The challenge of creating age-friendly indoor environments in a high-density city:

Case study of Hong Kong's Care and Attention homes

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Abstract

Aiming to find out whether the indoor environment quality (IEQ) of Care and Attention (C&A) homes in Hong Kong could meet the need of older people, this research conducted a field measurement and occupancy survey in nine C&A homes to assess their thermal, lighting, and noise environments according to both building standards and occupant satisfaction. The findings indicated that an operative indoor temperature of 24-27°C in summer and above 23°C in winter could be considered to mark a thermally comfortable zone. Noticeably, older people preferred a warmer environment in both summer and winter, while the measurement results showed that the indoor operative temperature was lower, and the humidity was higher than the comfort standard for summer, which was confirmed by the occupant survey. The mean illuminance level could meet the national threshold; interestingly, there was a negative correlation between age groups and their satisfaction of natural lighting in winter. The mean street noise level was between 74-75 dB, exceeding the maximum 55 dB for neighborhoods. The street noise level was significantly negatively correlated with

residents' satisfaction. The study made recommendations for regulating both outdoor and indoor environments for improving the elderly living conditions in high-density urban areas with hot humid climates.

Keywords: elderly people; residential care homes; indoor environment quality; occupant surveys; high-density living

Introduction

Research has indicated that indoor environment quality (IEQ) (such as thermal, lighting and acoustics) play a major role in ensuring occupants' comfort, and that a positive indoor environment is essential for a productive and healthy life. IEQ is extremely important for the elderly because the average daily home staying for an elderly is 17 hours [1]. Many studies highlighted individual differences that affect thermal comfort and should be carefully considered in the design and operation of the built environment [2]; among all, age is a crucial factor that affects the thermal sensation. Older adults had a lower metabolic rate and they might need a warmer thermal environment than the youngsters in all seasons [3]. Because of their metabolic rate, older people's upper limit of acceptable air temperature is higher [4]. Although research revealed a low satisfaction rate of indoor environment quality in nursing homes [5, 6], little guidance existed to understand how to design and operate indoor environment for older people [7].

IEQ in high dense urban settings with hot humid climates faces many challenges. Overheating is quite common in building of Hong Kong, due to high air temperature,

intense solar radiation and poor ventilation in the hot and humid seasons, the situation of which usually lead to thermal discomfort of elderly people because majority of them are physically disabled and financially less capable [8]. Daylighting is another crucial factor on human health and well-being, while it becomes challenging in high dense urban environment where high-rise buildings are closely packed together and studies revealed that the building codes in Hong Kong only ensured the minimum daylighting availability and did not take dense urban environment into consideration [9]. As per the noise level, Parra, Gomez [10] discovered that street noise level in dense urban areas was negatively associated with both physical and mental health in adults aged 60 and over. The study of built environment and elderly health found that street noise level was associated with quality, well-being, life satisfaction as well as successful ageing [11]. Arguably, Hong Kong is facing severe problems for creating and maintaining aging friendly IEQs for elderly people.

On the other hand, Hong Kong is facing a serious aging problem due to rapid growth of its elderly population and high life expectancy [12]. The Care and Attention (C&A) homes have become an increasing popular housing type among all elderly residential care services, which are responsible for the largest share (around 82%) of the market [13]. Today, most C&A homes in Hong Kong are situated in the renovated podiums of composite buildings and residential towers (Figure 1). In the early decades after World War II, mixed-use or composite buildings were the most common type of building in Hong Kong. The ground floors were designed as shops, while the upper floors were used for mixed residential and commercial purposes. These composite

buildings were typically built in the 1960s, and each was eight to twelve stories high. In the 1970s, in response to an increased demand for housing, developers started to construct tall tower houses. These tower buildings were also divided into two parts, with a 15-metre podium for multifunctional use and a tower section for residential use [14]. Under such circumstance where all abovementioned environmental challenges come together, the liveability of C&A homes is questionable and worthy of research interrogation.

Figure 1. C&A homes in tall buildings

This study aims to find out 1) what is the environmental condition in C&A homes in Hong Kong; 2) what is the environmental satisfaction in C&A homes in

Hong Kong, and 3) how does the environmental condition compare to building standards and findings from other studies in aged care facilities. Potential suggestions that could enhance the comfort level of the elderly are also explored based on the findings.

