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Balancing energy and daylighting performances for envelope design: a new index and proposition of a case study in Hong Kong

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Abstract:

Being healthy and energy saving have become two important principles of building development. Daylight is an influential factor with the characteristics of both photometry and radiometry. Irradiance brings solar heat gains, which transfer to building cooling load, while illuminance provides a luminous environment and affects artificial lighting system at the same time. To balance the energy and daylighting performances, it's reasonable to minimize the environmental load under moderate comfort conditions. This study first quantified luminous comfort with a dynamic daylighting metric, average daylight autonomy (Ave. DA_{300}), from a questionnaire survey and simulation work. The benchmark of this metric should range from 29.6 % to 57.8% for high-rise residential buildings. With this guideline, the Hong Kong public housing units is found that part of units lack of daylight due to the high building floor and density, while some units have potential to save energy by compromising daylighting performance. Therefore, a new index, energy daylight rate (EDR), is proposed to help decide the best scenario of envelope design for both daylighting and shading purposes. The results show that opening a secondary window is an efficient way to bring more light in and lengthening overhang is an efficient way to block excessive sunlight. This method and the new index are proved to have the ability to help defining proper building envelope design at the early stage.

Keywords: Luminous environment; Energy saving; Daylight autonomy; Energy daylight rate; Envelope design

1 Introduction

1.1 Characteristics of Daylight

Light is a valuable resource as it not only brings people brightness and affects human circadian physiology [1], but also enhances people's productivity [2] and satisfaction [3]. Increased consciousness about satisfaction such as thermal comfort, acoustic comfort, as well as luminous comfort has attracted people's attention to their living conditions. Researchers has adopted innovative feature [4] and glazing [5] to create a comfort luminous environment more intentionally and efficiently. Nowadays, being livable and energy saving have become two important principles of building development. Daylight is an influential factor as the characteristics of both photometry and radiometry. Irradiance brings solar heat gains, which transfer to building cooling load, while illuminance provides a specific luminous environment and affects energy usage of lighting system at the same time. Therefore, how to balance the energy consumption and daylighting performances becomes a critical issue [6], and three important questions should be addressed first: 1) should the energy be consumed as little as possible? 2) can the comfort level of luminous environment be quantified? 3) how to guide the energy-efficient daylighting design based on luminous comfort?

1.2 Energy efficient design about daylight

Hong Kong has a fruitful daylight resource for saving artificial lighting energy as the outdoor horizontal illuminance could reach to 10 000 lux for over 80% office hours in a year [7]. Both the simulated and measured data showed the daily lighting energy savings could reach to 8 kWh for 52 m^2 in spring and summer [8]. The Electrical & Mechanical Services Department (EMSD, Hong Kong) reported that the annual lighting consumes 9% of the total electricity end-uses, which ranks the third following the space-conditioning 36% and refrigeration 13% [9]. Better utilization of daylight and better control of lighting, such as window systems [10] and dimming control [11], could generate more lighting energy savings up to 30% and 60% respectively. However, daylight also brings radiation, and solar heat gain becomes cooling load which will increase around 28% of the energy consumption for air-conditioning (AC) system unintentionally [12]. Hong Kong still suffers from an intense increasing of annual total electricity consumption with an average rate of 6.67% per year over last 40 years [13]. It is reported that an ideal envelope design could reduce 33% of annual cooling load without consideration for daylighting [14]. Therefore, in order to achieve total energy-efficient objective, cooling load and artificial lighting electricity should be considered simultaneously when optimizing envelope design related to daylight [15].

To reduce the annual energy consumption, static or dynamic façade features are often adopted for envelope design. For an individual flat, the electricity savings could decrease from 40 to 28 kWh/m^2 when the angle of obstruction varied between 25° and 30° [16]. An automated control strategy of inside slat-type blind was proposed with the considering visual comfort, and an energy saving of 24.6% could be achieved [17]. The sensitivity analysis identified window to wall ratio and slat angle as highly influencing factors for energy performances regardless of façade orientation [18]. The glazing properties is also found as a great issue for energy performance [19]. A research [20] found a minimum saving of 10% in total energy consumption could be achieved by modifying the size of the windows. Except for energy saving purpose, façade features (balconies, sunshades and reflectors) are recommended by Hong Kong government to incorporate into building development also for enhancing luminous environment of residential units. To balance the energy consumption and daylighting performances and also answer the first question, it’s reasonable to minimize the environmental load under moderate comfort conditions [21].

1.3 Satisfaction with daylighting

The Director of interior lighting division of International Commission on Illumination (CIE), believes that people’s subjective perception of light should be quantified by objective metrics [22]. At present, the daylighting metrics are generally divided into three categories: static metrics, glare metrics and dynamic metrics. Static metrics include illuminance, brightness, color temperature, daylighting factor, uniformity, outdoor view, etc.; glare metrics include daylight glare coefficient (DGI) and daylight glare probability (DGP). Some researchers qualified the comfort as illumination level [23] and some treat it as uniformity [24]. While, most researchers believe offering luminous comfort environment means reducing glare problem [25]. With the development of climate-based daylight modeling (CBDM) technology and the continuous improvement of computer performance, cumulative effect of daylight on indoor luminous environment are put forward, namely daylight autonomy (DA) [26], useful daylight illuminance (UDI) [27], annual light exposure (ASE) [28] and so on. A basic study lead by Reinhart and Weissman [29] found that an objective dynamic metric - spatial daylight autonomy (sDA) can accurately representative the area in which students assessed subjectively as the mean daylit area, with an error of around 7%. Based on the process of proposing dynamic metrics [30], linking with energy savings [31] and linking with subjective assessments [32], the North American Institute of Illumination (IESNA) has incorporated the dynamic metrics sDA and ASE into the latest daylighting measurement methods [33]. In 2016, the latest version of the US LEED Green Building Assessment System also includes these two metrics and legalize them as one of three standard methods of indoor lighting evaluation [34]. At the same time, the Society of Light and Lighting (SLL) is studying the feasibility of using dynamic metric as a statutory evaluation metric [35], and it can be seen that the characterization of subjective requirements with dynamic metrics has become a trend [36]. Because the dynamic metrics can only be obtained by numerical calculation, the quantitative process needs further simulation work [37].

