENSITY CITIES

Edward NG  
Vicky Cheng  
Department of Architecture  
The Chinese University of Hong Kong  
Shatin, N.T., HKSAR  
edwardng@cuhk.edu.hk

## ABSTRACT

The sun is a source of energy and light. Daylight design for “extremely” obstructed urban environment is a relatively uncharted area of study. No city in the world has an urban density as high as Hong Kong. This paper summarises results of a five-year research project commissioned by the Hong Kong Government to develop an understanding and to develop a new set of building regulations.

The study first looked into the issue in terms of existing rules and policy, and identified their shortcomings. It then investigated daylight performance of the existing building stock with on-site measurements. Through a territory wide user survey, the study proceeded to relate these quantitative data to user satisfaction and requirements.

A minimum performance standard based on Vertical Daylight Factor on the surface of the window was established. Using theoretical modeling, on-site measurements and computational studies of real and hypothetical cases, a simplified design method based on ‘Unobstructed Vision Area’ (UVA) was developed. The Unobstructed Vision Area Method (UVA) is highly correlated to the Vertical Daylight Factor (VDF) of a building surface. This 2-dimensional plan based method is very easy to use at the early design and planning stage. With small modifications to its variables, the concept of the UVA method could be generally adopted for other “extreme-density” cities.

## 1. BACKGROUND

Around 20 cities in the world nowadays have 10 million inhabitants or more. This number will continue to increase in years to come. In cities like these, buildings are fighting each other for natural light and ventilation. Develop designs to optimize light and ventilation is an important task for architects, engineers and industry stakeholders. Naturally lit and ventilated buildings are not only energy efficient, they are also more natural and could be more comfortable for their inhabitants, as well as “green” and “sustainable”.

Hong Kong is the most densely populated city in the world. Typically, residential buildings are built to a plot ratio (total useable floor space / site area) of 10 or above and site coverage of 50%. This leads to the construction of high rise towers (40 - 80 storeys) built very closely together. Site density can be as high as 4000 person per hectare. (Figure 1)

Light and ventilation for buildings in Hong Kong is governed by the Building Regulations. The laws are more than 40 years old and were based on an aged UK model. They prescribe a minimum distance between building blocks based on the concept of vertical angle requirements (currently 71.5°), and a minimum glazing to floor ratio of 10% for all habitable space. However, this provision has proved to be ineffective. Worse still, it actually allows bad designs and discourages good designs. (Figure 2) A new regulatory method is needed.



Fig. 1: Old and new, the high-density cityscape of Hong Kong.

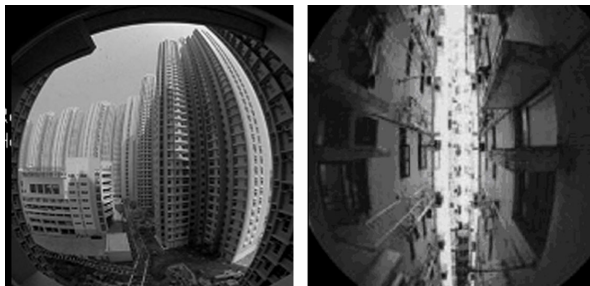


Fig. 2: (Right), the window facing into a narrow space and obstructed by an opposing building is allowed by the building regulations. (Left), the window facing directly a high block but with an open aspect on its left is not permitted.

## 2. A REVIEW OF CURRENT CONDITIONS

On-site daylight measurements were conducted in a number of dense housing estates in Hong Kong. 1 set of Krochmann multi-head (20 heads) photometers with multiplex and data-logger for the living space and 5 sets of Li-Cor 1400 photometers for the minor spaces were used. Fish eye photographs were taken from the photometer positions of windows measuring the vertical sky component for cross-reference. A synchronized single cell Li-Cor 1400 photometer was set up on the rooftop. Data was logged every 5 seconds, averaged and recorded every 1 minute. Each of the unit was monitored for a period of 1 to 3 weeks. Weather reports were obtained, together with the readings on the rooftop, periods of 'near' overcast sky were

predicted and noted. Useful data was recorded for further analysis.

