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Residents' preference of solar access in high-density sub-tropical cities

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Abstract

Solar access refers to the ability of a living unit to continue to receive sunlight without obstruction from any other properties or structures. The provision of appropriate solar access is considered to be important to residents' health, comfort and daily living. Guidelines and standards for the provision of sunlight have been formulated in the past few decades in low-density living environment. In subtropical high-density living environment like Hong Kong, associated guidelines and standards are generally lacking and it has become a growing concern for better provision of sunlight to residential units. It is also important to consider residents' preference of solar access in the formulation of standard for solar access and daylighting, as well as urban planning and building design. The present paper presents the results of a questionnaire survey regarding residents' preference of solar access in terms of time, amount, place, and purpose of the exploitation of sunlight, as well as an exploratory factor analysis (EFA) which examines the influence of environmental parameters on residents' preference. Results show that the majority of the respondents (72.0%) were satisfied with the current situation of solar access in their households. Only 12.4% of the respondents felt unsatisfactory about solar access of their flats. Over half of the respondents preferred to have sunlight penetration into their households in the morning. There is likely a need to improve the provision of solar access in terms of the time of sunlight received by residents since only about 40% of the respondents had the same time of sunlight entering their flats as they expected. There are not any particular preferences of the expected amount of solar access. Sufficient solar access was found to be more important than view outside respondents' flats with an overwhelming 70.2% of the respondents in favor of sufficient solar access. The EFA results indicate that observed microclimatic parameters were the dominant influencing factors and closely followed by visual elements of residents' subjective feelings about their flats. It implies that the incorporation of microclimatic environments into current design standard and guidelines should be considered. Further studies can also be conducted to examine the behavior of residents, i.e. activities occurred in the units, in more details. Current findings provide a basis of the preference of residents to solar access of residential flats in high-density tropical cities using Hong Kong as a case study. Policy-makers, as well as planners and architects, should therefore take the findings into account when establishing appropriate guidelines and standards, especially for high-density subtropical cities, in order to provide residential units with better sunlight environment.

Keywords: Sunlight; Solar access; Exploratory factor analysis; Questionnaire survey; High-density living; Residential

1. Introduction

The provision of appropriate solar access in residential units is recognized as an important contribution to comfort and household activities. Sunlight, as an important component of household lighting, has been proved that it helps to maintain health and prevent a wide range of diseases (Durvasula et al., 2010; Holick, 2008; Kricker and Armstrong, 2006). Sunlight also plays a significant role in energy efficiency of buildings as it provides warmth and illumination to households. Many studies suggested that the provision of sunlight, combining with sustainable building design, have the potential in reducing energy

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consumption by heating and cooling, illumination, and operation of buildings (Fontoynont et al., 1984; Menzies and Wherrett, 2005; Ne'eman and Shrifteilig, 1982).

People's attitudes to sunlight vary across different climatic regions of the world (Littlefair, 1996). Occupants of buildings in hotter countries may prefer sunlight to be excluded and controlled in order to avoid over-heating. In contrast, occupants in cooler countries like those in high-latitude northern hemisphere considered sunlight a pleasure rather than a nuisance (Collins, 1976; Ne'eman, 1974). The demand for sunlight also differs from the type of building and activities performed by the occupants (Ne'eman, 1974). In his questionnaire study on occupants' perception of sunlight, it was found that the proportion of occupants considering sunlight as pleasure ranged from 93% in residential units to 31% in hospital (staff). The activities occurred in the buildings also influenced occupants' perception. In the case of hospital, 93% of the patients considered sunlight as pleasure while only 31% of the staffs reckoned that sunlight has a pleasant effect.

Day and Creed (1996) also conducted a pilot study on the relationship between residents' subjective assessments of the sunlight received in dwellings and objectively calculated reference quantities. It suggested that residents were more sensitive to differences in insolation of dwellings when the survey was conducted in winter than that conducted in summer. Their findings supported the guidance suggested by the British Standard (*BS8206 Lighting for Buildings Part 2. Code of Practice for Daylighting*) that "the best way of define design recommendations is by careful analysis of the subjective responses on one hand and the effects of availability, orientation, latitude and local conditions on the other" (Day and Creed, 1996, p.51). Littlefair (1992) also detailed the standard and guidance suggested by the BS8206, which aim to ensure that sunlight is adequately provided to buildings and open spaces and solar heat is available at appropriate times of year. However, this standard is designed for low-density living environment and may not be appropriate for places with extremely high-density and sub-tropical climatic conditions like Hong Kong. Social and habitual aspects were not sufficiently considered by current standards and guidelines. As such, there is a great potential for the development of standards and guidelines on the provision of sunlight in high-density living environment.

One key issue associated with the provision of sunlight in high-density living environment is the seasonal variation in the availability of sunlight and daylight (Ng, 2003). The massive heat brought by summer sun causes a wide range of problems such as increasing consumption of energy by air-conditioning, thermal discomfort, and deterioration to building structure and furniture. On the other hand, residents would exploit the benefits of summer sun by drying clothes and beddings. Comparatively speaking, winter sun is generally more welcoming due to thermal comfort and reduced energy loads in times of cold weather. It is therefore important to incorporate residents' preference of solar access into the formulation of standard for solar access and daylighting, as well as energy-efficient building design. However, the understanding of desirable amount of solar access to residents living in high-density cities like Hong Kong is generally lacking. Although objective measurements and modellings of sunlight penetration are widely implemented (Knowles, 2003; Littlefair, 1998, 2001), subjective responses of residents' perception of solar access are rarely studied, especially in high-density living environment. It therefore results in a lack of basis for the consideration of solar access in urban planning and building design.

This paper presents residents' preference of solar access in their households, using the results of a questionnaire survey conducted in summer 2009. It aims to address the desirable amount of solar access to residents living in high-density living environment, using public rental housing estates in Hong Kong as a case study. Exploratory factor analysis (EFA) was carried out to examine how environmental parameters influence residents' preference of solar access. The results will contribute to the basis for potential guidelines and standards for the provision of sunlight in residential units in order to provide appropriate solar access to residents.

