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daylighting, building regulations, high-density city, computer simulation

Hong Kong is the most densely populated city in the world. Design of buildings in urban Hong Kong is regulated by the Building (Planning) regulations of the Government. This piece of law is over 40 years old and has been proven to be inadequate. This paper introduces a new simplified method, the Unobstructed Vision Area Method (UVA), for daylight design in high density cities. The method was developed based on empirical and theoretical formulation as well as extensive validation and studies using computational simulations. The paper highlights the steps necessary to apply computational methods for law making, the difficulties and possibilities in the process, as well as the practical and implementation of adopting computational results and techniques in everyday practical life of the architect and the controlling agency. The Government of Hong Kong has recently adopted the UVA method.

Hong Kong is the most densely populated city in the world (Ng 2001a) (Figure 1). It boasts a development density of some 2700 person per hectare. Typically, residential buildings are built to a plot ratio of 9 and site coverage of 50%. This leads to 40 to 80 storey high rise building blocks built very closely together. As buildings get higher and closer to each other, they begin to obstruct each other and reduce the availability of sun and daylight to the interiors through the window openings. The Building Regulations of Hong Kong prescribe a minimum distance between building blocks based on the concept of vertical sustained angle requirements; and a minimum glazing to floor ratio of 10% for all habitable space. (HKSAR 1959) This method of regulation, based on antiquated UK laws, is over 40 years old. While it was logically devised some 40 years ago to deal with building design of the time, it is no longer capable of safeguarding daylight provisions of contemporary building design in Hong Kong (Ng 2001b). New methods of design and regulation are badly needed.

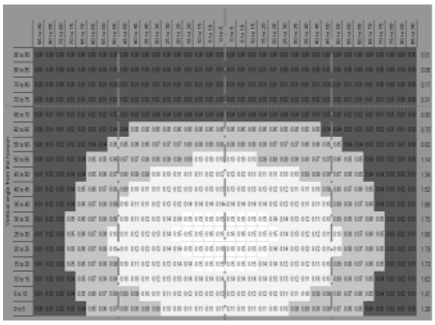
Noting the inadequacy of the existing laws, in 1999, the Government of Hong Kong commissioned a study to update the building regulations. Apart from making more sense of the old rules and their implications to design, the key task was to attempt, for the first time, a performance based approach to building control. The research contract was awarded to Anthony Ng Architects Ltd, a practice famous for its environmental approach to building design in Hong Kong. Researchers at the Department of Architecture, Chinese University of Hong Kong, was asked to conduct studies for the “daylighting” portion of the study. Since 1999, the study proceeded using on the following methodology and workflow, as in Table 1.

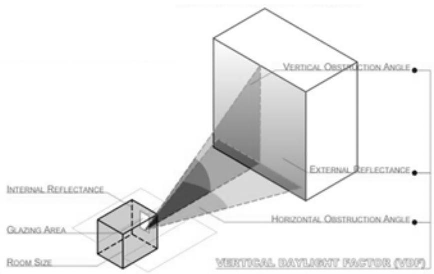
I, On-site daylight availability measurements	• To establish daylight performance of existing building stack • To identify problem areas • To propose empirical remedies and a way forward
II, Historical review of existing laws	• To understand the lineage and development of existing laws • To put the regulatory provisions within their logical context. • To identify areas of abnormality
III, User survey	• To establish minimum acceptable daylight performance acceptable to the local inhabitants. • To identify and establish key design parameters for good daylight design.
IV, A new design and regulatory method	• To examine and to establish applicability and suitability of existing methods • To develop a simple to use method for design and regulation • To legalise the new method through the publication of legal practice note and a Code of Practice.

This paper will concentrate only on the computational portion of study IV. There are a couple of sub-steps within this study. They will be discussed later.

The existing building regulations, which adopt a vertical unobstructed angle requirement, was developed based on the assumption that terrace buildings line both sides of a street, and the best way to safeguard daylight performance is to ensure that each of the windows on the façade sees a portion of the sky above the rooftop of the opposite buildings. An underlining assumption was that there would be a lot of windows along the street. And if each one of them could safeguard a small rectangular portion of unobstructed sky, the result will be a horizontal strip of unobstructed sky for each of the window. This way of regulation proves to be ineffective in Hong Kong nowadays. There are 2 reasons. Firstly, buildings are now tall towers, not terrace-like buildings anymore. Secondly, though 'ingenuous designs' aimed to compromise the laws, building façades are no longer flat. There are a lot of deep recesses. In a nutshell, staying with current regulations will not guarantee performance. A new method is needed.

