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Preferred solar access in high-density, sub-tropical housing

KL Lau PhD, **E Ng** PhD and **JZ He** PhD
School of Architecture, The Chinese University of Hong Kong, Shatin NT, Hong Kong SAR, China

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Appropriate solar access is considered to be important to residents' health, comfort and daily living. In the past few decades, guidelines and standards have been formulated for the provision of sunlight in low-density housing. However, in sub-tropical, high-density housing like that found in Hong Kong, relevant guidelines and standards are generally lacking. At the same time, better provision of sunlight to such housing has become a matter of concern. Residents' preference for solar access is very important to the formulation of standards for solar access and daylighting, as well as urban planning and building design. This paper presents the results of questionnaire surveys regarding residents' preferences for solar access in terms of timing, duration and location. Computer simulation provides information on the actual sunlight environment of the visited households. Policy-makers, as well as planners and architects, should take the findings into account when establishing appropriate guidelines and standards for high-density tropical cities like Hong Kong.

1. Introduction

Sunlight is of particular importance to residential dwellings. It provides the source of household lighting, benefits human health, and prevents a wide range of diseases.[1–3] It also plays a significant role in the energy efficiency of buildings through the provision of warmth and illumination. Many studies suggest that the provision of sunlight, combined with sustainable building design, has the potential for reducing energy consumption by heating, cooling and illumination during the operation of buildings.[4–6]

Studies of solar access, which refers to the ability of a dwelling to receive sunlight without obstruction from any other properties or structures, have been widely conducted in order to provide the necessary information for the formulation of guidelines and regulations. In this study, solar access particularly refers to the penetration of sunlight into residents' flats. Littlefair[7,8] describes a wide range of techniques that can be adopted to examine the solar gain of dwellings, including simple angle calculations, sun path diagrams, sunlight availability protractors, and advanced computational methods. Knowles[9] introduced the concept of a solar envelope which aims to provide information about the physical boundaries of the surrounding buildings and the timing of their solar access. By combining these, the envelope's final size and shape can be determined. However, while these techniques can be successfully implemented in low-density environments, virtually,

Address for correspondence: Ka Kun Lau, School of Architecture, The Chinese University of Hong Kong, Shatin NT, Hong Kong SAR, China
E-mail: kevinlau@cuhk.edu.hk

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no effort has been made to apply them in high-density urban settings. Therefore, their effectiveness in such settings remains doubtful.

The attitude which people take to sunlight differs across climatic regions of the world.[10] In hotter countries, occupants of buildings may prefer sunlight to be excluded and controlled in order to prevent over-heating. Conversely, occupants in cooler climates, such as the high-latitude parts of the northern hemisphere, consider sunlight a pleasure rather than a nuisance.[11,12] The demand for sunlight also varies over different types of buildings and with the activities performed by the occupants. In one questionnaire study of occupants' perception of sunlight,[11] it was found that the proportion of occupants considering sunlight a pleasure ranged from 93% in residential units to 31% of staff in a hospital. The activities occurring in the buildings also affected occupants' perceptions. In the case of the hospital, 93% of the patients welcomed sunlight while only 31% of the staff reckoned that sunlight had a pleasant effect.

According to the relevant British Standard,[13] daylighting design should consider health issues and it therefore describes preferable daylighting designs and criteria necessary to satisfy the occupants of buildings. Day and Creed[14] conducted a pilot study on the relationship between residents' subjective assessments of the sunlight received in dwellings and objectively calculated reference quantities. They suggested that residents were more sensitive to differences between insolation of dwellings when the survey was conducted in winter than they were in summer. Littlefair[15] also detailed the guidance suggested by the relevant British Standard,[13] which aims 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 a low-density living environment and may not be appropriate for extremely high-density subtropical cities like Hong Kong. The consideration of the socio-habitual aspects of solar access is generally deficient. As such, there is a great potential for the development of standards and guidelines on the provision of sunlight in high-density living environments.

One of the key issues concerning the provision of sunlight in high-density living environments is the seasonal variability of sunlight. Thermal discomfort due to excessive sunlight received by the dwellings in summer causes an increase in energy consumption by air-conditioning systems. On the other hand, residents could exploit the benefits of summer sun by drying clothes and bedding. Comparatively speaking, winter sun provides thermal comfort with an associated reduction in energy loads in times of cold weather. Therefore, residents' preferences for solar access should be considered during the formulation of standards for solar access and daylighting, as well as energy-efficient building design. However, the understanding of the desirable duration of solar access to residents living in high-density cities like Hong Kong is generally lacking. Although objective measurements and modeling of sunlight penetration are widely implemented,[7–9] subjective responses of residents' perception of solar access are rarely studied, especially in high-density living environments. As a result there is no basis for considering solar access in urban planning and building design.