2. Methodology

2.1. Questionnaire survey

In order to obtain residents' preference of solar access, a questionnaire survey was conducted in August, 2009 in three different public rental housing estates in Hong Kong. The estates are located in three different urban areas characterized by the high-density living environment and were inaugurated in the last decade with the contemporary architectural styles adopted in public housing development. These recently inaugurated estates were chosen because the future planning and design of public housing development will be based on the current practice. Households were randomly selected to cover a wide range of flats with different aspects, levels and sizes.

Personal questionnaire surveys were conducted due to the following reasons:

- Residents could respond to the survey questions when they actually perceive the current situation of solar access in their households. It could therefore provide more accurate responses with instant perception.
- Confusions to the survey questions could be avoided since they are immediately explained by the interviewers during the survey period.
- More information apart from the survey questions could be obtained as interviewers may ask for further elaboration on their responses where it is appropriate.

The questionnaire focused on residents who live in public rental housing estates. It aimed at understanding the preference of residents to solar access that may not be adequately considered in current guidelines and regulations of solar access. In order to ensure the clarity and relevance of the questionnaire, a pilot study with a preliminary version of the questionnaire was conducted in another public rental housing estate. The questionnaire was revised according to the feedback and a final version was obtained. Data collected in the development stage was discarded before the commencement of the main data collection stage.

Questions regarding the current and preferred solar access were asked in the first part in terms of time and amount of sun exposure in households. The overall importance of solar access was also asked and the importance of sunlight penetration into different parts of the households. The respondents were further asked about if they agreed with different advantages and disadvantages to their households. The questionnaire also included questions about the background of the respondents such as the age, sex and level of education, as well as information about their households such as the number of occupants and length of occupation.

2.2. Exploratory factor analysis

Exploratory factor analysis (EFA) was chosen in the present study as it addresses the research questions, testing the environmental parameters that influence residents' preference of solar access specific to a particular sample (Guada et al., 2011). It provides a preliminary analysis of how and to what extent, residents' preference was influenced. Statistical results from an EFA may assist with determining underlying factors structures of environmental parameters which influence residents' preference of solar access. In order to achieve this, 10 environmental parameters, by both subjective and objective means, were submitted to a principal components factor analysis with varimax rotation. The scree test and the eigenvalues-greater-than-one rule were used to determine number of factors (DeVellis, 2003). The analysis was carried out with SPSS Statistics 17.0 for the present study.

3. Survey findings

Data collection was started on 10th August 2009 and completed on 26th August 2009. A total of 382 responses were obtained in the questionnaire survey. Obtained information was processed and divided into several categories of residents' preference of solar access in terms of time, place, amount, and purpose of the exploitation of sunlight.

3.1. Background of participants

Table 1 shows the background of respondents and information about their households. 54.7% of the respondents were female and 44.5% were male with 0.8% not recorded. The respondents were divided into three age groups. 25.4% of the respondents were under 25 years of age while 29.8% were over 50. 42.2% of the respondents ranged between 25 and 50 years of age with 2.6% not recorded. For the level of education, 6.8% had no formal education while 23.6% and 59.2% completed primary and secondary education respectively. 8.1% completed tertiary education or above and 0.5% had other types of education with 1.8% not recorded.

Table 1
Background of respondents.

No. of interviews	382				
Sex			*Level of education*		
Male	170	(44.5%)	No formal education	26	(6.8%)
Female	209	(54.7%)	Primary	90	(23.6%)
No information	3	(0.8%)	Secondary	226	(59.2%)
Age			Tertiary or above	41	(8.1%)
Under 25	97	(25.4%)	Others	2	(0.5%)
25–50	161	(42.2%)	No information	7	(1.8%)
Over 50	114	(29.8%)			
No information	10	(2.6%)			

Table 2
Information about occupancy.

	Length of occupancy (years)	Number of occupants	Hours stayed in the flat on a normal day
Count	376	379	375
Mean	5.7	3.9	8
Median	5	4	8
Mode	4	4	12
Maximum	12	10	12
Minimum	0.3	1	1
Std deviation	2.6	1.4	3.8

Information about occupancy is shown in Table 2. The average length of occupancy is 5.7 years with a standard deviation of 2.6 years. On average, there are 3.9 occupants (with a standard deviation of 1.4) in each surveyed household with a maximum of 10 occupants.

3.2. When does sunlight entering your flat?

The respondents were first asked to assess the time of solar access to their flats according to their impressions (Fig. 1). 18.1% and 21.2% of the respondents claimed that there was no sunlight penetrating to their living rooms and bedrooms respectively while a slightly higher proportion (22.3%) is observed for kitchens. However, the overall pattern was similar across living room, bedroom and kitchen. About 33% and 25% of the visited flats received sunlight penetration in the morning and afternoon respectively while approximately only about 14% had sunlight entering the flats at noon. In addition, approximately 10% of the visited flats received sunlight penetration for the whole day.

3.3. Do you reckon that there is enough sunlight entering your flat?

The adequacy of solar access was then assessed by the respondents. 72.8% of them felt that they have

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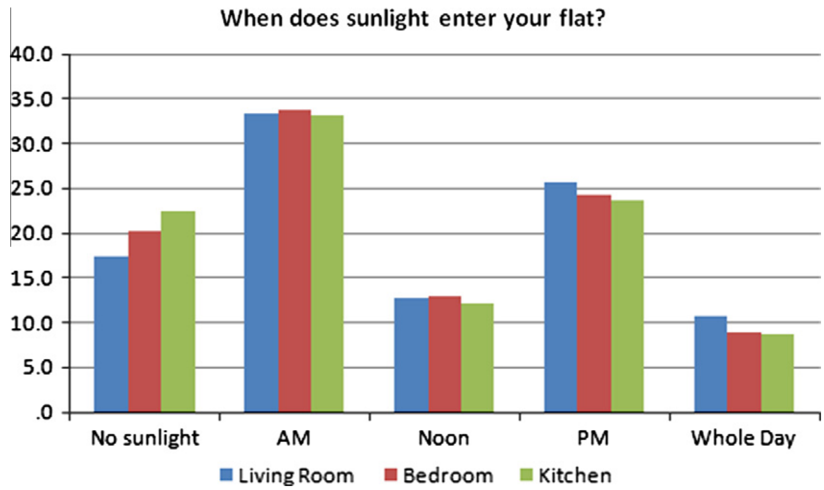

Fig. 1. Period of solar access as assessed by residents.