In this study, the rest two questions above-mentioned will also be answered. A dynamic daylighting metric, average daylight autonomy (Ave. DA_{300}), will be first tested to quantify luminous comfort with the data from a questionnaire survey [38] and simulation work. The benchmark of this metric will be established for high-rise residential buildings. With this guideline, the daylighting performances of Hong Kong typical public housing units could be checked to decide whether they needs daylighting or shading. Several different scenarios will be built trying to meet the balanced daylighting and energy requirements. A new index, Energy Daylight Rate (EDR), is then proposed to help decide the best scenario of envelope design.

2 Methodology

2.1 Questionnaire survey

Hong Kong is the most dense city with the highest number of high-rise buildings all over the world. However, the regulations for ‘rights of light’ (window to floor ratio should be more than 10%) do not ensure an acceptable daylighting in many residential building units because of the external obstruction. A questionnaire survey was conducted in a public housing estate to obtain the residents’ subjective comfort feeling for the living room luminous environment. Participants chose the comfort level based on the Likert 5-point scale [39]. The type of the buildings is selected as Harmony 1 with the building plan shown in Fig. 1a. This is the most famous type of public housing, as there exists 293 the same buildings in Hong Kong. Questionnaires were coded and issued by mail, and 108 valid questionnaires were collected through collection boxes for further analysis. These coded questionnaires reveal the specific physical information, including floor level, orientation and shading devices of the living room (Fig. 1b). By searching further information from Housing Authority, each unit's external obstructions could be known based on real location and surroundings (Fig. 1c).

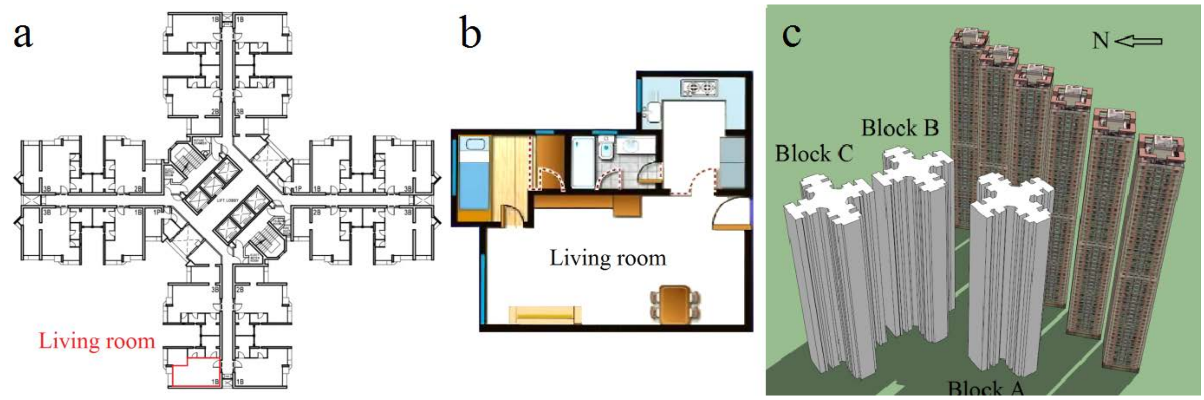


Fig. 1. Physical layout: (a) building plan; (b) living room; (c) blocks

2.2 Simulation set-up

The building model has 40 storeys and 16 units on each floor level according to the real conditions. To investigate the individual difference among the units, a group (3×3) of building blocks is built, which is closed to real condition (Fig. 2a). The center block is the target building which the units are built in.

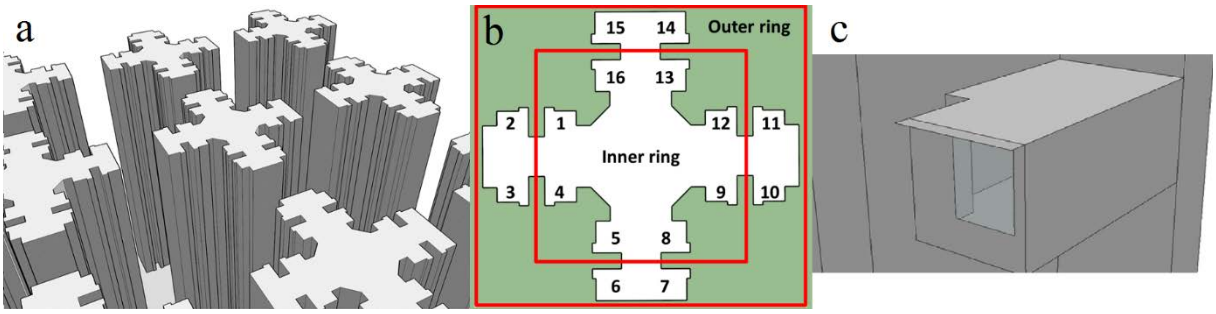


Fig. 2. Simulation models: a) A group of building blocks in 40 storeys high; b) Layout and categories of the units in one certain floor; c) Living room model of a unit

As there are 640 units in a single building block, it is essential to study the daylighting and energy performances with typical units. The typical models are built according to the characteristics of the units. Except for the orientation and floor level, the location of the neighbour rooms differ much when considering the self-shading. Therefore, the total 16 units in one certain floor is separated into two groups, namely inner ring and outer ring, and 8 units for each (Fig. 2b). The units in inner ring are more sensitive to the self-shading than the ones in outer ring. However, the distance of the buildings is also an influential factor as it affects much about the angle of obstruction. In this case, the inner and outer rings' units are modelled in the target building on 5, 15, 25 and 30 storeys facing 4 different orientations in a group of building blocks with the distance of 15 m, 25 m and 35 m for each other. In this way, there will be totally 96 combinations of different units. For each combination (Fig. 2c), the daylighting performance and the energy performance of the units will be simulated by Daysim and EnergyPlus respectively.