Methods to predict daylight performance exist. One of the most commonly used, or misused, method is CIBSE's simple Daylight Factor equation (Ng 2001c; Ng 2001d). Some available methods are more accurate (Tregenza 1998) (Baker et al 1993). However most of them are cumbersome to use during the initial design stage. They are best reserved for checking the design at the scheme design stage. The UVA method was first empirically developed based on the understanding that daylight to a window of a building comes from a sky vault that is 3-dimensional (Figure 2). An embryonic idea very similar to the logical reasoning of the UVA method exists and has been used earlier in the UK (Hopkinson 1966; Crompton 1955).



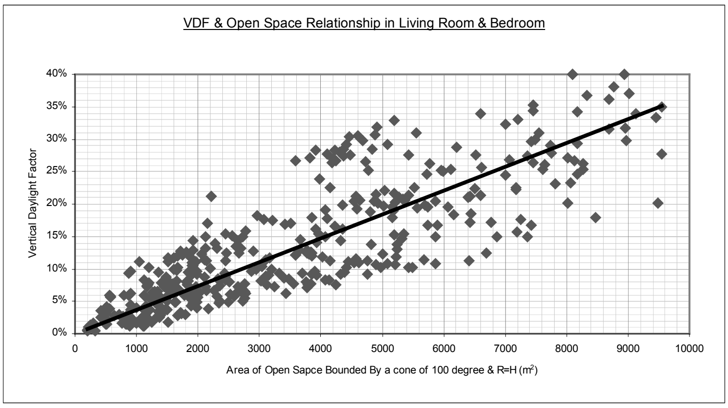


This sky vault depends on 2 design parameters: firstly, the height of building opposite (vertical obstruction angle), and secondly, obstruction on both sides of the window (horizontal obstruction angle). For a site with high buildings, the vertical angle could be assumed. The horizontal angle could be approximated with "an area" in front of the window. In addition, since the efficacy of light entering the window reduces as their incident angles from the normal increases. A limiting angle of 50 degree from the window normal could be used. A cone of area could now be drawn based on the area in front and the 100 degree limiting cone. This is the Unobstructed Vision Area (UVA). A mathematical formulation of a perfect cone could be expressed in equation 1. Note the constant k.

$$A = \left[\frac{\pi(\phi_L + \phi_R)}{360(\tan^2 \theta_L)} \right] H^2 \ \textit{or} \ \ A = kH^2 \ \textit{(k being a coefficient)} \qquad (1)$$

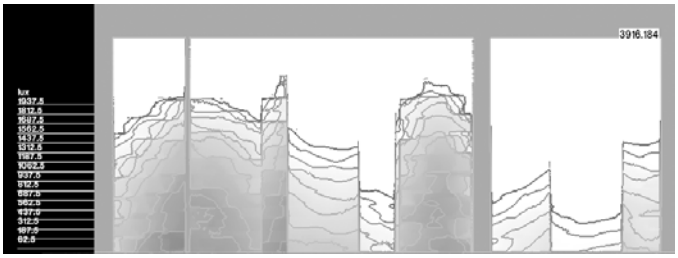
[Take a cone of light $\phi_L+\phi_R=100°$ from the window, given a vertical obstruction angle of $\theta_L=71°$, the mathematical formula relating the horizontal area in front of the window (A) and the Height of the building (H) can be given here, k is a constant relating A with H^2.]

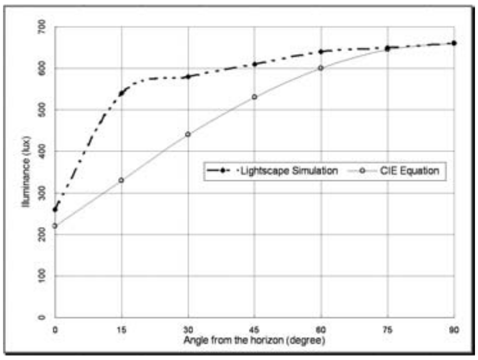
The mathematical formulation takes into account only the area of a zone of light and ignores other areas of an enclosed space in front of the window. To ensure that when these other area are accounted for in an area-based regulation, it is necessary to factor in an allowances for it. As the shape, size and geometry of these areas are different, it is impossible to devise a simple mathematical formula for it. This is where computational simulation could be used. The hypothesis is that k could be statistically devised based on a study of building block planning likely to be encountered by designers in Hong Kong. A pilot study was made using 11 housing estates. The vertical daylight factor, VDF (the amount of daylight arriving at the window pane from the exterior environment including the sky vault and reflections from surrounding buildings), clearly relates linearly to the amount of unobstructed area in front of the window (Figure 3). This paper will not report this particular study. Instead, a related study using hypothetical scenarios will be reported here.