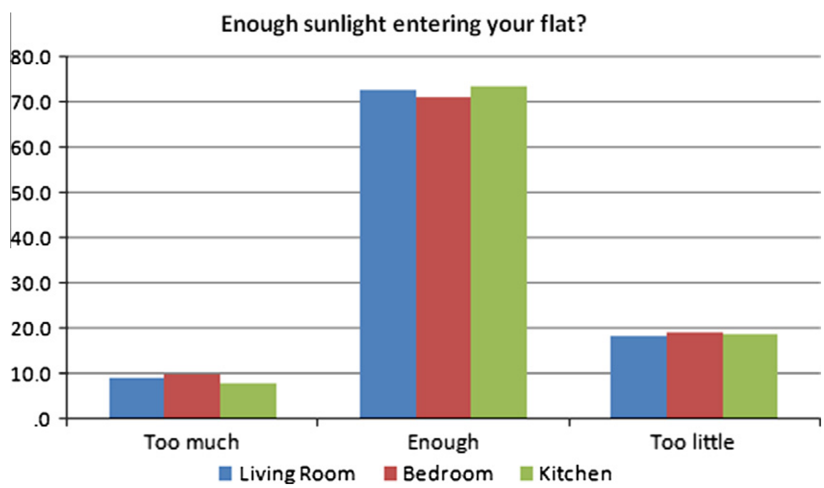

Fig. 2. Sufficiency of solar access.

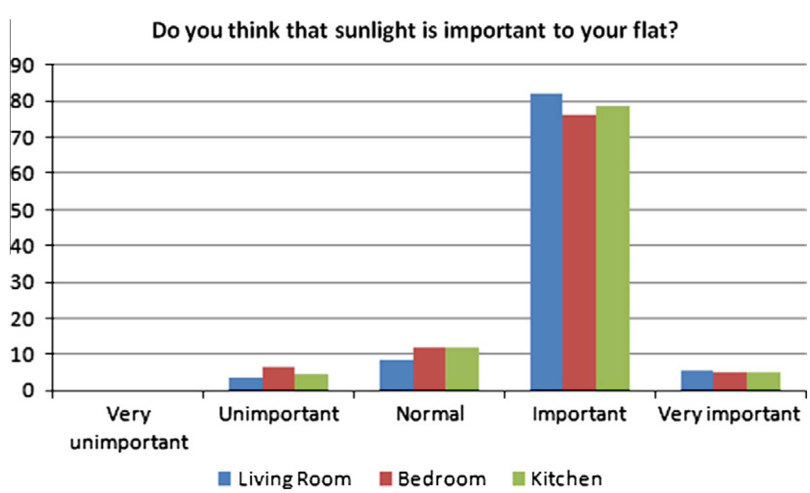

Fig. 3. Importance of sunlight to respondents' flats.

enough sunlight when it shone while 9.2% considered that there was too much sunlight in the living room. Despite of that, there were still near 20% of the respondents feeling that they receive too little sunlight. Similar figures were obtained for the bedroom and kitchen (see Fig. 2).

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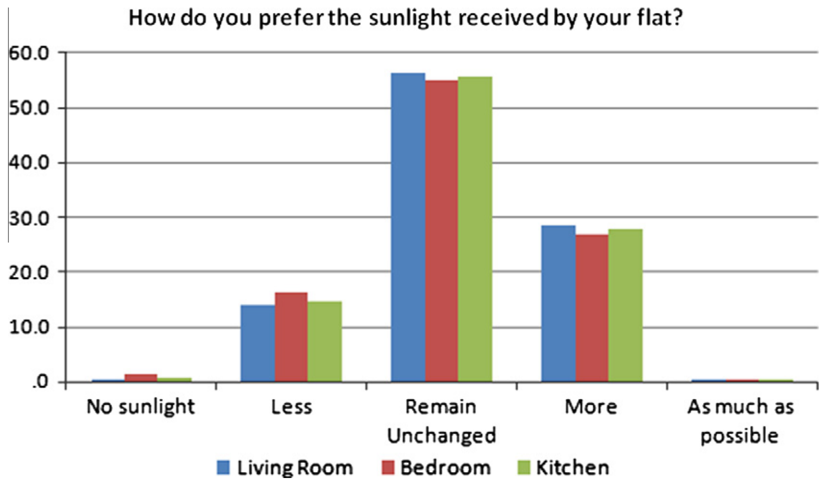

Fig. 4. Preferred solar access in compare to present situation.

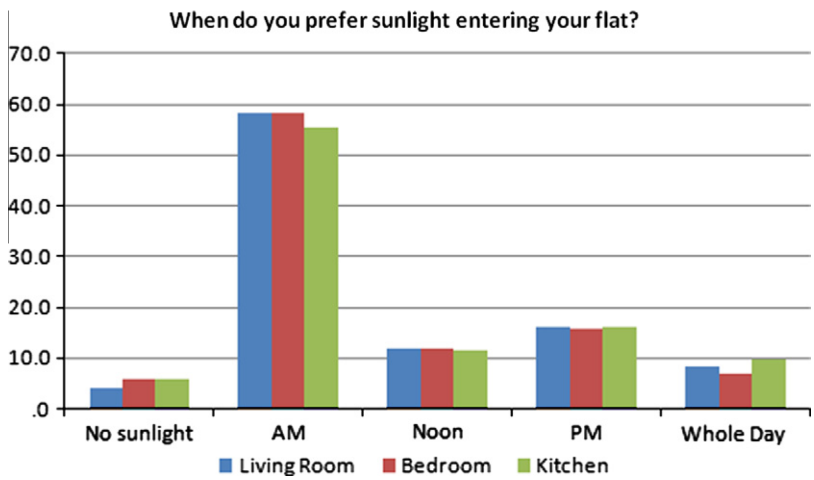

Fig. 5. Preferred period of solar access.