This paper presents residents' preferences for solar access in their households, using the results of a questionnaire survey conducted in winter and summer. It aims to address the desirable duration of solar access to residents living in high-density living environments, using public rental housing estates in Hong Kong as a case study. The results will contribute to the basis for potential guidelines and standards for the provision of sunlight in residential units.

2. Methodology

2.1 Questionnaire survey

In order to obtain residents' preferences for solar access, two rounds of a questionnaire survey were conducted in August 2009 and January 2010 in a public rental housing estate in Hong Kong (Figure 1). This estate can be characterised as a high-density living environment and was constructed in the last decade using the contemporary architectural styles adopted in public housing development. This recently inaugurated estate was chosen because future planning and design of public housing development will be based on current practice. Households were randomly selected to cover a wide range of flats of different aspect, level and size.

Personal questionnaire surveys were conducted for the following reasons:

- Residents could respond to the survey questions as they actually see the solar access in their households. The surveys could therefore provide more accurate responses based on actual perception.
- Confusion could be avoided because the survey questions could be immediately explained by the interviewers.
- More information apart from the survey questions could be obtained as interviewers could ask for further elaboration on responses where appropriate.

The questionnaire focused on residents who live in the surveyed public rental housing estate. It aimed at understanding the preference of residents for aspects of solar access that may not be adequately considered in current guidelines and regulations. In order to ensure the clarity and relevance of the questionnaire, a pilot study using 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 of the questionnaire, seeking details of the timing and duration of sun exposure in the flat. The overall importance of solar access was also asked as was the importance of sunlight penetration into different parts of the flat. The respondents were further asked if they agreed with different advantages and

Figure 1 Northern side of Hoi Lai Estate (left); a closer look at the building blocks within (right)

disadvantages of solar access to their flat. The questionnaire also included questions about the background of the respondents such as their age, sex and level of education, as well as information about their household such as the number of occupants and length of occupation. The questionnaire survey was conducted in both summer and winter in order to examine the seasonal difference in the pattern of residents' preferences for solar access.

2.2 Computer simulation

Computer simulations were carried out for the flats whose occupants were interviewed during the questionnaire surveys to obtain information on the actual solar access. Models of the surveyed estates were prepared as the input for the simulation. The software ECOTECT was employed to obtain sun path diagrams which provide information on the timing and duration of sunlight penetration to three parts of the visited flats. The actual solar access calculated was compared to the preferred solar access, in terms of timing and duration, as obtained from the questionnaire surveys.

3. Questionnaire survey

Two rounds of questionnaire survey were conducted in summer and winter with a total of 207 and 55 responses obtained, respectively. Obtained information was processed and divided into several categories of residents' preference for solar access in terms of timing, place, duration and use.

3.1 Background of participants

The background of the respondents and the information about their households is presented in Table 1. In the summer round of the questionnaire survey, 52.8% of the respondents were female and 47.5% were male with 0.1% not recorded. In winter, female and male respondents were 69.1% and 29.1% of the total respondents, with 1.8% not recorded. The respondents were divided into three age groups. In summer, 24.6% of the respondents were under 25 years of age while 19.8% were over 50 years of age. 50.7% of the respondents were in the age range 25 and 50 years with 4.9% not recorded. Table 2 shows the information collected about occupancy. In summer, the respondents stayed in their flats for an average of 7.70 hours while, in winter, they stayed in their flats for longer, 8.70 hours on average.

3.2 Timing of solar access as assessed by residents

The timing of sunlight penetration into residents' flats was first assessed according to their reports (Figure 2). In summer, 14.0% of the respondents reckoned that there was no

Table 1 Demographics of survey respondents

	Summer		Winter			Summer		Winter	
No. of interviews	207		55		*Level of education*				
Sex					No formal education	6	(2.9%)	3	(5.5%)
Male	97	(47.1%)	16	(29.1%)	Primary	46	(22.2%)	11	(20.0%)
Female	109	(52.8%)	38	(69.1%)	Secondary	135	(65.2%)	34	(61.8%)
No information	1	(0.1%)	1	(1.8%)	Tertiary or above	15	(7.2%)	7	(12.7%)
Age					Others	2	(1.0%)	0	(0.0%)
Under 25	51	(24.6%)	18	(32.7%)	No information	3	(1.5%)	0	(0.0%)
25–50	105	(50.7%)	31	(56.5%)					
Over 50	41	(19.8%)	3	(5.4%)					
No information	10	(4.9%)	3	(5.4%)					

sunlight penetrating to their living rooms, which means that sunlight did not shine directly into the flat. There were 33.3%, 11.1% and 27.1% of the respondents claiming that sunlight penetration was observed in the morning (7–11 am), around noon (11 am to 2 pm) and in the afternoon (2–6 pm), respectively. In addition, sunlight was available for the entire day in 14.5% of the visited flats.