2.3 The Average Daylight Autonomy 300 lux

DA is a percentage of time that the target illuminance threshold level is met. It has been known as a dynamic daylight metric to evaluate the cumulative daylighting performance just like UDI and ASE. Based on this metric, another term, spatial daylight autonomy (sDA), which describes the qualified area, has been accepted as a new way for daylight evaluation by IESNA and LEED. $sDA_{(300/50)}$ reports the percentage of the space area that meets the target illuminance of 300 lux at least 50% of the occupied time. In this study, a further step of sDA is made to average the space DAs. The average DA_{300} (Ave. DA_{300}), which is the average value of the DA in the target plan, is proposed not only as a cumulative metric for assessing daylighting, but also a spatial metric to quantify residents' luminous comfort.

2.4 Energy Daylight Rate

Due to the characteristics of photometry and radiometry happen at the same time, when there is more daylight, daylighting performance and cooling load increase, while the energy consumptions of artificial lighting has a contrary effect. Aiming to consider the sum energy of lighting and AC, and also to evaluate the daylighting performance and energy performance at the same time, a parameter, Energy Daylight Rate (EDR), is proposed. The calculation is shown as equation 1.

$$Energy\ Daylight\ Rate = \frac{\Delta\, Total\ energy}{\Delta\, DA_{300}} \tag{1}$$

From the equation (1), the EDR can be both negative and positive. If EDR > 0, it means the increasing of daylighting performance will lead an increasing of total energy consumption. If EDR < 0, it means the increasing of daylighting performance will lead a decreasing of total energy consumption. It will be the very best condition that the total energy consumption reduces while more daylight could be brought into the room. This new parameter can be used to check the effectiveness of the designs of daylighting systems and shading systems.

According to the Building Energy Code of Hong Kong [40], the COP of chiller at full load should be 2.8 W_{th}/W_{el}. In this study, the energy of AC is converted from the cooling load with the COP of 2.8

W_{th}/W_{el}.

3 Results

3.1 Luminous comfort level by a dynamic metric

Based on the results from simulation work and questionnaire survey [41], the relations between objective daylight metric and subjective feeling is studied. Bivariate association between luminous comfort and Ave. DA_{300} [36] is shown in Fig. 3 (1: strongly dissatisfied; 2: dissatisfied; 3 neither dissatisfied nor satisfied; 4: satisfied; 5: strongly satisfied).

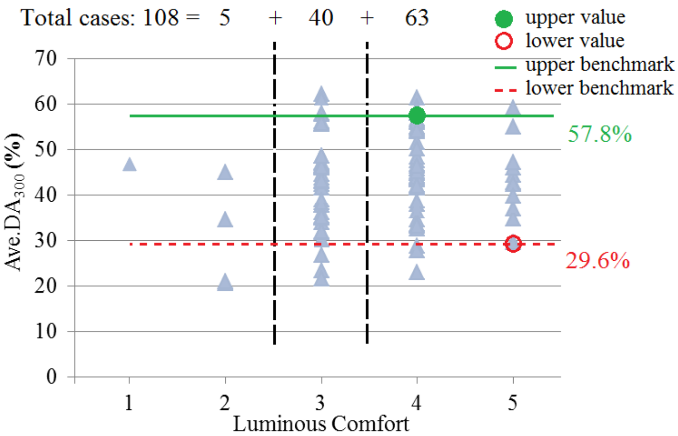


Fig. 3. Bivariate association between luminous comfort and Ave. DA_{300}

As shown in Fig. 3, Ave. DA_{300} presents a strong relations with luminous comfort level. This trend can be described as narrow scope at the high comfort level side and wide scope at the low comfort level side. The value of this metric is relative concentrated from the residents with the highest luminous comfort level, and this scope becomes wider with the decreasing of the comfort level. In other words, for the widely accepted comfort environment, the value of Ave. DA_{300} should not be too low, either not too high. The low value indicates the lack of daylight, while the high value means too much daylight which may bring glare, overheat and fading furniture problems to residents.

Referring to the thermal field, even in the most thermal comfort condition there still exist at least 5 % people who feel dissatisfied [42]. That is to say the dissatisfied rate never goes below 5 %. If the benchmark is established like this, it is essential to find a threshold that guarantees 95 % of the satisfied units are included. The satisfied category was grouped with the luminous comfort of level 4 and level 5. Therefore, with the total satisfied number of 63, the comfort value of Ave. DA_{300} ranges from 29.6 % to 57.8 %.

3.2 Comfort level in density buildings

Obtained from the climate-based daylight simulation, Ave. DA_{300} is proved to represent the luminous comfort level from the real on-site survey. Based on the real model mentioned in section 2.2, 96 cases

(4 orientations, 4 distance, 4 floor levels and 2 rings) are then built to study the units' possible daylighting performance in density buildings. All of the Ave. DA_{300} results in 96 cases are shown in Fig. 4. Each subgraph contains 16 units in a certain ring and a certain distance among buildings.