Software for daylighting study exists. Some commonly used software are: Radiance (Figure 4), MicroLumen, Lightscape and so on (Love et al 1991). Theoretical and on-site validations of some of the software have been conducted by researchers (Mardaljevic 1997) (Ng et al 2000). Unfortunately, most of the validation works were for buildings situated in relatively open sites. For this study it is necessary to re-validate these tools for high rise, high density environment. Two software were tested, Desktop Radiance and Lightscape, and it was found that Lightscape coped well under the conditions we are interested in (Ng 2001e). Since the earlier validation works, further works were done here. Firstly, validation works were conducted to verify the Sky model of Lightscape. Secondly, additional studies were made on the sensitivity of settings and configuration files on the simulated results.

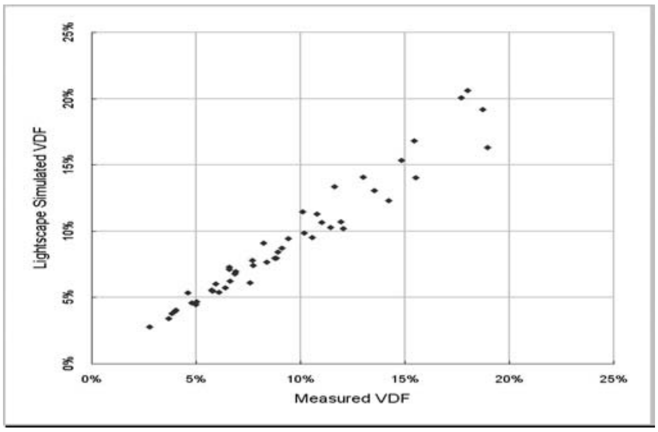
Based on the sky model study, it can be concluded that the Sky model used in Lightscape does not match the CIE Overcast Sky model (Figure 5). However, from the experimental data, it is demonstrated that the sky model used in Lightscape is reasonably accurate for high altitude sky. The expected error when a≥60º is only 5%.

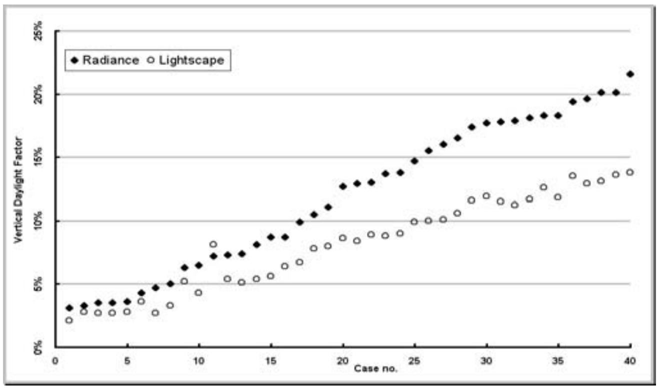




Altitude	Light-scape	CIE equation
0^o	260 lux	220 lux
15^o	540 lux	330 lux
30^o	580 lux	440 lux
45^o	610 lux	530 lux
60^o	640 lux	600 lux
75^o	650 lux	645 lux
90^o	660 lux	660 lux

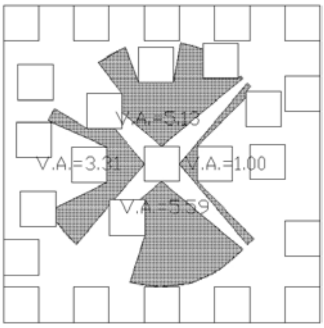
In addition to an understanding of the sky model used, it is necessary to establish how the Local Illumination Model used by the software copes with high density conditions. Two experiments were conducted. Firstly, Scale building blocks with photometric sensors were used to compare measured results with simulated results of Lightscape (Figure 6). Secondly, computational results of Lightscape and Desktop Radiance were compared (Figure 7).