For bedrooms, there were a slightly higher proportion of the respondents (18.4%) claiming no sunlight penetration to their flats. About 30.6% of the visited flats received sunlight in the morning while 27.7% had sunlight penetration in the afternoon. Another 12.1% of the respondents received sunlight around noon and only 11.2% received sunlight for the whole day. A similar pattern was observed for kitchens except the highest percentage of the respondents (20.9%) received no sunlight.

In winter, the timing of solar access perceived by residents was similar to that in summer despite a higher percentage of respondents receiving no sunlight. A slightly higher percentage of households received sunlight around noon and in the afternoon while there was also a considerably lower percentage (5.6%) receiving sunlight for the entire day.

Table 2 Information about occupancy

	Length of occupancy (Year)	Number of occupants	Hours stayed in the flat on a normal day
Summer			
Count	205	206	206
Mean	3.90	4.17	7.70
Std deviation	0.92	1.02	3.28
Winter			
Count	54	55	54
Mean	4.45	3.85	8.70
Std deviation	0.94	0.83	3.35

3.3 Preferred timing of solar access

The respondents were then asked about their preferred timing for solar access (Figure 3). In summer, 58.5% of the respondents preferred sunlight penetrating into their living rooms in the morning while sunlight penetration in the afternoon was preferred by 16.4%. 11.1% and 10.6% of the respondents preferred to have sunlight penetration around noon and for the whole day respectively. Only 3.4% did not want any sunlight entering their flats.

Similar results were obtained for the bedrooms and kitchens except slight variations were observed in the preference for solar access in the morning. A slightly higher percentage (59.9%) was observed for bedrooms while sunlight penetration to kitchens was less preferred (54.6%). In addition, the highest percentage (12.1%) was found for receiving sunlight penetration for the whole day.

The winter data did not show any differences across the three parts of the flats. 57.5% of the respondents preferred solar access in the morning while 15.4% of them preferred sunlight being received in the afternoon. There were also 13.5% of the respondents preferring solar access around noon while the same proportion preferred to receive sunlight for the whole day.

3.4 Expected duration of solar access

The expected duration of sunlight as assessed by respondents is relatively variable (Figure 4). For living rooms, 18.4%, 21.7% and 35.3% of the respondents expected to have about 1–2, 2–3 and 3–4 hours of sunlight penetration to their flats, respectively. A further 21.7% of the respondents would prefer more than 4 hours of solar access per day at home. Only 2.9% did not wish for any sunlight penetration into their households.

For the bedroom, 21.7% of the respondents expected about 1–2 hours of solar access on a normal day while 19.8% and 35.3%

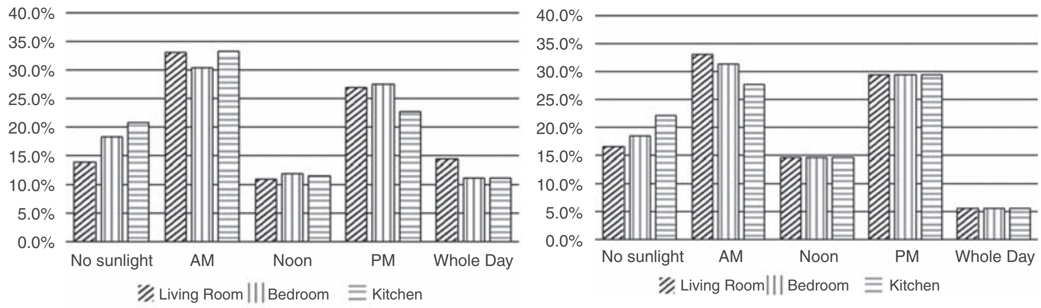

Figure 2 Timing of solar access as assessed by residents; summer (left) and winter (right)