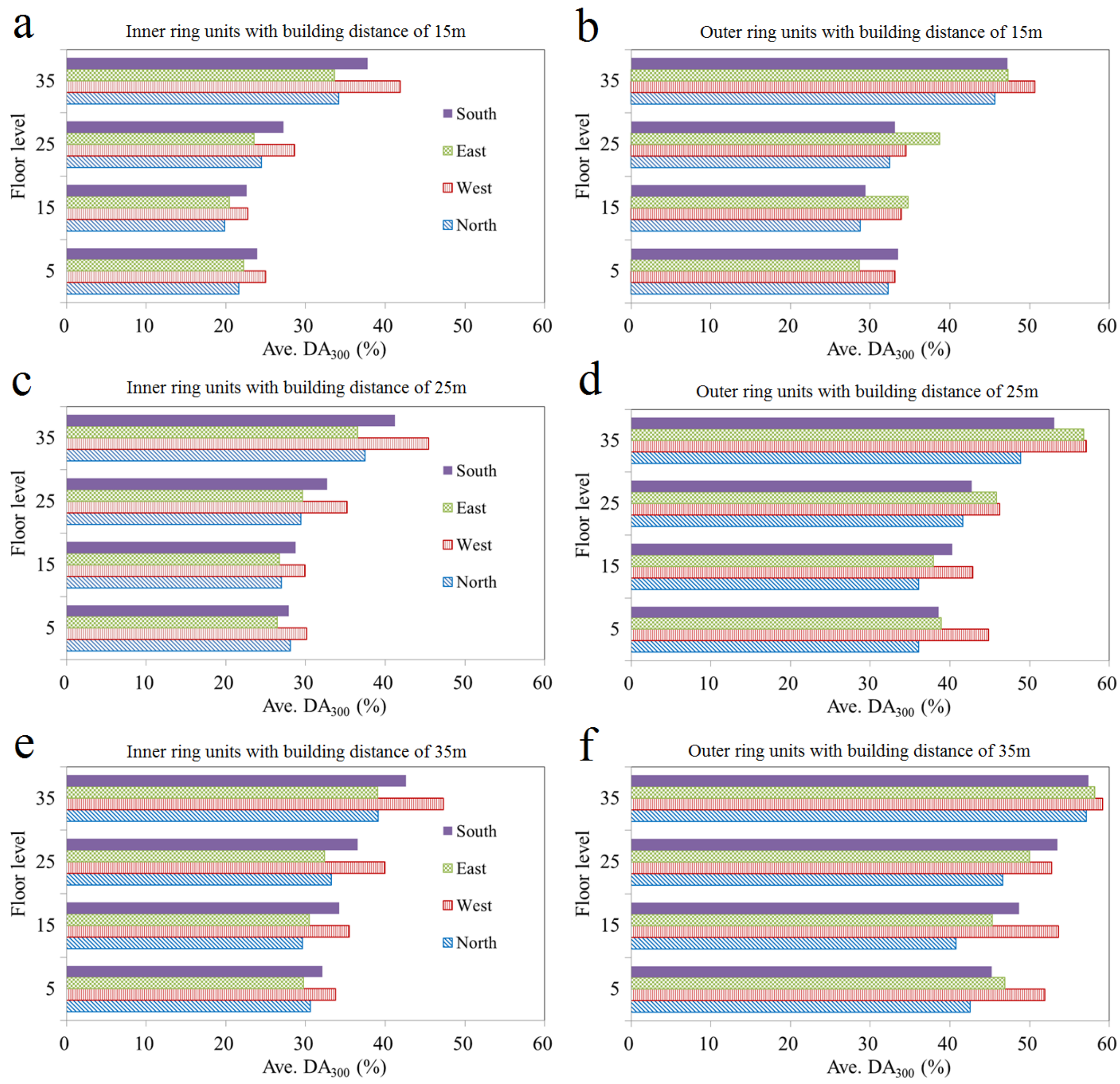


Fig. 4. The Ave. DA_{300} of all cases

From any subgraph in Fig. 4, it can be easily concluded that a higher floor has a higher value of Ave. DA_{300}, no matter for inner units or outer units. The longer distance between the buildings also offers a better opportunity to receive the daylight as Ave. DA_{300} increases with the increasing of the distance. Compared with units in inner ring, the ones in outer ring have a bigger value of Ave. DA_{300} because they are less likely to be shaded by the building itself. From the data, the value of the outer units can be 25% more than the inner units. This is often the truth that the all these three factors, namely distance between buildings, floor levels, and inner or outer rings, reflect the condition of obstruction.

When comparing the results among different orientations, the units facing west always obtain the highest Ave. DA_{300} than other sides. While, the units facing north often have the lowest value of the Ave. DA_{300}. This is because the north units received the least daily direct sunlight. The south units do not have the best performance as the solar elevation angle is too high. The reason that the west units and east units have different performance results from the position of the window, which is not fixed in the middle of the external wall. However, the difference among the orientations is acceptable as sunlight can still shine into the north units. This is benefit from the location of Hong Kong, which is situated just south of the Tropic of Cancer.

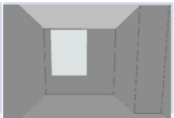
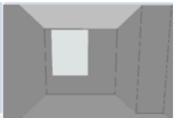
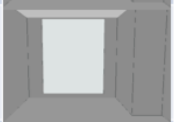
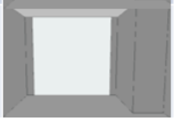
Considering the comfort benchmark of the Ave. DA_{300}, some bad conditions cases can be found refer to the results in Fig. 4. Almost all outer ring units meet the standard value with the distance between buildings more than 15 m, except for few lower floor level units. For the inner ring units, all units under 25 floor level with the distance between buildings of 15 m could not reach the standard (Ave. DA_{300} equals to 29.6%), which means they could not receive enough daylight. Aiming to guarantee the condition of the inner ring lower level units, the distance between the buildings should be more than 35 m. However, in that condition, the outer ring high level units could beyond the upper benchmark very much (Ave. DA_{300} equals to 57.8%), which may bring overheat problem.

Therefore, the façade of all units should not be the same. In other words, inner and lower units need to bring more light into the room, while outer and higher units need to block some light and save energy.