Methods

This study was conducted in Hong Kong from 2015 to 2016 and involved nine Care and Attention (C&A) homes with compact living conditions. The methods of this study included IEQ measurement and satisfaction questionnaire. The physical measurement included thermal parameters of air temperature, air velocity, relative humidity, illuminance levels, and noise levels. The survey adopted CBE IEQ satisfaction questionnaire (<https://cbe.berkeley.edu/resources/occupant-survey>). This set of measurements was used to explore both satisfaction and expectations of IEQ from older people who live in C&A homes in Hong Kong.

Site Selection

A walk-through survey was conducted in 30 C&A homes. The research team collected basic architectural information such as date of construction, building structure, number of floors, typical floor plan, and ventilation characteristics (natural, mechanical, hybrid, etc.). Other information on the facilities, such as their capacity and duration of operation, was provided by the facility managers. Aspects of the indoor environment, along with residents' clothing and daily activities, were photographed, with indicators of personal identity avoided or erased. Finally, the study selected nine C&A homes (R1–R9) with compact living conditions for the investigation. All the nine C&A homes are located in the podium of tall

buildings, representing typical aged care facilities in high dense urban areas (Figure 2).

Figure 2. Nine C&A homes and their locations

Physical Measurement

According to Steemers and Manchanda (2010), the most efficient way of assessing comfort is to use a combination of measurable parameters for the environment and occupants' self-reported comfort level. In this study, both objective measurement and subjective environment evaluations were used. The physical measurements were obtained under Hong Kong's typical summer and winter conditions. The study was conducted in July 2015 and January 2016, and thus covered Hong Kong's hottest and coolest seasons. The mean temperature for these two seasons were 29.3°C and 16°C respectively.

A Kestrel 4500 weather meter was used to measure the ambient thermal parameters for comparison with the outdoor measurements, such as temperature, relative humidity (RH) and wind velocity (the resolution of temperature, RH, and air velocity are 0.1 °C, 0.1 %RH and 0.1 m/s respectively). The indoor thermal comfort parameters were measured using the Testo 480 which measure percentage of mean vote (PMV) and predicted percentage of dissatisfaction (PPD) based on ISO 7730 and has a resolution of temperature, RH, and air velocity at 0.1 °C, 0.1 %RH and 0.1 m/s respectively. These parameters included air temperature, radiant temperature, RH, air velocity, PMV and PPD. The sensor was placed at seat level 0.60 meters above the floor in the center of each room. The device was stabilized for 25 minutes before performing the measurement process. The duration of each measurement was 10 minutes, with an interval of 1 second. The metabolic rate of the elderly residents (seated and relaxed) was assumed to be 58 W/m² (1.0 met) based on their daily activity, and their clothing insulation was assumed to be 0.7 clo (underwear, shirt,

trousers, socks, shoes) during summer and 1.0 clo during winter (panties, shirt, trousers, jacket, socks, shoes) based on the survey and observation. After the measurements had been performed, the thermal-comfort data were exported using Testo Easy Climate Software 3.0TM and analyzed using SPSS version 20.0 (IBM).

Lighting levels were measured to determine whether the elderly residents were living in properly lit rooms. The places in which the residents spent most of their time, namely living rooms and bedrooms, were selected for the measurements. Lighting was measured during the daytime, when most daily activities occurred. The horizontal illuminance at desk level (0.75 meters) was measured in one living room and one bedroom in each C&A home. A Konica Minolta T10A illuminance meter was used to measure daytime illuminance, with measurement range of 0.01 to 299,900 lx.

The indoor noise level in C&A homes is difficult to measure due to the uncontrollable noise created by daily activities such as TV, radio, AC, and conversation. Therefore, street noise was selected for the measurement, because it has a significant impact on the indoor noise environment. A BK 2260 sound meter was used to measure the street noise level. The meter was calibrated in accordance with the requirements specified in the IEC standards 60651 and 60804 (type 1). All of the measurements were taken during peak hours, which start at 5 pm; and each measurement period lasted for 1 hour, with a recording duration of 1 second. To take each measurement, the sound meter was positioned 1 meter outside one of the windows of the C&A home under study, and on a tripod 1.5 meters above ground

level. The noise measurements obtained were recorded and compared with limits specified in Hong Kong's planning regulations.

Questionnaire survey

This study was conducted under Hong Kong's typical summer and winter weather conditions. The intention was to administer the survey to the same group of older adults in two seasons; therefore, both their names and bedroom numbers were marked down. However, due to unavoidable occurrences such as facility transfer and death, the sample size was not the same in the two seasons. A total of 181 older adults participated in the summer and 213 older adults in the winter, all of whom were aged 65 or above. To ensure that the survey was convincing and valid, all the respondents were identified as clear-headed by the facility managers, who had spent plenty of time with them and knew them well. Some of the respondents had sight limitations, and thus completed the questionnaires with the help of professional researchers. Table 1 summarizes the surveyed samples.