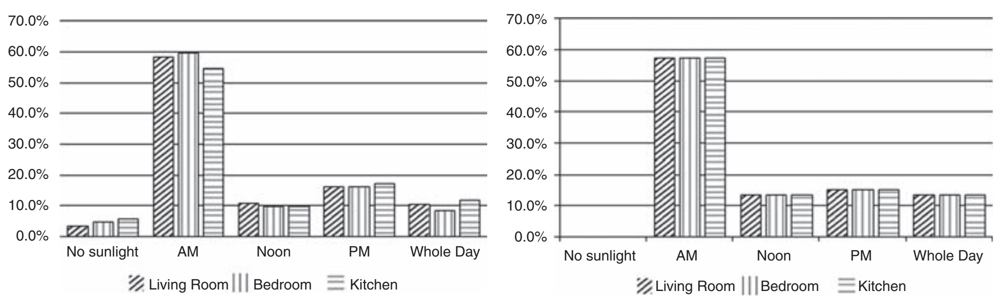

Figure 3 Preferred timing of solar access; summer (left) and winter (right)

expected to have 2–3 and 3–4 hours of sunlight entering their flats, respectively. 19.3% of the respondents would prefer more than 4 hours of sunlight penetration per day at home. A similar pattern was observed for the kitchen.

In winter, the expected duration of solar access is the same for living room, bedroom and kitchen. 10.9% of the respondents preferred 1–2 hours of solar access while solar access over both 2–3 and 3–4 hours accounted for 27.3%. Moreover, the percentage wishing for sunlight to be received for more than 4 hours in winter (32.7%) is substantially higher than in summer.

4. Computer simulation

Computer simulation was conducted after the completion of the questionnaire surveys for the flats visited. Plans obtained from the Hong Kong Housing Authority provided input data for the simulation of the sunlight environment of the visited flats. Two aspects, provided by the simulation, were used to further comparison between the residents' preferences for solar access and what actually occurred.

4.1 Simulated timing of solar access

According to the simulation results (Figure 5), 28.2% of the visited flats in the summer round had sunlight entering the living rooms in the morning while sunlight penetration in the afternoon was observed in 36.4% of them. Another 29.6% of the visited flats received sunlight around noon while only 5.3% did not receive any sunlight penetration. A negligible proportion had sunlight penetration for the entire day.

For bedrooms, 22.3% and 26.2% of the visited flats had sunlight penetration in the morning and afternoon respectively while

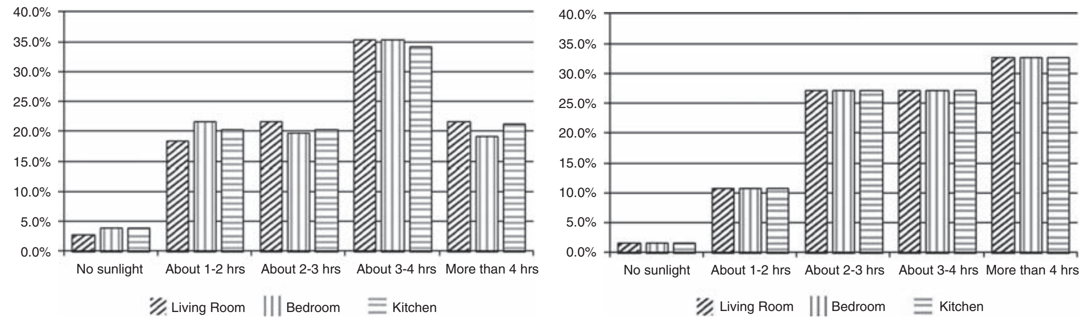

Figure 4 Expected duration of solar access; summer (left) and winter (right)

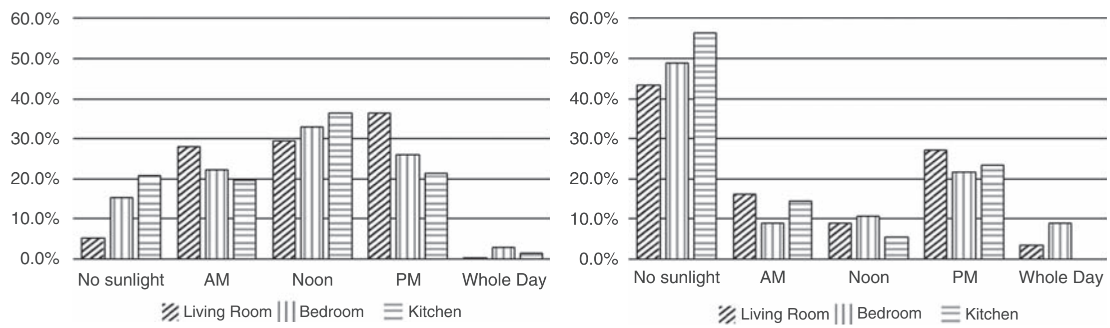

Figure 5 Actual timing of solar access according to simulation results; summer (left) and winter (right)

33.0% received sunlight around noon. Moreover, in comparison with living rooms, there was a higher percentage (15.5%) having no sunlight penetration.