3.3 Optimization of windows (daylighting system)

To bring more light into the room, enlarging the openings on the wall is the most common way. Enlarging a single window and opening a secondary window are two different scenarios. To enlarge a single window for the living room, 5 cases are built according to the reference case. The aspect rate of the reference window is 1.25 and so do the other cases. The window to wall rate (WWR) of the reference case is 0.35 and the following cases are built with the WWR of 0.45, 0.55, 0.65, 0.75 and 0.85. The corresponding window to floor rates (WFR) are shown in Table 1. Another way to enlarge the window size is opening a secondary window for the living room. As the outer ring units in Hong Kong residential buildings always have two outer walls, so it is very likely and possible to open an additional window for the living room. 5 more cases are built according to the Case 1 to 5. There is no changing about the reference window, and the secondary window is set on the other side of wall in a square shape. WWR is not available as new cases have an additional window on another wall, therefore, the WFRs of the new Case 6 to 10 are equal to the ones of Case 1 to 5 respectively, as shown in Table 1.

Table 1. Cases of window openings with different dimensions (unit: m)

Case	Height	Width	WWR	WFR	Drawing	Case	Height	Width	WWR	WFR	Drawing
Reference	1.755	1.405	0.3544	0.1263		Reference	1.755	1.405	0.3544	0.1263	
1	1.979	1.584	0.4505	0.1606		6	0.820	0.820		0.1608	
2	2.188	1.751	0.5507	0.1962		7	1.170	1.170		0.1964	
3	2.378	1.904	0.6508	0.2319		8	1.435	1.435		0.2318	
4	2.530	2.063	0.7502	0.2673		9	1.659	1.659		0.2673	
5	2.530	2.338	0.8502	0.303		10	1.858	1.858		0.3031	

The two ways of changing window size has been presented, and the effective one should be selected by comparing the results together. To make the comparison clear, the results of units facing south orientations are presented in Fig. 5.

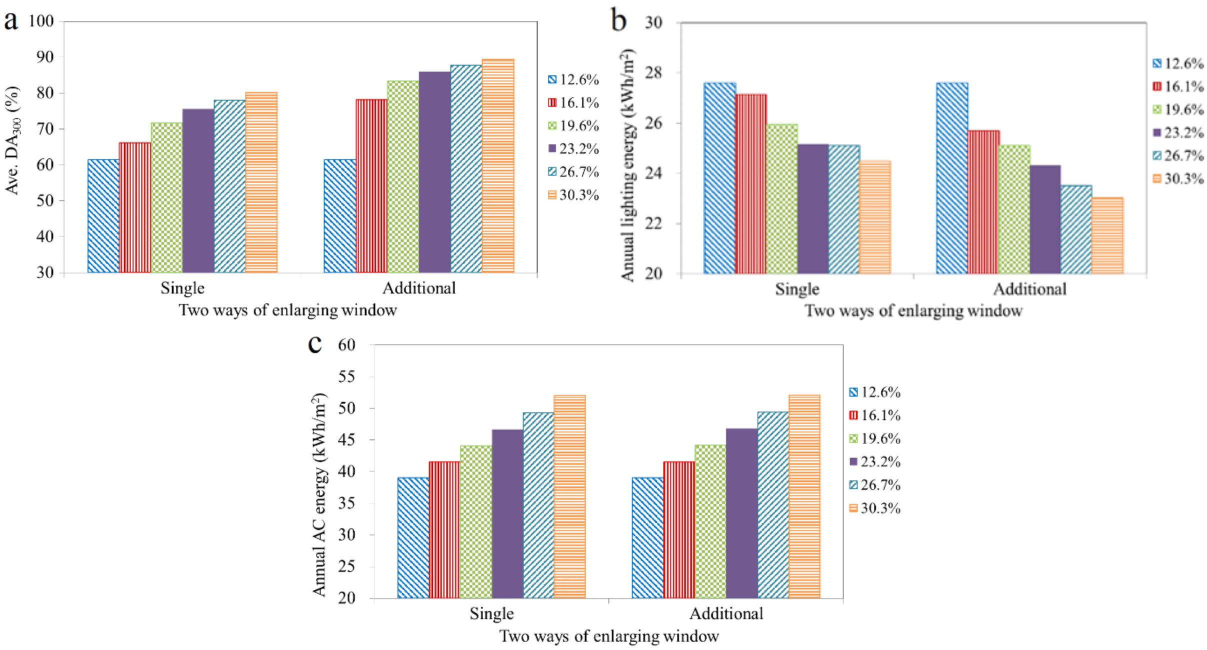


Fig. 5. Comparison between the two ways of enlarging window in facing south unit: a) Ave. DA_{300}; b) lighting; (c) AC

From the Fig. 5, with the same value of WFR, opening additional window has obvious advantages in improving Ave. DA_{300} than enlarging the single window. This is because the additional window is faced to west, and it could receive much more direct sunlight in the afternoon than the same area of south window. What's more, it could also reduce the energy consumption of artificial lighting. About the solar heat gains, both two methods have a similar results as the opening areas of the window are the same. The advantage of the secondary window can be concluded as it bring more light to the poor daylighting condition area, while the other is not.

In these two scenarios, the energy of AC increases more than the reduction of artificial lighting. Considering both daylighting and energy performances, it is scientific and easy to evaluate these two scenarios by adopting the new parameter, energy daylight rate (EDR). The result is shown in Fig. 6.