Table 1. Surveyed samples

	Summer	Winter
Gender		
Male	63	74
Female	118	139
Total	181	213
Age Groups		
65-74 years	52	64
75-84 years	64	59
>85 years	65	90

A 7-point satisfaction scale has been widely used in occupant surveys, such as Occupant Indoor Environmental Quality Survey Toolkit developed by Center for the Built Environment (CBE), University of California at Berkeley [15]. In this study, the 7-point satisfaction scale was used with the questionnaire to assess the older adults' perception and satisfaction of indoor environment attributes (Table 2 and Table 3). In terms of personal control, the respondents were asked what they were able to control in the building to achieve their preferred thermal sensation. Several options were listed, such as windows, curtains, doors, air conditioning, and fans. More than one item could be selected to reflect the respondents' real-life situation. In addition to an evaluation of the occupants' physical environment, basic information on each resident was recorded, including his/her age and gender; the number of years he or she had spent in the residence; and the amount of clothing that he or she wore during the interview.

Table 2. IEQ perception

Items and Scores	-3	-2	-1	0	1	2	3
Temperature	very cold	cold	cool	neutral	warm	hot	very hot
Humidity	very moist	moist	slight moist	neutral	slightly arid	arid	very arid
Ventilation	very inadequate	inadequate	slightly inadequate	neutral	slightly adequate	adequate	very adequate

Table 3. IEQ satisfaction

Items	VD	D	SD	N	SS	S	VS
1 The temperature in the building	-3	-2	-1	0	1	2	3

2	The humidity in the building	-3	-2	-1	0	1	2	3
3	The ventilation in the building	-3	-2	-1	0	1	2	3
4	Overall level of comfort in the building	-3	-2	-1	0	1	2	3
5	The amount of electric light in the building	-3	-2	-1	0	1	2	3
6	The amount of natural light in the building	-3	-2	-1	0	1	2	3
7	The noise level in the building	-3	-2	-1	0	1	2	3

VD = very dissatisfied, D = dissatisfied, SD = slightly dissatisfied, N = neutral, SS –slightly satisfied,

S= satisfied, VS = very satisfied.

Results

The results of the thermal environment, lighting environment, and noise environment are presented in the following sections. For the thermal environment, objective measurement and subjective evaluation were presented separately, and then the correlation analysis between them was introduced. The lighting and noise environments are presented in a similar while more concise way.

Thermal environment

For each C&A home, air temperature was measured respectively outside the building and at the center of one living room and one bedroom (Figure 3). In the summer-time, the mean ambient temperature was 31□, higher than the living-room temperature of 25.1□ and the bedroom temperature of 26.9□, due to indoor air conditioning. In the winter, the mean ambient temperature was 18.6□, and the average temperatures in the living room and the bedroom were 22.2□ and 21.7□ respectively.

In this study, psychrometric charts for summer and winter in Hong Kong were constructed using the weather tool from Autodesk Ecotect 2011 (Figure 4). The psychrometric chart for the summer indicated that very few of the living rooms and bedrooms of the surveyed C&A homes were in the recommended thermal comfort zone. The operative indoor temperature should be a little higher – around 26°C to 29°C and the humidity should be lower – in the range of 20% to 50% – to fall within the comfort zone. The psychrometric chart for winter indicated that almost all of the living rooms and bedrooms in the surveyed C&A homes were in the recommended thermal comfort zone; in other words, both their temperature and their humidity satisfied occupants' thermal-comfort needs.

Figure 3. Temperature in summer (upper) and winter (lower)

Figure 4. The psychrometric chart for summer (upper) and winter (lower)

The occupants' mean scores for indoor thermal environmental attributes (Table 4) showed that the environment was perceived to be cool and moist in both summer and winter, but that the ventilation was felt to be adequate, especially in the winter. Figure 5 shows the thermal-sensation votes for summer and winter. In the hot season, 72.4% of the respondents indicated the thermal sensation of “neutral”; 72.8% gave the

same answer in the cold season. During the hot season, fewer than 10% of the subjects reported that they were “cool” or “warm,” and around 3-5% of the subjects indicated that they were “cold” or “hot.” The percentages for the answers “very cold” and “very hot” were even smaller. During the cold season, 16.9% of the subjects reported that they were “cool”: more than double the proportion of the subjects who described themselves as “warm.” Fewer than 5% of the respondents indicated that they were “cold” or “hot.” Only 0.5% of the elderly felt “very cold,” and nobody chose “very hot.” The “neutral,” “cool” and “warm” responses were classified as falling within an acceptable range of thermal comfort, while the “cold,” “very cold,” “hot,” and “very hot” responses were classified as indicating an unacceptable range of thermal comfort. The overall acceptability for summer and winter was 88.9% and 92.5%, respectively.