3.4. Do you think that sunlight is important to your flat?

As shown by Fig. 3, the majority (over 80% on average) took the attitude that sunlight is important to their flats, especially for living room (approximately 88%). About 20% of them reckoned that they received too little sunlight and would like to have more sunlight penetrating to their flats. 49.7% were satisfied with the current situation while 26.9% preferred more sunlight penetration into their living rooms. In further question asking the respondents to rank the importance of three parts of their flats (i.e. living room, bedroom and kitchen) to receive sunlight, over 80% of the respondents felt that it is the most important to have sunlight penetration into living room while near 60% reckoned that sunlight penetration into kitchen is of the least importance.

3.5. How do you prefer the sunlight received by your flat?

The respondents were then asked for their preferred solar access in compare to current situation. Around 56% of the respondents were satisfied with current availability of sunlight while another 28% of them would like to have more sunlight penetrating to their living rooms and kitchens (Fig. 4). There was also a slightly higher proportion (16.2%) of respondents who would prefer less sunlight in their bedrooms.

3.6. When do you prefer sunlight entering your flat?

58.1% of respondents preferred sunlight penetrating to their flats in the morning while 16.2% preferred sunlight penetration in the afternoon (Fig. 5). About 10% of them preferred to have sunlight penetration both at noon and for the whole day. Compared to the current period of sunlight penetration as assessed by the respondents, about 40% of the living rooms have the same period as the respondents expected.

3.7. How much sunlight do you prefer on a normal day?

The expected amount of sunlight as assessed by respondents is relatively variable (Fig. 6). For living rooms, 16.0%, 23.6% and 33.0% of the respondents expected to have about 1–2, 2–3 and 3–4 h of sunlight penetration to

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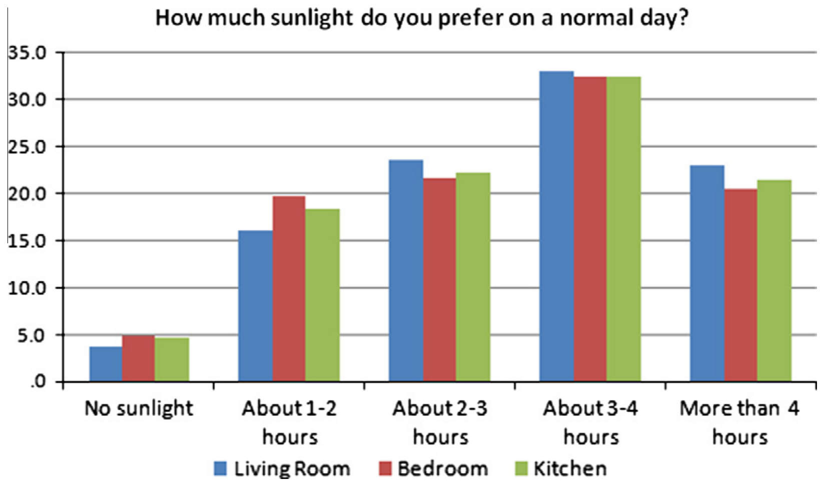

Fig. 6. Expected amount of solar access as quantified by the respondents.

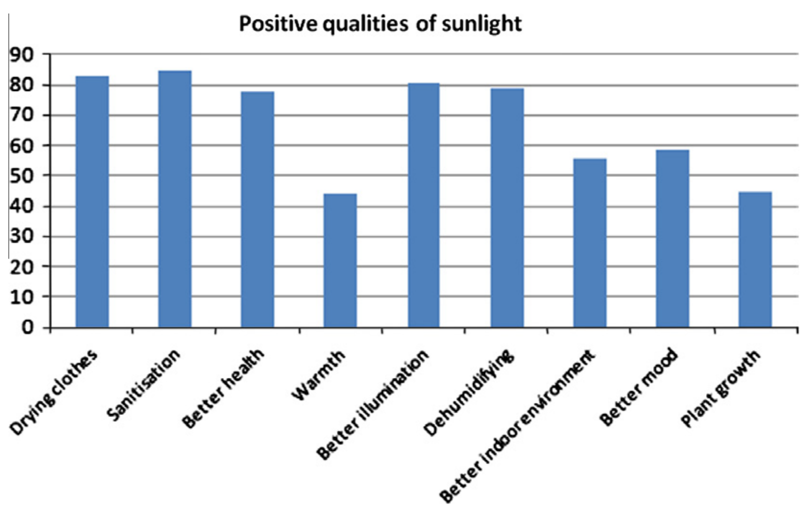

Fig. 7. Advantages of sunlight to residents' flats as assessed by respondents.

their flats respectively. A further 23.0% of the respondents would prefer more than 4 h of solar access per day at home. However, a higher proportion (19.6%) of respondents preferred to have 1–2 h of sunlight penetration to their bedrooms with less proportion to prefer long duration of solar access.

Among the respondents feeling that sunlight penetration into living rooms is enough, about one-third of them expected to have 3–4 h of solar access with slightly less figures obtained in bedrooms and kitchens (about 30%). More than 20% of the respondents expected more than 4 h of solar access on a normal day. It is also observed that respondents have fewer requirements on the amount of sunlight available for the bedrooms and kitchens. About 1–2 h of sunlight were more preferred for both bedrooms and kitchens (over 20%).

3.8. Positive and negative qualities of sunlight

Nine positive qualities or purposes were asked for the purposes or reasons why residents like sunshine (Fig. 7). Five of these were recognized by approximately 80% of the respondents, including drying clothes, sanitization, better health, dehumidifying and better illumination. Psychological effects provided by sunlight were recognized by about 58.6% of them while 55.8% agreed that provision of sunlight can enhance indoor appearance. Surprisingly, thermal comfort was less recognized with only 44.2% positive responses while the contribution to plant growth had only 44.8%.

Three negative qualities of sunlight, namely thermal discomfort, fading object and glare, were asked in the questionnaire (Fig. 8). The responses were much less than positive qualities with a maximum of only 50.3% on thermal discomfort. There are 23.8% and 31.4% of the responses considering fading objects and glare as disadvantages of sunlight respectively.