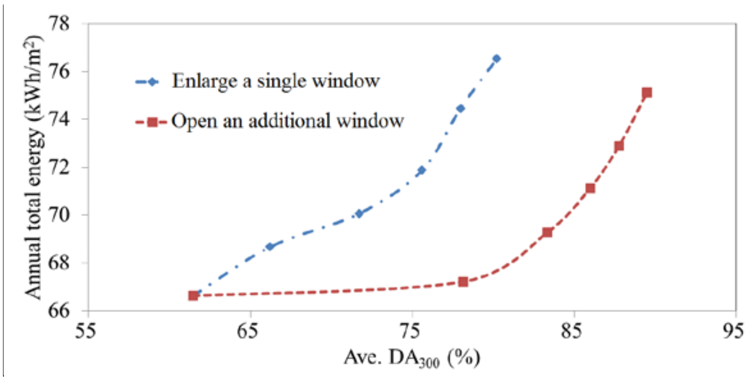


Fig. 6. EDR (slope) of two scenarios for window opening

In the Fig. 6, the slopes between the points are EDRs. When adopting daylighting system, the EDR should be as small as possible, even to the negative value. In other words, improving daylighting performance will lead to a relative increasing of energy consumption even a reduction. As seen from the figure, the EDR for opening additional window is smaller than enlarging as single window. This results from the similar energy performances and different daylighting performances. It means that to improve the Ave. DA_{300} into the same level, a secondary window will add less total energy for the unit. Therefore, it can be concluded that opening an additional window is a better way than enlarging the single window. It's better to open a second window in the living room, no matter how small it is.

3.4 Optimization of shading system

In the high-rise residential buildings in Hong Kong, some of the outer units and higher floor level units may need shading system to block more light into the room. To prevent direct sunlight and solar heat gains, most of the public housing are integrated with overhangs outside each units' living room. To optimize the performance of the overhang, two scenarios are proposed based on the dimensions of the configuration (Fig. 7). Overhang's length and tilted degree are studied and the results are presented.

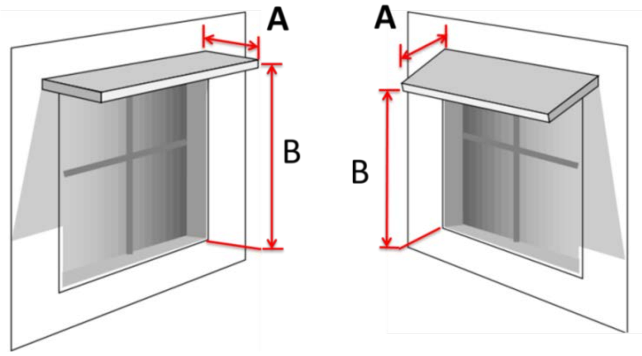
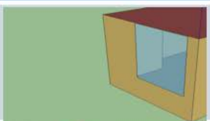
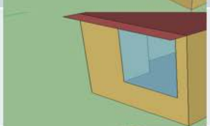
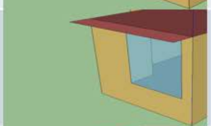
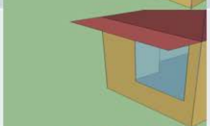
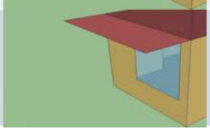


Fig. 7. Configuration of an overhang

In current public housing units, the overhang outside the living room is measured with the A of 0.375 m and B of 1.780 m horizontally. To study the different lengths of the overhang, models are built with the dimensions shown in Table 2. A case without overhang and three cases with longer overhangs are built without any outside obstruction. Four more cases are built according to the reference case to further study the tilted degree of the overhang. The overhang width (A) stays as 0.375 m in horizontal, and the edge points will be up and down with a certain slope. The selected slope degree are tilted up 20°, tilted up 10°, tilted down 10° and tilted down 20°. The detailed dimensions of the built overhangs are also shown in Table 2.

Table 2 Cases of overhangs with different dimensions (units: mm)

Case	A	B	Drawing	Case	Tilted degree	A	B	Drawing
No overhang	0	1780		21	20°	375	1916	
Reference (Now)	375	1780		22	10°	375	1846.1	
11	500	1780		Reference	0	375	1780	
12	750	1780		23	-10°	375	1713.9	
13	1000	1780		24	-20°	375	1644	

The two ways of optimizing overhang has been presented, and the effective way should be investigated by comparing the results together. The same as daylighting analysis, only the results of units facing south direction are presented in Fig. 8.

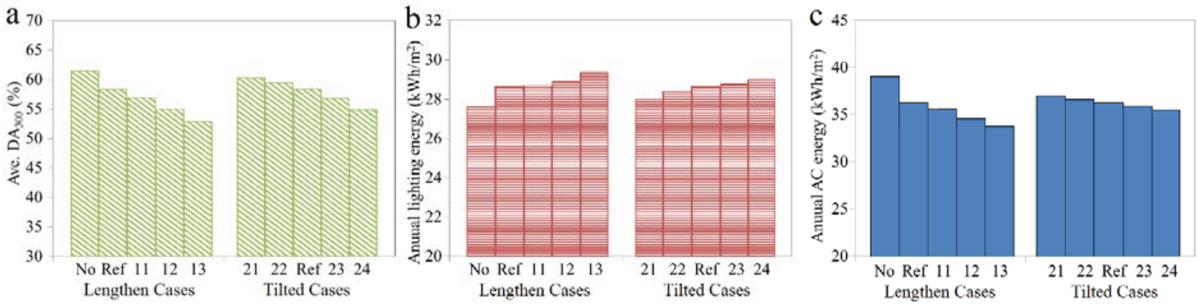


Fig. 8. Comparison among different scenarios: a) Ave. DA_{300}; b) lighting; (c) AC

From the Fig. 8, the Ave. DA_{300} decreases with length from short to long and the tilted degree from up to down. The units without overhang and with tilted up overhang will have the larger value of the DA than the reference case. The lighting energy increases with length from short to long and the tilted degree from up to down. The units with tilted up overhang have the greatest potential to save lighting energy. The AC energy decreases with length from short to long and the tilted degree from up to down and the units with longer overhang have the greatest influence on saving AC energy.