For kitchens, the results were considerably different. 36.4% of the visited households received sunlight around noon while 19.9% and 21.4% had sunlight penetration in the morning and afternoon, respectively. The kitchen also had the highest percentage of households (20.9%) that did not receive any sunlight at all.

The winter data showed very different results for the solar access of the surveyed households. Over 40% of the households received no sunlight in their living rooms in winter. 16.4% and 27.3% of the visited flats had sunlight penetration in the morning and afternoon respectively while only 9.1% received sunlight around noon. For bedrooms, nearly half of the visited flats had no sunlight penetration while 21.8% had sunlight entering in the afternoon. There were nearly 10% of the households receiving sunlight around noon, in the afternoon, and for the whole day. For kitchens, 56.4% of the households received no sunlight while there were 14.5% and 23.6% of the visited flats having sunlight penetration in the morning and afternoon, respectively.

4.2 Simulated duration of solar access

The simulated duration of solar access was considerably different from the preferred duration of sunlight penetration (Figure 6). Further, there was a significant difference between the actual durations in summer and winter. 23.3% of the visited flats had about 1–2 hours of solar access in their living rooms while 21.4% and 18.4% received sunlight in their living rooms for about 2–3 and 3–4 hours, respectively. Moreover, nearly 30% of the visited flats had sunlight penetration for more than 4 hours. Only about 8.3% had no sunlight penetration into the living rooms of the visited flats.

For bedrooms, 20.9% of the visited households had about 1–2 hours of solar access. However, there were 35.9% of the visited households that did not receive any sunlight in their bedrooms. The duration of solar access received by the kitchens of the visited flats was different from those received in living rooms and bedrooms. It was found that 33.0% of the households had no sunlight penetration in kitchens while there were only 13.6% having sunlight penetration for more than 4 hours. 28.2% of them received sunlight for about 1–2 hours while 11.7% and 13.6% had sunlight penetrating into the kitchens for about 2–3 and 3–4 hours, respectively.

The amount of solar access for the visited flats in winter was very different from what it was in summer. Over 50% of the households received no sunlight penetration and 23.6% had sunlight entering into their living rooms for about 1–2 hours. There were also less than 10% of the living rooms receiving about 2–3, 3–4 and more than 4 hours of sunlight. For bedrooms, 56.4% of the visited flats received no sunlight while 14.5% and 12.7% had sunlight penetration for about 1–2 and 2–3 hours, respectively. 14.5% received sunlight for more than 4 hours while only a negligible proportion had about 3–4 hours of solar access in their bedrooms. The highest percentage (67.3%) receiving no sunlight was observed in kitchens where less than 20% of the visited households had sunlight penetration for more than 2 hours.

5. Comparison between preferred and actual solar access

Simulation results were compared to residents' preference for solar access so that residents' satisfaction could be assessed.

5.1 Timing of solar access: Simulation versus preferred

According to the comparison between the preferred timing of solar access and that by simulation in summer (Table 3), 37.9% of the visited households had the desired period of solar access in their living rooms. Among the respondents who preferred morning solar access, 20.9% of them received sunlight at their desired time, 18.0% had sunlight penetration around noon and 16.0% received sunlight in the afternoon. Only 3.4% had no sunlight penetration with a negligible proportion having solar access for the whole day. Furthermore, 10.7% of the respondents who preferred afternoon solar access received sunlight in the afternoon.

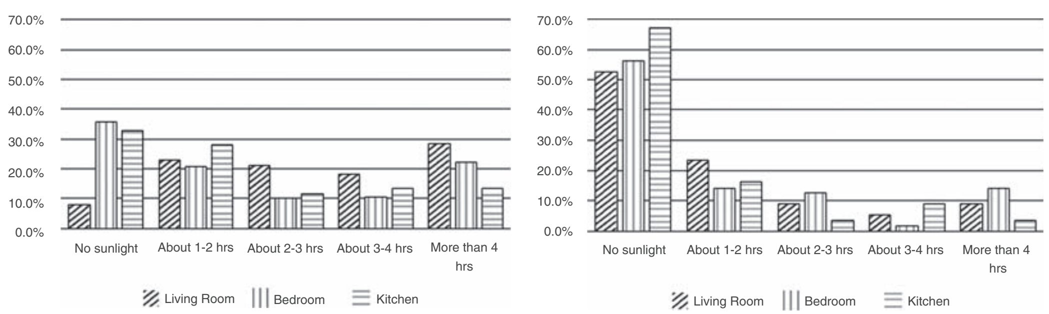

Figure 6 Duration of solar access by simulation; summer (left) and winter (right)

About 31.1% of the visited households had the desired timing of solar access in their bedrooms. For those who preferred morning solar access, only 16.0% actually received sunlight in the morning. 17.5% had sunlight penetration around noon while another 14.6% received sunlight in the afternoon. A higher proportion did not have any sunlight penetrating to their bedrooms. Among those who received sunlight during their desired time, 5.8% preferred solar access around noon while 7.8% had sunlight penetration in the afternoon.