Daylight performance at the lower floors of high-rise residential development was very poor. VDF of approximately 6% to 8% were recorded. The room average daylight factor for habitable rooms was typically in the order of 0.2%, whilst kitchens located at the rear end of a deep re-entrant recorded close to 0.0% - hardly any light at all. (Figure 3)

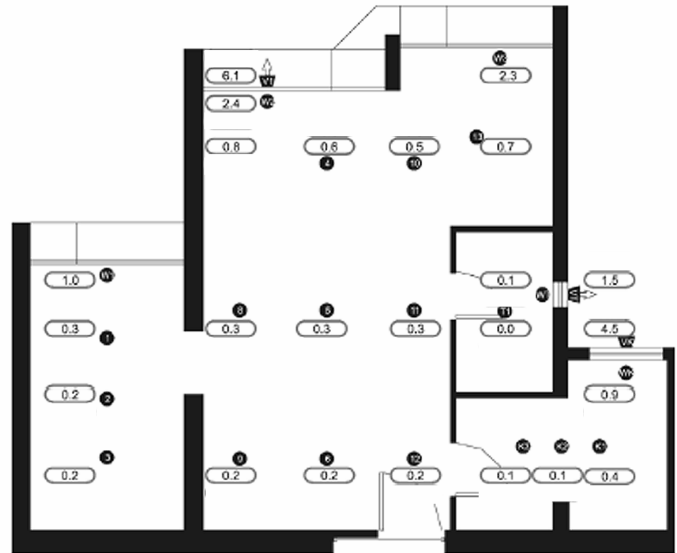


Fig. 3: Daylight performance of a typical residential unit in high density sites in Hong Kong. Daylight Factor at the rear of the space is about 0.2%

Some key problem areas were identified. Whilst satisfying the building regulations, these windows do not provide adequate daylight to their respective interior spaces.

- (A) Windows placed inside deep re-entrant (local term for deep recesses from the main façade).
- (B) Windows facing into narrow streets where no height restriction in force.
- (C) Windows placed in the 'large' light well formed by surrounding building blocks.
- (D) The misuse of the regulatory Rectangular Horizontal Plane (RHP). This results in tight spaces being formed between building blocks.
- (E) Windows not properly positioned in the space.

## 3. USER REQUIREMENTS

What is the acceptable daylight performance for the type of high-density dwellings that Hong Kong is building?

Daylight performance standards exist and are stated in various documents, for example British Standard 8206 Part 2. Some of these standards were established largely based on experimental data of human responses. In urban Hong Kong, buildings have a lower overall daylight performance. It could be hypothesized that inhabitants could acclimatize to accept a lower daylight standard and this is dependent on various socio-cultural and climatic factors.

To establish this acceptable standard of daylight performance of high-rise residential buildings, user survey and computational simulation was used. 12 major high-density housing estates were selected. (Figure 4)

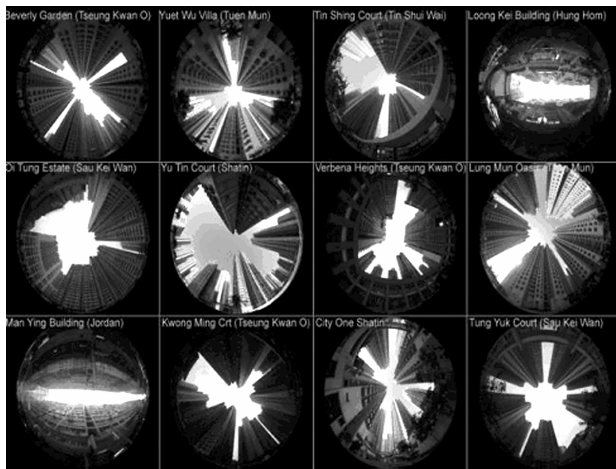


Figure 4 Typical fish-eye lens photographs towards zenith of the 12 housing estates of the user survey.

At the same time, daylight performances of around 6000 windows of the 12 housing estates were computed using simulated results (Figure 5). Lightscape was used as it has been noted previously that it could cope with high-density conditions reasonably well. From the computed results, daylight availability of the windows of each of the residential unit that were user surveyed was identified and coded into the survey forms. The performance data of each of the space and the associated user responses were then used to compute user satisfaction rates.

Results of the study indicate that the minimum acceptable daylight performance levels of inhabitants of Hong Kong are very low. Most of the people surveyed expressed an attitude of indifference to daylight. Only when daylight performance is obviously low and sub-standard that people begins to notice and complaint about it. This switch of opinion happened very quickly at a certain threshold level. Thus, although the minimum acceptable standard is low, the fact is that it exists. Based on the data available, it is possible to calibrate a standard based on this switching behaviour.