4. Effects of environmental parameters

Common factor analysis was carried out to investigate how environmental parameters, by both subjective and

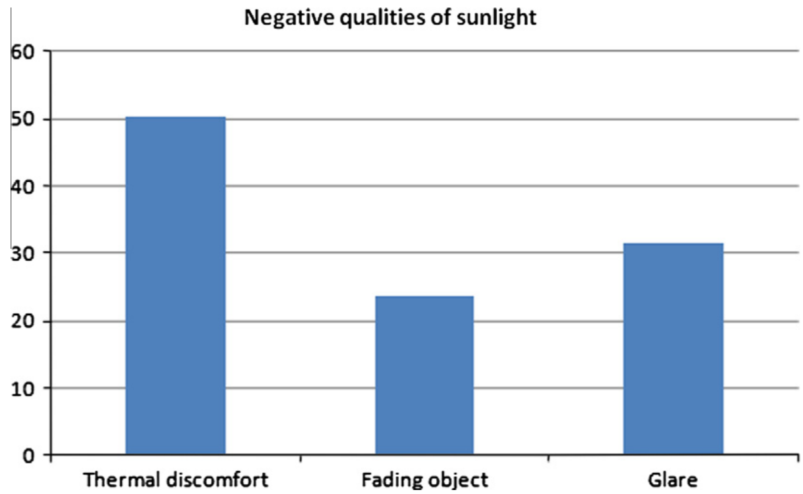

Fig. 8. Disadvantages of sunlight to residents' flats as assessed by respondents.

Table 3
Assessing the appropriateness of factor analysis: correlation among variables.

		V_1	V_2	V_3	V_4	V_5	V_6	V_7	V_8	V_9	V_{10}
V_1	Hotness	1.000	**−0.19**	0.082	−0.055	**−0.149**	−0.045	0	0.062	**0.126**	**−0.099**
V_2	Ventilation		1.000	**−0.226**	**0.311**	**0.322**	−0.007	−0.002	−0.014	0.062	**0.151**
V_3	Wetness			1.000	−0.076	−0.081	**−0.092**	**−0.102**	0.072	−0.067	0.082
V_4	Brightness				1.000	**0.283**	**0.095**	0.037	−0.081	**0.157**	**0.182**
V_5	View outside					1.000	0.03	−0.028	−0.033	0.013	**0.213**
V_6	Solar radiation						1.000	**0.936**	**−0.955**	0.032	0.035
V_7	Temperature							1.000	**−0.913**	0.072	0.007
V_8	RH								1.000	−0.033	−0.044
V_9	Orientation									1.000	−0.075
V_{10}	Level										1.000

Note: bolded values indicate correlations significant at the 5% significance level.
Overall measure of sampling adequacy: 0.720.
Bartlett's test of sphericity: 1943.142.
Significance: 0.000.

objective means, influence residents' preference for solar access. It aims to analyze the inter-relationships among different parameters and to explain these parameters in terms of their common underlying dimensions (factors). The respondents were asked about five subjective environmental parameters, including:

1. Hotness (Is it hot in your flat?)
2. Ventilation (Is your flat well-ventilated?)
3. Wetness (Is it wet in your flat?)
4. Brightness (Is it bright enough in your flat?)
5. View outside (Do you satisfy with the view outside your flat?)

Another five objective environmental parameters were incorporated into the factor analysis, including:

1. Observed solar radiation on survey day.
2. Observed temperature on survey day.
3. Observed relative humidity (RH) on survey day.
4. Orientation of the surveyed flat.
5. Level which the surveyed flat locates.

The overall significance of the correlation matrix of the 10 parameters was first assessed with the Bartlett's test at 1% significance level ($\alpha = 0.01$). 17 of the 45 correlations were statistically significant (Table 3). However, this test can only indicate the presence of non-zero correlations, but not the pattern of such correlations. As such, the measure of sampling adequacy (MSA) was carried out to examine the patterns between variables. In this case, the overall MSA value was in the acceptable range (above 0.50) with a value of 0.720. However, since V_9 (Level of the surveyed flat) had a MSA value under 0.50 (0.451), it was omitted in the further test in order to improve the MSA levels of the variables (Table 4).

Table 5 shows the correlation matrix of the revised set of variables (with V_9 deleted) with 16 statistically significant correlations out of a total of 36. As with the full set of variables, the Bartlett's test indicated that non-zero correlations exist at the significance level of 1%. The revised set of variables collectively satisfied the threshold of sampling adequacy with an overall MSA value of 0.728. With V_9 deleted, each of the variables also exceeds the threshold value (Table 6), indicating that the revised

Table 4
Assessing the appropriateness of factor analysis: measures of sampling adequacy and partial correlations among variables.

		V_1	V_2	V_3	V_4	V_5	V_6	V_7	V_8	V_9	V_{10}
V_1	Hotness	**0.602**									
V_2	Ventilation	−0.146	**0.606**								
V_3	Wetness	0.059	−0.206	**0.583**							
V_4	Brightness	0.026	0.235	−0.007	**0.608**						
V_5	View outside	−0.068	0.226	−0.03	0.16	**0.675**					
V_6	Solar radiation	−0.027	−0.128	−0.05	0.147	0.077	**0.687**				
V_7	Temperature	0.111	0.086	−0.056	−0.141	−0.131	0.546	**0.81**			
V_8	RH	0.074	−0.064	−0.08	0.034	−0.019	−0.688	−0.182	**0.771**		
V_9	Orientation	0.122	0.028	−0.041	0.17	0.005	−0.08	0.121	−0.002	**0.451**	
V_{10}	Level	−0.048	0.079	0.123	0.123	0.142	−0.005	−0.012	−0.025	0.09	**0.652**

Note: bolded values indicate measures of sampling adequacy (MSA).

Table 5
Assessing the appropriateness of factor analysis for the revised set of variable ("orientation" deleted): correlations among variables.