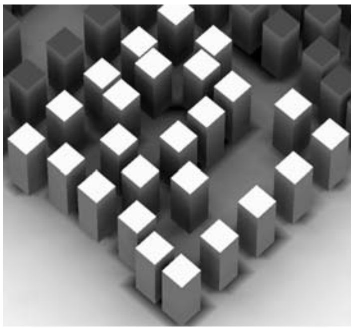


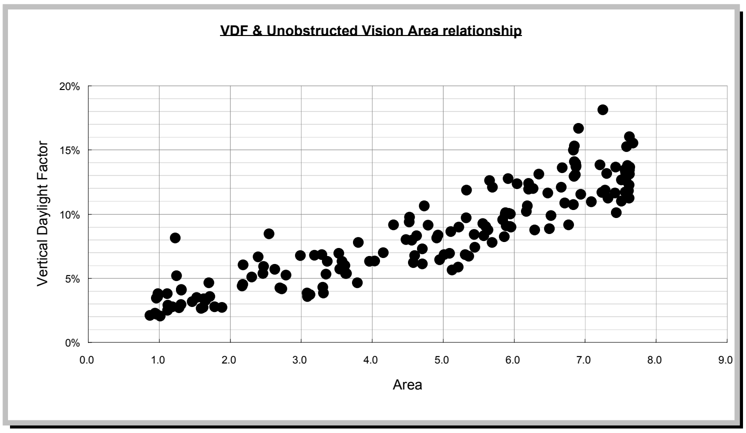


It can be concluded that despite the problem with the sky model, Lightscape gives good results under high obstruction conditions. When results of Desktop Radiance were compared with Lightscape, it can be concluded that Desktop Radiance overestimate daylight performance by approximately 50% compared to Lightscape. It must be reserved that: as it is important for the designers and regulators to use the interface and setting as the software is, we believe that, although more accurate results may be possible, it may not be appropriate for them to twist the software at script level. Lightscape was eventually adopted for its ease of use, close coupling with architectural drafting software, and acceptable error for high rise high density conditions.

40 theoretical configurations were used to test the relationship between Vertical Daylight Factor (VDF) of windows and the Unobstructed Vision Area (UVA) in front (Figure 8). The 40 scenarios were designed in such a way that UVA of windows at the bottom of the tower are evenly distributed. This allows us data points at different VDF performance levels.



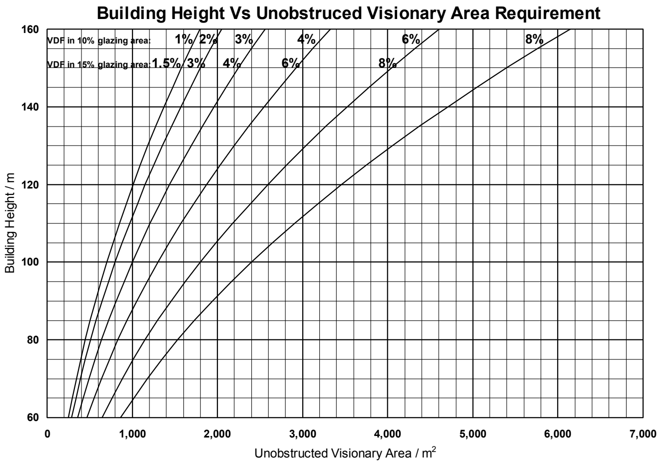




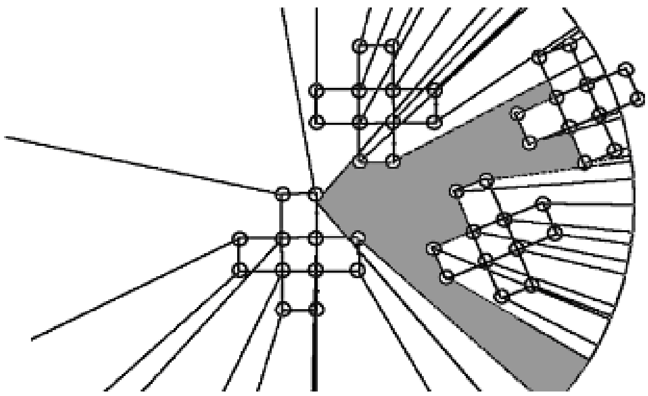
Comparable with the results obtained earlier with real housing estates, our results indicate that there is a linear relationship between VDF and UVA (Figure 9).