In these two scenarios, the changing of AC energy is still more than the changing of artificial lighting. Considering both daylighting and energy performances, it is scientific and easy to evaluate these three scenarios by adopting the EDR. The result is shown in Fig. 9.

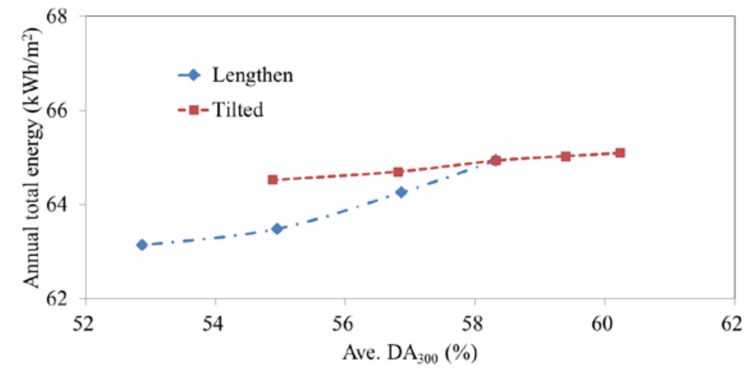


Fig. 9. EDR (slope) of two scenarios for shading

In the Fig. 9, the slopes between the points are EDRs for shading. When adopting shading system, the EDR should be as big as possible. In other words, compromising daylighting performance should lead to a relative decreasing of energy consumption as well. As seen from the figure, the EDR of changing overhang’s length is bigger than the other. It means that to reduce the same amount of total energy, lengthening overhangs will compromise less daylighting performance and luminous comfort. Therefore, it can be concluded that lengthening overhangs is a better way for shading.

4 Discussion

As Hong Kong is situated just south of the Tropic of Cancer, all orientations could reach the direct sunlight. Then the wall in each direction should consider both luminous comfort and energy saving. In order to select the better scenarios and make the comparison clear, the results in section 3.3 and 3.4 only present the units facing south direction. By adopting the EDR method for units facing south, an efficient way for daylighting purpose is to open an additional window and for shading purpose is to lengthen the overhang. The efficient ways for units facing other directions should be also investigated. Sections 3.2 only shows the comparison of daylighting performance among orientations, and the comparison of energy performance will be presented in this section.

4.1 Energy performance in orientations

Aiming to explain the energy performance more accurate, the consumption used by lighting and AC are calculated separately. As the trend of the energy performance is relatively stable among orientations, the results of the efficient ways for daylighting (opening an additional window, Case 6 to 10) and shading (lengthening overhang, Case 11 to 13) are shown in Fig. 10 and 11.

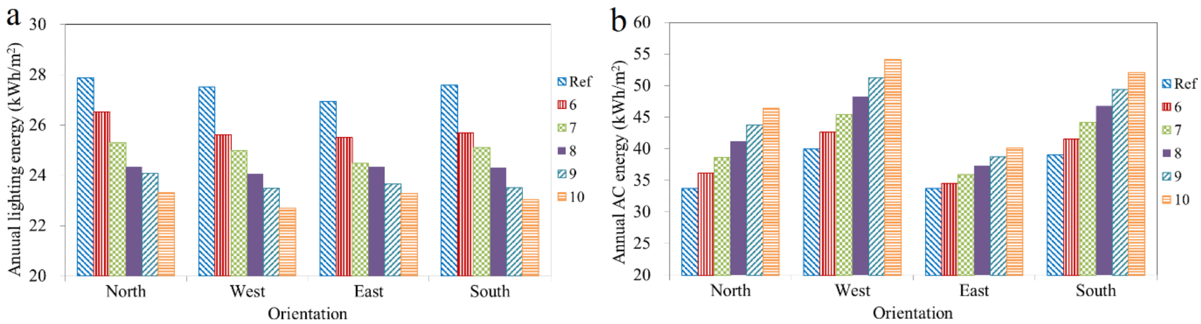


Fig. 10. Energy performance in all orientations by opening additional window: a) lighting; b) AC

Fig. 10a shows the artificial lighting consumption, and the reference case consumes the most all over the year. The bigger the additional window is, the more light it will bring. Therefore, the consumption of lighting decreases. For the orientation, the units not differ too much in the value of annual lighting energy. But it can also be found that the units facing east consume the least while the units facing north consumes the most. For the AC energy (Fig. 10b), bigger window brings more solar heat, so does the cooling load. The units facing west consume the most energy for AC while the units facing east consumes the least. This is because the units facing east has an additional windows facing north, while the units facing north has an additional window facing west, and the increasing area of additional west window has a bigger influence than that of north window.