		V_1	V_2	V_3	V_4	V_5	V_6	V_7	V_8	V_{10}
V_1	Hotness	1.000	**−0.19**	0.082	−0.055	**−0.149**	−0.045	0	0.062	**−0.099**
V_2	Ventilation		1.000	**−0.226**	**0.311**	**0.322**	−0.007	−0.002	−0.014	**0.151**
V_3	Wetness			1.000	−0.076	−0.081	**−0.092**	**−0.102**	0.072	0.082
V_4	Brightness				1.000	**0.283**	**0.095**	0.037	−0.081	**0.182**
V_5	View outside					1.000	0.03	−0.028	−0.033	**0.213**
V_6	Solar radiation						1.000	**0.936**	**−0.955**	0.035
V_7	Temperature							1.000	**−0.913**	0.007
V_8	Relative humidity								1.000	−0.044
V_{10}	Level									1.000

Note: bolded values indicate correlations significant at the 5% significance level.
Overall measure of sampling adequacy: 0.728.
Bartlett's test of sphericity: 1917.175.
Significance: 0.000.

Table 6
Assessing the appropriateness of factor analysis for the revised set of variables ("orientation" deleted): measures of sampling adequacy and partial correlations among variables.

		V_1	V_2	V_3	V_4	V_5	V_6	V_7	V_8	V_{10}
V_1	Hotness	**0.593**								
V_2	Ventilation	−0.143	**0.598**							
V_3	Wetness	0.055	−0.207	**0.572**						
V_4	Brightness	0.048	0.243	−0.014	**0.636**					
V_5	View outside	−0.068	0.227	−0.03	0.163	**0.672**				
V_6	Solar radiation	−0.038	−0.131	−0.047	0.136	0.076	**0.69**			
V_7	Temperature	0.128	0.09	−0.061	−0.123	−0.131	0.542	**0.816**		
V_8	Relative humidity	0.074	−0.064	−0.08	0.034	−0.019	−0.69	−0.184	**0.77**	
V_{10}	Level	−0.06	0.076	0.127	0.11	0.142	0.003	−0.023	−0.025	**0.672**

Note: Bolded values indicate measures of sampling adequacy (MSA).

set of variables meets the fundamental requirements for factor analysis. Finally, only two partial correlations are higher than 0.50 (V_6–V_7 and V_6–V_8), which indicates the strength of the inter-relationship among variables in the revised set. All of the above measures suggested that the revised set of variables is appropriate for factor analysis and the analysis can proceed to the next stage.

Table 7 contains the information regarding the nine possible factors and their relative explanatory power as expressed by their eigenvalues. In addition to assessing the importance of each component, the eigenvalues can also be used to select the number of factors. If the latent

Table 7
Total variance explained according to initial eigenvalues.

Components	Total	% of Variance	Cumulative %
1	2.901	32.229	32.229
2	1.849	20.543	52.772
3	1.113	12.367	65.139
4	0.95	10.561	75.7
5	0.751	8.34	84.039
6	0.697	7.746	91.786
7	0.616	6.844	98.63
8	0.084	0.934	99.564
9	0.039	0.436	100

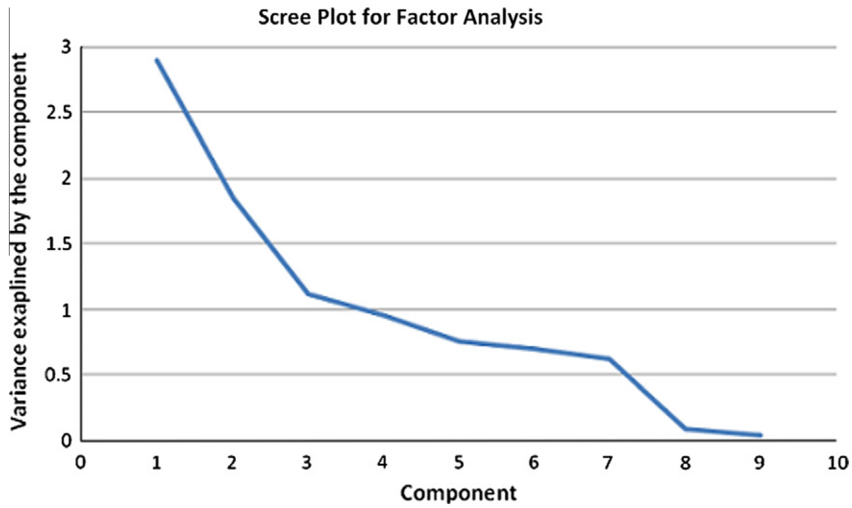

Fig. 9. Scree plot for factor analysis.

Table 8
Unrotated component matrix.

		Factor 1	Factor 2	Factor 3	Factor 4	Communality
V_1	Hotness	−0.082	−0.391	0.143	**0.857**	0.915
V_2	Ventilation	0.071	**0.728**	−0.233	0.075	0.595
V_3	Wetness	−0.154	−0.277	**0.783**	−0.117	0.728
V_4	Brightness	0.147	**0.619**	0.139	**0.419**	0.599
V_5	View outside	0.073	**0.688**	0.125	0.066	0.499
V_6	Solar radiation	**0.981**	−0.088	0.034	−0.002	0.972
V_7	Temperature	**0.961**	−0.141	−0.001	0.017	0.944
V_8	Relative humidity	**−0.973**	0.079	−0.045	0.026	0.956
V_{10}	Level	0.069	**0.445**	**0.622**	−0.126	0.605
						Total
Sum of Squares (eigenvalues)		2.901	1.849	1.113	0.95	6.813
Percentage		32.229	20.543	12.367	10.561	75.7

root criterion of retaining factors with eigenvalues over 1.0 is applied, three factors will be retained. However, the scree plot (Fig. 9) shows that four factors may be appropriate when considering the change in eigenvalues since the fourth factor was only slightly less than the latent root criterion value (1.0) with a value of 0.950. The four factors retained represented 75.7% of the variance of the nine variables, which is considered to be sufficient in terms of total variance explained.

The unrotated component analysis factor matrix is presented in Table 8. The factor loadings of each variable on each of the factors are shown and the sum of squared loadings (eigenvalues) is indicated at the bottom of Table 8. The sums of squares for the four factors were 2.901, 1.849, 1.113 and 0.950 respectively, with the corresponding percentage of 32.229%, 20.543%, 12.367% and 10.561% respectively. The overall solution shows that 75.7% of the total variance is represented by the information contained in the factor matrix of the four-factor solution. Therefore, the index for this solution is high and the variables are actually highly related to one another.