Based on our user survey on minimum acceptable daylight performance, it could be concluded that for habitable room (living room and bedroom) is around 8% VDF.

Given an assumption made for average reflectance of building surfaces (r=0.4), and results obtained using computational results, the coefficient k could be determined for the respective VDF required for habitable spaces (Figure 10).



To assist designers and regulators, 2 design aids are designed: manual method and computational method. The manual method requires the use of scale plans and overlays. Since most architect offices nowadays use computers for drawing production, it was deem necessary to develop a computational method for the chore. Version 1 of the UVA Computer Tool is basically a 'passive' tool written using Autolisp. Basically, the software detects the position and orientation of a window, draw the UVA area in front of it, and report the results in a table format (Figure 11). A version working under MicroStation is developing. These are the 2 most commonly used drawing software in Hong Kong. Future version will hope to deal with optimisation algorithms.



The draft version of the UVA method of regulating daylight has been circulated among the design professionals and building developers for comment in the form of a new practice note. In December 2002, the method will be implemented and made into new building regulations in Hong Kong. Soon, may be in a few years' time, the research team could re-visit the method and evaluate designs based on it.

From the computational perspective, a couple of points could be notes. Before we do that, it is important to bear in mind what has been achieved. For the first time in the law making history of Hong Kong, and perhaps in the world, computational results have been accepted as evidence for establishing the performance standard required. This requires a lot of faith from the lawmakers. On the other hand, it requires a lot of care and logical methodology from the researchers.

For the real world, it is absolutely important to ensure and to demonstrate that computational methods are validated, accurate and, more importantly, reliable. All software used must be validated for the context in question. It is useless to simply borrow results conducted elsewhere. The error boundary, no software is perfect, must be established and accepted by all parties concerned. For daylighting study, it is typical to accept an error as high as +/-20%. For law making proposes, it is prudent to limit that to something like 10%. This limited error range must be regarded as 'operational', not scientific. In addition, 'reliability' is important. That is to say, results must be repeatable. A certain error limit, say +/-5% could be established and accepted.

Secondly, it is important to establish the limits of the software as well as to state the range of configuration variables acceptable and must be used. This is important, as it is well known that 'garbage in, garbage out'. For regulation propose, it is not useful to consider too many variables. Nor is it useful to design a system to cater for particulars. Those must be regarded as exceptional to the normal operation of the rules. For example, the setting of reflectance has been greatly debated. At the end, it was deemed administratively appropriate to state a single setting that all submission must be used. Currently, this was set at r=0.4 for building surfaces and r=0.2 for ground. Exceptions to the norm could be entertained, but for the regulators, it is important to check the settings as well as the results.

Thirdly, one often overlooked detail is that it is very important to demonstrate the sensitivity to the simulated results when setting different variables. This gives users a scale to determine what is more important to control and to pay attention. For daylighting, the reflectance of surfaces has a deterministic effect on the results, whereas, for Lightscape, using settings that appropriate CIE overcast sky, it is not important whatsoever to set the date and time of the simulation.

Fourthly, perhaps not a problem but a precaution, for Lightscape, it is important to construct the model in such a way that 'light leak' does not occur. In general, all software require the 3D model to be constructed in a certain manner, this must be carefully adhered to. For the regulator, it can be difficult to check the robustness of the modelling. However, they should be made aware of signs of inconsistency.

Lastly, it must be highlighted that the validation process should be repeated every time a newer version of the software is made available. Similarly, when settings and variables very different from those originally adopted are subsequently used, the validation process must be repeated.

On a similar note, an advice could be offered. For CAD or Computer aided studies to be creditable. There is no point creating empty shells of frameworks or 'make believe' systems that could not be used, verified or evaluated. Unfortunately, many recent so call 'case base' learning or indexing systems, and CAD based knowledge packages belong to this type of offering. It may still be reasonable to search and to dream about things. It must be noted that the path must be completed every time an investigation is made. It is not scholarly to pretend results when a hypothesis is offered. How good a system or methodology is depends on how it performs, not how it is structured.

This paper offers an example of a complete path. From understanding the problem, offering a hypothetical solution, tool our methodology, conduct testing and validation, collect data and analyse them, to building a new design method that is robust in front of the rigours of the regulating authority and the general public. The message of the paper, as far as computational study is concern, is: be serious and stand by your claims with validated proofs.

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