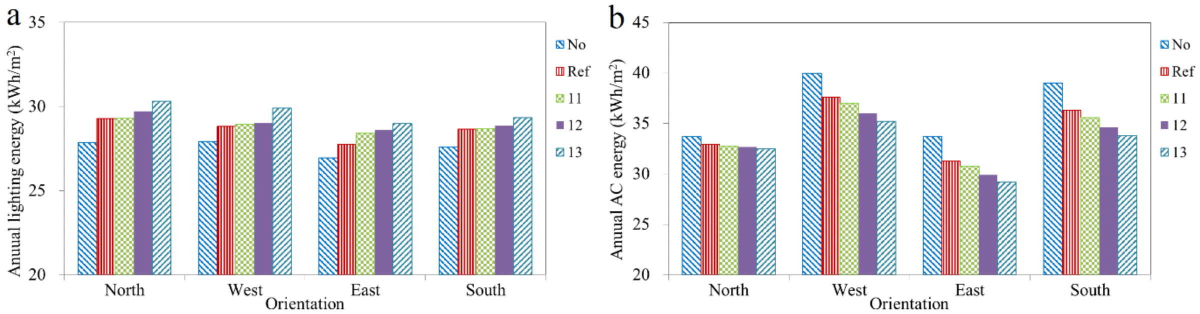
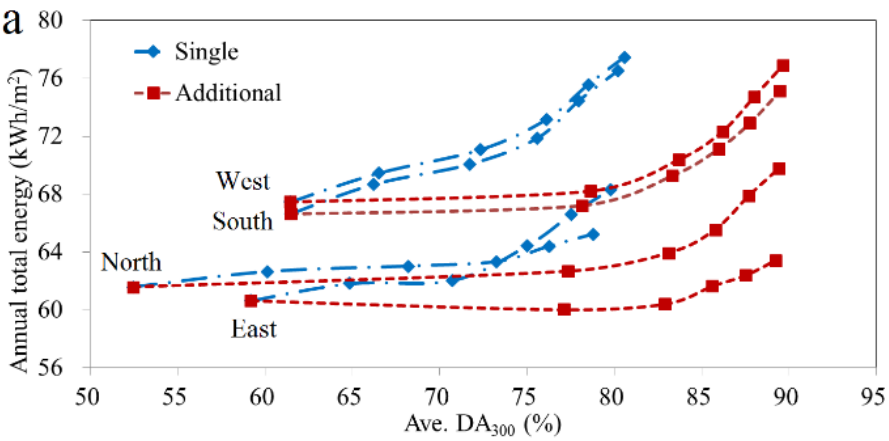


Fig. 11. Energy performance in all orientations by lengthening overhang: a) lighting; b) AC

Fig. 11a shows the artificial lighting consumption, and the utilization of the overhang will affect the lighting usage very much. The units with longer overhang will consumes more energy on artificial lighting. The fact can be also found that the units facing north consumes the most while the units facing east consume the least. For the AC energy (Fig. 11b), the consumption differs not too much. The results show that the units facing west use the most annual AC energy to eliminate the cooling load and the units facing east use the least.

4.2 Efficient scenario in orientations

With more daylight into the room, it can be concluded that the daylighting performance and AC consumption increase while lighting consumption decreases in all orientations. However, the changing values are not the same, which may lead to different efficient scenarios for units facing different directions. To select the better scenarios, the EDR method is adopted here again, and the results are shown in Fig. 12.



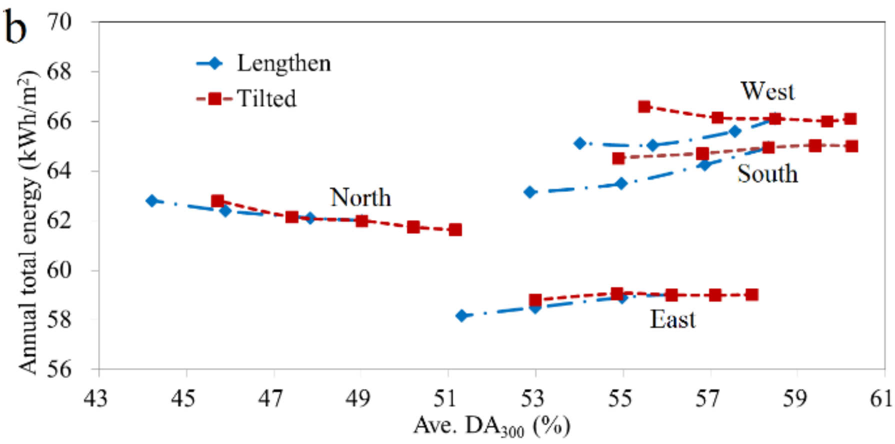


Fig. 12. EDR (slope) in all orientations: a) daylighting scenarios; b) shading scenarios

In Fig. 12a, the EDR results of daylighting scenarios for four typical units facing different directions are shown. Though the four reference case have different energy and daylighting performances, the daylighting scenario for bringing more light into the room is the same. Opening an additional window is a better way compared to enlarging the single window for all orientations.

In Fig. 12b, the EDR results of shading scenarios for different directions could not lead to a unified conclusion. The scenarios of lengthening overhang for units facing west, south and east show a better performance than make the overhang tilted down. The EDR value should be as big as possible to decrease the energy consumption with the decrease of daylighting performance. However, the EDRs of the unit facing north are negative under both scenarios. In other words, adopting shading system for the units facing north will lead to an increasing in lighting energy, even to the total energy consumption. Therefore, this kind of units should use the internal shading instead of any shading scenario for envelope design.

5 Conclusions

In this study, a questionnaire survey of residents' subjective feelings about luminous environment is first conducted. 108 cases are then simulated based on the real condition of the marked units to quantify the satisfaction of luminous environment with a dynamic metric, Ave. DA_{300}. Then the benchmark of this metric is guided range from 29.6 % to 57.8% for high-rise residential buildings.

With this guideline, 96 cases are built and simulated to study the influence of orientations, rings, floors, and distance between buildings on the units' daylighting performance. The results found daylighting performance differs much from the orientations and floor levels in Hong Kong public housing units. Therefore, the façade of all units should not be the same. In other words, inner and lower units need to bring more light into the room, while outer and higher units need to block some light and save energy.

To help decide the best scenario of envelope design for both daylighting and shading purposes, a new index, energy daylight rate (EDR), is proposed. Based on the simulation results, several general conclusions could be drawn:

1) With the same feature, the units facing west and south always have higher values of Ave. DA_{300} and consumes more AC energy; the north units always obtain the lowest value of Ave. DA_{300}; the units facing east always use the least annual lighting energy;

2) Opening an additional window is a better way than enlarging the single window for all orientations. It's better to open a secondary window in the living room, no matter how small it is;

3) Lengthening overhangs will compromise less daylighting performance and luminous comfort and it is a better way for shading than make overhang tilted down;

4) Adopting shading system for the units facing north will lead to an increasing in lighting energy, even to the total energy consumption. These units should use the internal shading instead of any shading scenario for envelope design.

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