As expected, the first factor accounted for the highest proportion of the total variance while the second factor is somewhat a more general factor, with four variables having a high loading (>0.40). Both the third and fourth factors have two high loadings. It is noted that two of the nine variables were found to have cross-loadings and the significance of the loadings are fairly low. Rotation of the factor loading matrix may improve the understanding of the relationship among variables. All of the communalities were sufficiently high to proceed with the rotation of the factor matrix which obtains a simpler and theoretically more meaningful factor pattern by redistributing the variance from the earlier factors to the later factors.

The VARIMAX-rotated component analysis factor matrix is shown in Table 9. The total amount of variance extracted is the same as it was in the unrotated one (75.7%) since no variables have been eliminated. However, two differences were observed. First, the variance was redistributed so that the pattern of factor loading and the percentage of variance for each of the factors were slightly different. For example, the first factors accounted for 31.989% of the variance in the VARIMAX-rotated factor solution, compared to 32.229% in the unrotated solution. Likewise, the other factors also changed. The second factor was decreased by 0.932% while the third factor was

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Table 9
VARIMAX-rotated component analysis factor matrix.

		Factor 1	Factor 2	Factor 3	Factor 4	Communality
V_6	Solar radiation	**0.985**				0.915
V_7	Temperature	**0.97**				0.595
V_8	Relative Humidity	**−0.976**				0.728
V_4	Brightness		**0.744**			0.599
V_2	Ventilation		**0.689**			0.499
V_5	View outside		**0.686**			0.972
V_3	Wetness			**0.81**		0.944
V_{10}	Level		**0.45**	**0.609**		0.956
V_1	Hotness				**0.952**	0.605
						Total
Sum of squares (eigenvalues)		2.879	1.765	1.114	1.055	6.813
Percentage		31.989	19.611	12.378	11.722	75.7

Note: factor loadings less than 0.40 is not stated and variables are sorted by loadings on each factor.

Table 10
VARIMAX-rotated component analysis factor matrix for the reduced set of variables (V_{10} deleted).

		Factor 1	Factor 2	Factor 3	Factor 4	Communality
V_6	Solar radiation	**0.985**				0.943
V_7	Temperature	**0.969**				0.598
V_8	Relative Humidity	**−0.976**				0.931
V_4	Brightness		**0.787**			0.653
V_5	View outside		**0.728**			0.564
V_2	Ventilation		**0.647**			0.973
V_3	Wetness			**0.961**		0.944
V_1	Hotness				**0.965**	0.957
						Total
Sum of squares (eigenvalues)		2.876	1.582	1.07	1.034	6.564
Percentage		35.947	19.772	13.379	12.925	82.023

Note: factor loadings less than 0.40 is not stated and variables are sorted by loadings on each factor.

increased by 0.011%. Therefore, the explanatory power shifted slightly to a more even distribution due to the rotation. Second, the interpretation of the factor was simplified so that the factor loadings for each variable were maximized for each variable on one factor. In the rotated factor solution, all of the significant loadings were above 0.60, implying that more than half of the variance was explained by the loading on a single factor.

Cross-loading was observed in V_{10} (0.445 and 0.622 in Factor 1 and 2). Therefore, it had been omitted and the rotated factor matrix was recalculated. The rotated factor matrix and associated information for the reduced set of 8 variables are shown in Table 10. It was observed that the factor loadings remained almost identical and exhibited the same pattern. The amount of explained variance considerably increased to 82.023%. With the simplified pattern of factor loadings, all communities above 50% and the overall level of explained variance sufficiently high, the four-factor solution was accepted.

In the resultant factor solution, all the 8 parameters comprised the four factors derived from component factor analysis with a VARIMAX rotation of 8 subjective and objective environmental parameters affecting residents' preference of solar access. The cutoff point for interpretation purposes is all loadings ±0.40 or above. All the loadings were substantially above or below this threshold. In the first factor which accounted for over one-third of the variance, all the three observed climatic parameters had loadings over 0.95. Positive loadings were observed in solar radiation and mean temperature of the survey day (0.985 and 0.969) while negative loading was observed in relative humidity of the survey day. The second factor was comprised of three subjective environmental parameters assessed by the respondents, including brightness of the surveyed flat (0.787), view outside the surveyed flat (0.728), and the ventilation of the surveyed flat (0.647). It accounted for near 20% of the total variance. In the third and fourth factors, both with about 13% of the variance, both wetness and hotness had a loading of over 0.95 respectively.

5. Discussion

The total 382 responses allowed the present study to provide a reasonably representative picture of residents' preference for solar access in high-density living environment. The high number of responses shows that personal questionnaire survey is an effective way to obtain responses from a huge amount of residents, especially in areas with an aging population which has limited knowledge to other means of communications, for example, letter or online surveys. It also confirms that residents have their own perceptions of solar access in their households, despite guide-

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lines and regulations have been widely adopted in the design stage of development.

5.1. Residents' preference of solar access

The present survey shows that the majority of the respondents are satisfied with the current situation of solar access in their households. This may be a result of the incorporation of concepts of sustainability into the planning, design and construction of Public Rental Housing (PRH) estates since 2000 (Transport and Housing Bureau, 2007). It leads to better provision of sunlight penetration into residential flats in the increasing density of urban living environment. Nevertheless, there is still a considerable number (near 20%) of respondents considering that too little sunlight was received by their flats. Most of these respondents live in flats with north-facing façade which has virtually no sunlight penetrating into their flats. Care and consideration in the orientation of building blocks in an estate is recommended.

It is also shown that near 60% of the surveyed flats had sunlight penetration either in the morning or in the afternoon according to the respondents' perception. It can be explained by the predominance of east- or west-facing façade adopted in the three surveyed estates. The near 20% of the respondents which felt no sunlight entering their flats were found to be supportive to the perception of lack of sunlight penetration as mentioned above. When the respondents were asked about the preferred time of solar access, approximately 60% preferred to have sunlight penetration into their flats in the morning. Such figures were obtained since most of the respondents were housewives who exploit sunlight for household purposes such as drying clothes and sanitization. Designers must bear in mind this habitual preference when blocks are layouted and windows are positioned when they design the interior spaces.