The worst match (28.6%) between preferred and simulated timing of solar access was observed for kitchens. Around 13.1% preferred morning solar access while 8.3% preferred solar access in the afternoon. Another 5.3% preferred sunlight penetration at noon. For the most preferred period of solar access (i.e. in the morning), only 13.1% had solar access while 21.4% had sunlight entering their kitchens around noon and 8.7% received sunlight in the afternoon.

In winter, the distribution of residents' preferences was notably different from that in summer (Table 4). Only 17.3% of the visited households had the desired timing of solar access in their living rooms. According to the simulation results, 44.2% of the visited households had no sunlight penetration while 17.3% and 26.9% had sunlight penetration into their living rooms in the morning and afternoon respectively. Another 7.7% had sunlight penetration around noon while a negligible percentage of visited households had sunlight penetration for the whole day.

About 9.6% of the respondents had their preferred timing of solar access in bedrooms. Over 50% of the visited households had no sunlight penetration while 19.2% had sunlight entering their bedrooms. Less than 10% of the households received sunlight in the morning, around noon, and for the whole day. For kitchens, a higher proportion (15.4%) received sunlight at the desired time but more households (55.8%) had no sunlight penetration into the kitchens. 15.4% and 23.1% of the visited flats had sunlight entering into their kitchens in the morning and afternoon while 5.8% received sunlight around noon. However, there were no visited flats that had solar access for the whole day.

Table 3 Percentages of visited households that received their preferred durations of solar access during their preferred time of the day during summer. L = living room, B = bedroom, K = kitchen

			Preferred timing of solar access				
		Location	No sunlight	Morning	Noon	Afternoon	Whole Day
Simulated timing of solar access	No sunlight	(L)	0.5%	3.4%	0.0%	1.0%	0.5%
		(B)	1.0%	10.7%	0.5%	2.4%	1.0%
		(K)	1.9%	11.2%	1.5%	3.4%	2.9%
	Morning	(L)	0.0%	20.9%	1.9%	2.9%	2.4%
		(B)	0.5%	16.0%	3.4%	1.0%	1.5%
		(K)	0.0%	13.1%	1.5%	2.4%	2.9%
	Noon	(L)	1.9%	18.0%	5.8%	1.5%	2.4%
		(B)	2.4%	17.5%	5.8%	3.9%	3.4%
		(K)	3.4%	21.4%	5.3%	2.9%	3.4%
	Afternoon	(L)	1.0%	16.0%	3.4%	10.7%	5.3%
		(B)	1.0%	14.6%	0.5%	7.8%	2.4%
		(K)	0.5%	8.7%	1.0%	8.3%	2.9%
	Whole	(L)	0.0%	0.5%	0.0%	0.0%	0.0%
		(B)	0.0%	1.0%	0.0%	1.5%	0.5%
		(K)	0.0%	0.5%	1.0%	0.0%	0.0%

Table 4 Percentages of visited households that received their preferred duration of solar access during their preferred time of the day during winter. L = living room, B = bedroom, K = kitchen.

			Preferred timing of solar access				
		Location	No sunlight	Morning	Noon	Afternoon	Whole Day
Simulated timing of solar access	No sunlight	(L)	0.0%	25.0%	7.7%	5.8%	5.8%
		(B)	0.0%	28.8%	11.5%	3.8%	7.7%
		(K)	0.0%	34.6%	7.7%	5.8%	7.7%
	Morning	(L)	0.0%	9.6%	0.0%	1.9%	5.8%
		(B)	0.0%	3.8%	0.0%	1.9%	3.8%
		(K)	0.0%	7.7%	0.0%	1.9%	5.8%
	Noon	(L)	0.0%	3.8%	1.9%	1.9%	0.0%
		(B)	0.0%	3.8%	1.9%	3.8%	0.0%
		(K)	0.0%	1.9%	1.9%	1.9%	0.0%
	Afternoon	(L)	0.0%	15.4%	3.8%	5.8%	1.9%
		(B)	0.0%	13.5%	0.0%	3.8%	1.9%
		(K)	0.0%	13.5%	3.8%	5.8%	0.0%
	Whole	(L)	0.0%	0.0%	0.0%	0.0%	0.0%
		(B)	0.0%	0.0%	0.0%	0.0%	0.0%
		(K)	0.0%	0.0%	0.0%	0.0%	0.0%