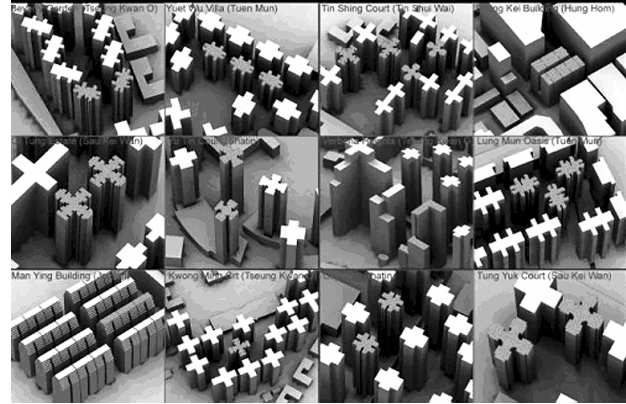


Fig.5: The 12 surveyed estates simulated using Lightscape.

For living rooms, it is noted that satisfaction rate stays at around 80% when VDF is 10% or above. Satisfaction rate goes up as the amount of available light increases, however this improvement is not significant. In short, there is little to be gain by providing say 15% VDF and 30% VDF. However, once daylight performance fails below a certain level, around 8% in this case, satisfaction rate drops very rapidly.

For bedrooms, people generally prefer a higher daylight standard. The satisfaction rate stays at around 80% when VDF is above something like 20%. Between VDF of 10% to 20%, around 70% finds it acceptable. Acceptance rate drops off below something like 7% to 8% VDF.

For kitchen, the acceptable minimum standard is very low. This may have to do with inhabitants getting used to the general poor performance of existing building design. At 4% VDF, around 80% of the return still expresses that it is satisfactory. Acceptance rate fails very rapidly indeed. This confirms that despite a low required standard, a threshold exists.

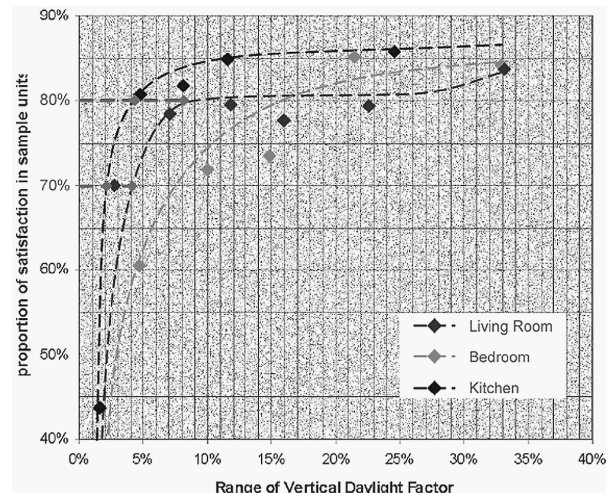


Fig. 6: User satisfaction vs. simulated daylight performance

Based on the survey results, it was recommended that an 80% satisfaction rate be used for establishing the standard threshold (Figure 6). And for simplicity of operation, living room and bedroom are considered together as habitable rooms. For the minimum acceptable threshold, Vertical Daylight Factor (VDF) for habitable room should be at least 8%. For kitchen, it should be at least 4%.

#### 4. TOWARDS A NEW DESIGN AND REGULATORY METHOD

How to formulate a simple method for daylight design and building regulations is the next task. It is important to strike for “simplicity” and “reasonable accuracy” at the same time.

A method based on a two-dimensional “the visible area / volume in front of the window” was first speculated – on a napkin during a dinner session! It was considered very similar in spirit to the existing regulatory Rectangular Horizontal Plan (RHP) requirements. The method was based on modifications a more accurate three-dimensional sky component overlay method developed by Tregenza.

It was speculated that for high-density environment where surrounding buildings are high, the sky component above the buildings could be assumed to be very small. Light from gaps of buildings could then be approximated using the plans. Reflected light depends largely on how the surrounding surfaces are illuminated and thus the openness of these surfaces to the sky. It seemed that it was possible to devise a design method based only on two-dimensional plan information.