Apart from the low percentage of preference for "no sunlight", there is not a particular preference for the expected amount of solar access. About one-third of the respondents expected to have about 3 to 4 h of solar access on a normal day. Such an amount of solar access is considered to be appropriate to respondents' households although the average time that the respondents stayed in their flats is near 8 h per day. Apart from that, there are near 25% of the respondents would prefer to have more than 4 h of solar access, which is predominantly required by respondents who stayed longer in their flats everyday. The respondents were further asked if they would choose to have sufficient solar access or better view of their flats. 70.2% of the respondents were in favor of sufficient solar access while the rest (29.8%) preferred to have better view outside their flats. It is supportive to the fair influence of the subjective parameters "view outside" in the factor analysis.

For the advantages of sunlight, five advantages were identified by about 80% of the respondents on average, namely drying clothes, sanitization, better health, dehumidifying and better illumination. As most of the households in PRH estates are lower-income families, drying machine are not common due to the high cost of fuel or electricity. They are largely dependent on sunlight for the purpose of drying clothes. In addition, respondents also believed that more sunlight penetration would help to reduce the high humidity in their households since dehumidifying machines are not widely used for dehumidifying purpose in PRH estates.

Sanitization and hygienic reasons are two other common purposes for the exploitation of sunlight as identified by the respondents since most of them believed that sunlight can kill germs and maintain the hygiene of their flats without any frequent cleaning. It is also the reason why curtains are not installed in a considerable amount of households in the PRH estates. As the questionnaire survey was carried out in summer, cleaning was required before the storage of winter beddings in a large number of households. Traditionally, the beddings were sanitized by sunlight in public areas of the estates with the permission of the management authorities. However, the increasing density and limited public areas has caused management problems regarding such an issue. The provision of sunlight would therefore allow this to be done in residents' households instead of in the public area of the estates.

Surprisingly, thermal comfort was not recognized as an advantage of sunlight as identified by only 44.2% of the respondents in the questionnaire survey. The major reason is predominantly due to the hot weather when the survey was conducted. Only about half of the respondents agreed that sunlight has a beneficial psychological effect to residents and enhance indoor appearance of their households. The least recognized advantage is the assistance to plant growth since planting or gardening is not common in the high-density living environment of Hong Kong.

5.2. Environmental parameters

Factor analysis was conducted and it resulted in four distinctive factors. The results show that microclimatic factors were the most influential parameters to residents' preference for solar access with factor loadings over 0.95 in the first factor which accounted for 35.947% of the total variance, i.e. more than one-third of the respondents' preference of solar access was affected by the microclimatic environment of the flats, which is represented by the first factor. Positive loadings were observed in solar radiation and mean temperature (0.985 and 0.969) while negative loading was observed in relative humidity. It indicates that the influence of solar radiation and temperature was inversely related by relative humidity.

The second factor, accounted for 21.288% of the total variance, is composed of visual elements, like brightness of and view outside the flat, and level of ventilation as subjectively assessed by the respondents. Brightness, which implied the level of illumination, had the highest loading of this particular factor (0.787) followed by view outside the flat with a loading of 0.728. It indicates that the subjective feeling of brightness influenced residents' preference of solar access and residents' who required more sunlight penetrating into their flats were largely from north-facing households. The least influential parameter in this factor was level of ventilation of the respondents' flats with a relatively lower loading of 0.647. It suggested that the influence of ventilation of the flat on residents' preference was limited.

In the third and fourth factors, with similar level of variance explained (13.379 and 12.925 respectively), wetness and hotness as subjectively assessed by the respondents were the two parameters of the two factors respectively. High levels of factor loading were observed (0.961 and 0.965 respectively). It somewhat indicates that how hot and wet residents feel may influence how they prefer sunlight to be received. The high loading can be reflected in the highest percentage of respondents who recognized thermal discomfort as a disadvantage of sunlight penetration. It is also influenced by the hot weather when the questionnaire survey was being conducted since the respondents may tend to prefer less sunlight penetration, especially in the flats that receive excess sunlight than the respondents expected. For example, a considerable amount of respondents from west-facing flats reckoned that sunlight penetration brings thermal discomfort and preferred less sunlight entering their flats.

6. Conclusions

A questionnaire survey was conducted to investigate the preference of residents to solar access of residential flats in high-density sub-tropical cities using Hong Kong as a case study. This study aims to address residents' preference in terms of time, amount, place, and purpose of exploiting sunlight. The results show that the majority of the respondents (72.0%) were satisfied with the current situation of solar access in their households with 15.3% neutral responses. Only 12.4% of the respondents felt unsatisfactory about solar access of their flats.

In this study, the preferred time and amount of solar access were investigated. Near 60% of the respondents preferred to have sunlight penetration into their households in the morning. There is likely a need to improve the provision of solar access in terms of the time of sunlight received by residents since only about 40% of the respondents had the same time of sunlight entering their flats as they expected. Moreover, it is found that, except for "no sunlight", there are not any particular preferences of the expected amount of solar access. Sufficient solar access was also found to be more important than view outside respondents' flats. Designers of PRH estates and units are recommended to make reference to the findings that indicates, in general, the inhabitants' needs and preferences of solar access.

Exploratory factor analysis was carried out to investigate the influence of environmental parameters on residents' preference of solar access. Results indicated that observed microclimatic parameters were the dominant influencing factors and closely followed by visual elements of residents' subjective feelings about their flats. It implies that the incorporation of microclimatic environments into current design standard and guidelines should be considered. Further studies can be conducted to address this issue in more details.

This present study can serve as a pilot study which aims to address the preference of residents to solar access in high-density living environment in tropical region. In order to provide better solar access to residential units, further studies are needed to examine the pattern of household activities in relation to the availability of sunlight to residential units as the types of participants and the activities they hold in the dwellings influence the preference of solar access. The effect of microclimatic conditions on residents' preference should also be considered. For example, air temperature, relative humidity, and wind environment can have a significant effect on residents' preference of solar access.

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