5.2 Duration of solar access: Simulation versus preferred

In summer, 21.8% of the respondents received their desired duration of sunlight in their living rooms. There were 22.3% having about 1 hour of solar access more than they expected, while another 9.7% had about two hours of solar access more. On the other hand, 23.3% of the respondents had about 1 hour of sunlight penetration less than they preferred while 12.6% experienced a deficiency in solar access when the received about two hours less. There were also another 4.4% of the respondents who received about 3 hours of solar access less than they expected.

For bedrooms, a slightly lower percentage of respondents (19.9%) received the desired duration of solar access. 12.6% of the respondents had about 1 hour of sunlight penetration more than they preferred, while 9.2% had a surplus of solar access when they received about 2 hours. Conversely, there were 18.5% and 16.0% of the respondents who had sunlight penetrating to their bedrooms for about 1 and 2 hours less than they preferred, respectively. A further 13.1% of the respondents experienced a deficiency in solar access when they received about 3 hours of sunlight less than preferred.

Sunlight penetration was more deficient in the kitchens of the visited flats. There were 22.0% and 19.2% of the respondents having about 1 and 2 hours of solar access less than they expected. A further 14.0% who had about 3 hours of solar access in their kitchens experienced a deficiency. There were only 17.0% having their desired duration of solar access. On the other hand, there were only 12.6% of the visited households that had a surplus of solar access when they received sunlight for 1 hour more than preferred. It was the least among the three parts of the flats surveyed.

In winter, the deficiency of solar access was more prominent, as shown by the high percentages for living rooms (81.8%), bedrooms (74.6%), and kitchens (85.5%). It can also be shown by the heavily skewed graph in Figure 7. Only 9.1% of the visited households received sunlight in their living rooms for their desired duration. 18.2% of the respondents received their desired amount of solar

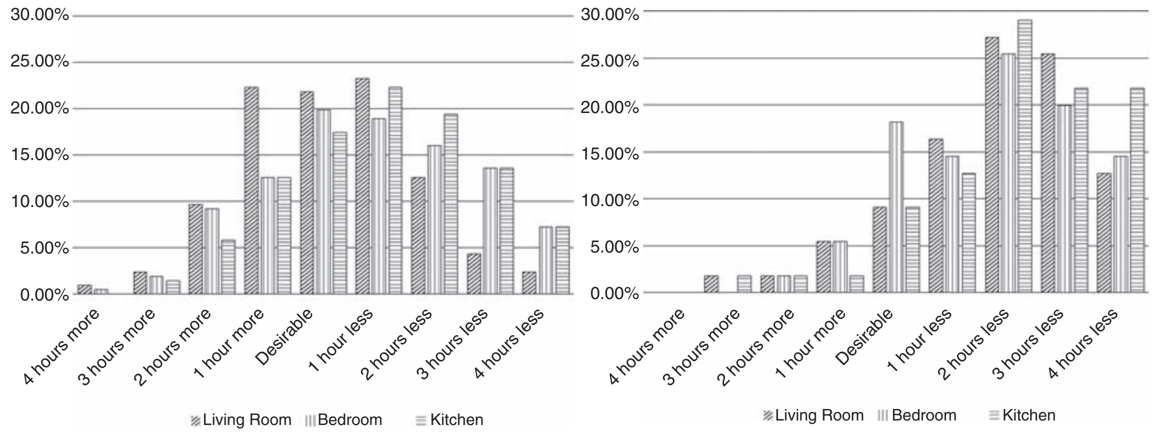

Figure 7 Simulated versus preferred duration of solar access; summer (left) and winter (right)

access in their bedrooms while only 9.1% had the desired amount of sunlight penetration in their kitchens.

6. Discussion

The responses from the households in the two rounds of questionnaire survey allowed the present study to provide a reasonably representative picture of residents' preference for summer and winter solar access in a high-density living environment. The high number of responses shows that a personal questionnaire survey is an effective way to obtain responses from a large number of residents, especially in areas with an aging population which has limited knowledge of 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 the guidelines and regulations that have been widely adopted in the design stage of the development.