The new method, dubbed the Unobstructed Vision Area Method (UVA) is a simple method suitable for high-rise, high-density development. The method is not fundamentally new. R G Hopkinson proposed similar offering before. The Unobstructed Vision Area (A) is formulated as follow:

$$A = \left[ \frac{\pi(\phi_L + \phi_R)}{360(\tan^2 \theta_L)} \right] H^2 \quad or$$

$$A = kH^2 \quad (k \text{ being a coefficient}) \quad (1)$$

[Take a cone of light  $\phi_L + \phi_R = 100^\circ$  from the window, given a vertical obstruction angle of  $\theta_L = 71^\circ$ , the mathematical formula relating the horizontal area in front of the window (A) and the Height of the building (H) can be given here, k is a constant relating A with  $H^2$ . ]

This mathematical formulation takes into account only the area of a cone of light and ignores other enclosed areas in front of the window. When these other areas are accounted for in an area-based methodology, it is necessary to factor them in. Since the shapes and geometries of these areas are site specific, it is impossible to devise a simple formula for it. Simulation studies could be used. The hypothesis is that k could be statistically devised using block plans that are likely to be encountered by designers in Hong Kong. (Figure 7 and 8)

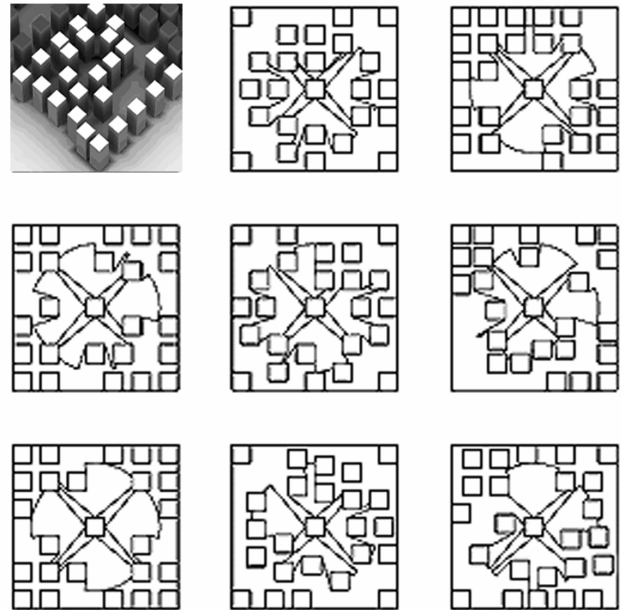


Fig. 7: 9 of the 40 scenarios constructed to test the relationship between UVA and VDF using Lightscape. Top left corner illustrates the 3D model.

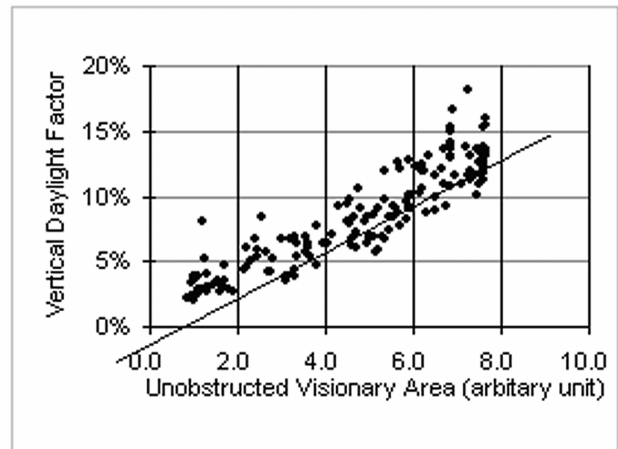


Fig. 8: VDF vs. UVA of the 40 scenarios with 160 data points. A regression line representing the lower quantile values of the data is drawn. ( $H/W=3$ ,  $VDF=0.0163 \text{ UVA} + 0.0077$   $R^2=0.7956$ .  $H/W=3$ ,  $K = 0.58$ .)