Current guidelines and regulations in Hong Kong have focused on daylighting design with limited attention being paid to the provision of sunlight in residential dwellings. There are also no particular guidelines for the duration and timing of solar access provided to residents in Hong Kong. In Britain, Part 2 of the BS8206[13] states that at least 25% of probable sunlight hours, which refer to the long term average of the total number of hours during the year in which direct sunlight reaches the unobstructed ground, should be provided to the interior of residential dwellings. The present study provides information about the timing and duration of solar access preferred by residents for potential use in the formulation of guidelines and regulations.

The present study shows that the majority of the respondents preferred solar access in the morning in their households. It is predominantly because most of the respondents were housewives and retired people who normally stayed at home in the morning and exploited sunlight for household purposes such as drying clothes, illumination and sanitation. The milder sunlight is also a reason for residents' preference for morning solar access. The simulation results indicate that less than 40% of the visited households had the desired timing of solar access in their living rooms while the percentages were even lower in bedrooms and kitchens. The distribution of sunlight in living rooms was concentrated in the morning and afternoon while sunlight penetration around noon was more commonly observed for bedrooms and kitchens. It can therefore be concluded that although sunlight penetration is currently provided, the time of solar access is not quite desirable.

There are no particular preferences for the expected duration of solar access. 35.3% of the respondents expected to have about 3–4 hours of solar access in the living rooms on a normal day. Such a duration of solar access is considered to be appropriate to respondents' households although the average time that the respondents stayed in their flats is nearly 8 hours per day. Apart from that, there are still over 20% who would prefer to have more than 4 hours of solar access, which is predominantly required by respondents who stayed longer in their flats, everyday. The lower requirement for sunlight penetration for bedrooms and kitchens is also reflected in the lower percentages of respondents who preferred more than 4 hours of solar access.

A previous study[16] used factor analysis to determine the environmental parameters influencing residents' preference and it suggested that microclimatic conditions in the residence affect the choice of preferred solar access. It therefore implies that residents' preference for solar access can be satisfied by better site layout planning which improves microclimatic conditions of high-density residential environments. Whilst existing guidelines and standards regarding the provision of solar access focus on low-density mid-latitude regions, there is clearly a need for design guidance for practitioners in the high-density, sub-tropical environment.

Simulation results show that the ability of visited households to receive sunlight is very different between summer and winter. In summer, one-third of the respondents were able to receive about 1–2 hours of sunlight in the living rooms and only about 15% had more than 4 hours on a normal day. Bedrooms and kitchens had even less sunlight duration. It was somewhat consistent with residents' preference for the duration of solar access. Residents' preference for solar access was similar between summer and winter. However, in comparison with the actual situation, residents generally received less sunlight penetration in the flats, the deficiency being much more pronounced in winter. It is therefore suggested that there is a general deficiency in the duration of sunlight received by residents, especially in bedrooms and kitchens. To compensate for such a deficiency, residents may seek other means to replace sunlight in household activities. For example, the use of drying machines and dehumidifiers provides a possible solution for drying clothes and reducing the humidity inside the flat, which will cause an increasing energy demand. On the other hand, excessive solar access may result in the use of air-conditioning systems in order to reduce the heat brought in by sunlight. Potential guidelines and regulations of solar access should therefore take notice of a more evenly distributed sunlight environment in residential dwellings and increase the duration of sunlight penetration to different parts of the flats.

7. Conclusion

Residents' preference for solar access was obtained by a questionnaire survey and a computer simulation was conducted to determine the actual situation for solar access of the visited flats. This study aims to address residents' preferences for sunlight in terms of timing, duration and location. The results show that the majority of the respondents preferred solar access in the morning and that the preference for morning solar access is lower in bedrooms and kitchens. There is a need to improve the provision of solar access in terms of the timing of sunlight received by residents since less than 40% of the respondents had sunlight entering their flats when they wanted it, according to simulation results. Moreover, it is found that there are no particular preferences for the expected amount of solar access. Simulation results also showed that about 33% of the visited households received about 1–2 hours of solar access in their living rooms while about one-fourth had sunlight penetration for more than 4 hours. It was also found that solar access was less for bedrooms and kitchens. Moreover, it is important to note that the availability of sunlight was much less in winter that in summer.

This study aims to address residents' preferences for solar access in a high-density living environment. 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. Activities occurring in the households have different requirements for sunlight in terms of timing, duration and location. Potential formulation of guidelines and regulations regarding residential solar access should provide sufficient guidance on both the amount, in terms of areas, of sunlight reaching residential units and the timing and duration of sunlight penetration to different parts of the units. The information about residents' needs and preferences for solar access is important to architects, designers and planners as they can consider this to achieve a better indoor environment for residential units in the future. As the population continues to grow, a denser living environment is expected and improving the quality of living environment becomes one of the priorities for future developments.

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