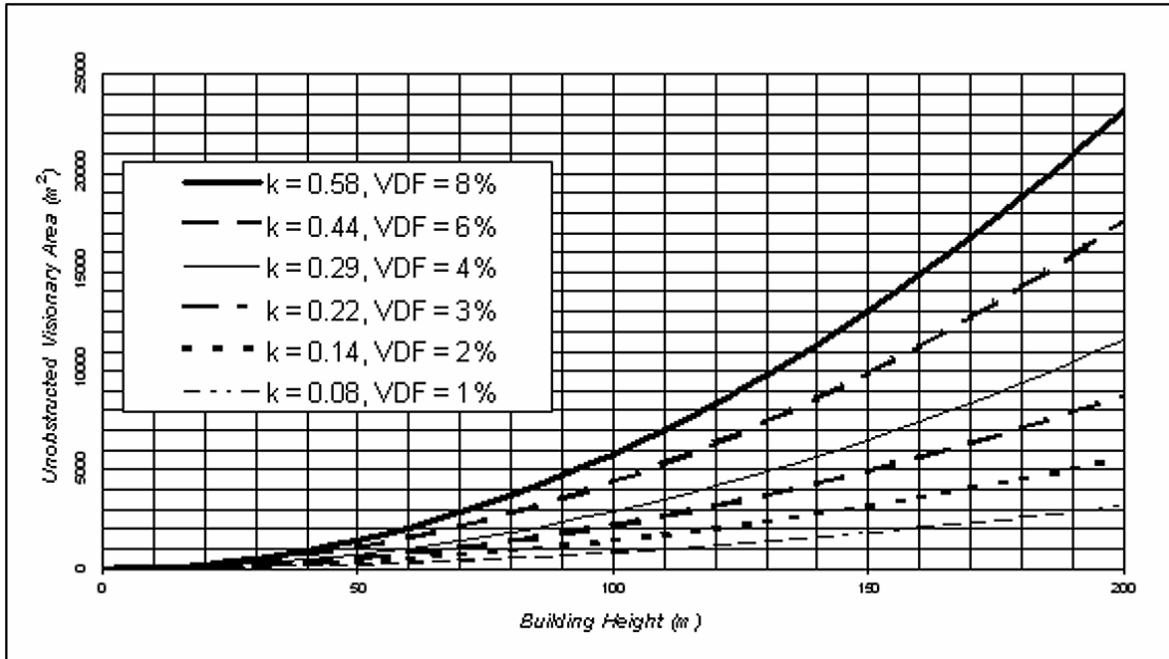


Fig. 9: UVA requirements of various VDF performance

K is a constant and its value depends on the daylight performance (VDF) required. K is worked out statistically based on tests using built and theoretical examples using computational results. For example, if VDF required is 8%,  $k = 0.24$ . The higher the VDF required, the higher the value of k. Therefore, it can be stated that “if a window located on the surface of a building 100 m high could achieve a UVA of 2400 m<sup>2</sup>, there is a 75% chance that the window could achieve a VDF of 8%.”(Figure 9).

## 5. CONCLUSION

The UVA method has been adapted by the Government of Hong Kong as a basis of regulatory control of daylight performance of buildings in Hong Kong Under their recently issued PNAP278.

## 6. ACKNOWLEDGEMENT

The study is conducted under a consultancy project from Buildings Department, HKSAR commissioned to Anthony Ng Architects Ltd. (CAO G05). Professor Chan Ying Keung of Department of Sociology, CUHK and Professor Peter Tregenza of School of Architectural Studies, Sheffield University, UK collaborated and contributed to the studies.

## 7. REFERENCES

- (1) Allen, W.A., Daylighting of Buildings in Urban Districts, *Jnl Royal Institute of British Architects*, 50, p.85, 1943.
- (2) *British Standard 8206: Part 2: 1992 - Code of Practice for Daylighting*, BSI, United Kingdom, 1992.
- (3) *Post-War Building Studies no.12*, 'The lighting of buildings', HMSO London 1944.
- (4) Ng, E, Chan, Y K and Tregenza, P, Review of Daylight Factors recommendable/acceptable to HK in consideration of the local climate and socio-cultural aspects, *Technical Report for Anthony Ng Architects Ltd. and Buildings Department*, HKSAR, TA00491, (41 pages), Dec 2001.
- (5) Ng, E, 'Daylighting simulation of heavily obstructed residential buildings in Hong Kong' in *Proceedings of International Building Performance Simulation Association Conference*, ed. R Lamberts, C O R Negrao, J Henson, Rio, Brazil, vol. 2, pp. 1215-1222, 2001.
- (6) Ng, E, Chan, T Y, Leung, R and Pang, P, 'Issues regarding the development of a daylight design and regulatory method for high density cities using computational lighting simulations', *Proceedings of CAAD Futures Conference*, Taiwan, 2002.
- (7) Tregenza, P, Daylight Criteria and a simple graphical tool, unpublished note sent to the author of this paper, 2001. See also *CIBSE Daylighting and Window Design Guide LG10:1999*.
- (8) This method was incorporated into the Daylight Code by the Ministry of Housing and Local Government in the UK. See R G Hopkinson, et al., *Daylighting*, Heinemann, London, 1966.