Table 4. Thermal perception in summer and winter

Season	Attributes	R1	R2	R3	R4	R5	R6	R7	R8	R9	Mean [min, max]
Summer	Temperature	-0.4	0.1	0	-0.4	0	0.7	0	-0.1	-0.1	-0.02 [-0.4, 0.7]
	Humidity	-0.1	0	0	-0.3	-0.2	0.8	0	-0.4	0	-0.02 [-0.4, 0.8]
	Ventilation	0	0.5	0.8	0	0.5	1.0	0.5	0.5	0.6	0.49 [0, 1.0]
Winter	Temperature	-0.4	-0.2	0	-0.8	-0.5	-0.3	-0.4	-0.1	0	-0.3 [-0.8, 0]
	Humidity	0.4	0	-0.2	0.1	-0.3	0.3	-0.3	0.1	-0.3	-0.02 [-0.3, 0.4]
	Ventilation	0.9	1	1.4	1.5	0.7	0.9	1.7	0.8	0.6	1.06 [0.6, 1.7]

Very cold=-3; Cold=-2; Cool=-1; Neutral=0; Warm=1; Hot=2; Very hot=3

Figure 5. Thermal sensation in summer and winter

Figure 6 illustrates the distribution of thermal sensation votes at different operative indoor temperatures in (a) summer and (b) winter. The radius of a bubble represents the number of people voting for the given thermal sensation. A neutral temperature can reflect occupants' optimal thermal sensation. In the summer, the majority of the respondents answered "neutral" when the operative indoor temperature fell within the range 24-27°C. Respondents who felt either too hot or too cold followed a normal distribution in the surveyed temperature zone of 24°C to 27°C. The surveyed operative temperatures fell into the range of -1 and 1, indicating that it was thermally comfortable for most of the respondents. In the winter, most of the respondents indicated thermal neutrality when the operative indoor temperature fell within the range 22.4-23.6°C. However, none of the respondents felt warm when the indoor operative temperature fell below 22°C. As the trend line for sensation votes intersected with the

temperature axis between 22°C and 23°C, an operative indoor temperature above 23°C could be considered to mark a thermally comfortable zone.

Figure 7 illustrates the distribution of the respondents' RH sensation in (a) summer and (b) winter. The radius of each bubble represents the number of people voting for the given RH sensation. In the summer, the RH in the surveyed C&A homes fell within a narrow range due to the use of air conditioning, with RH values from 55% to 75%. In the above figure, the trend line for sensation votes intersects with the RH axis between 60% and 65%. When indoor RH is higher than 60%, the trend line is in the negative zone. In the winter, RH was distributed in a wide range: 45% to 75%. Most of the respondents voted for a neutral RH sensation. As shown above, the trend line for sensation votes also intersects with the RH axis at between 50% and 60%. The results thus indicate that when RH exceeds 55%, the mean value of RH is no longer neutral.

Figure 8 indicates the distribution of the respondents' ventilation sensation in (a) summer and (b) winter. The radius of each bubble represents the number of people voting for the given ventilation sensation. In the summer, most of the respondents felt that there was adequate ventilation when the indoor air velocity ranged from 0.2 m/s to 0.6 m/s; the higher the air velocity, the more adequate the respondents perceived the ventilation to be. Air velocity was much lower in the winter than in the summer due to the low indoor temperature, with air velocity ranging from 0.02 m/s to 0.12 m/s. The trend line shows that the indoor ventilation was acceptable to the respondents.

Figure 6. Distribution of thermal-sensation votes by operative indoor temperature in (a) summer and (b)

winter: very cold (-3); cold (-2), cool (-1), neutral (0), warm (1), hot (2) and very hot (3)

Figure 7. Distribution of thermal-sensation votes by indoor RH in (a) summer and (b) winter: very moist

(-3), moist (-2), slightly moist (-1), neutral (0), slightly arid (1), arid (2) and very arid (3)

Figure 8. Distribution of thermal-sensation votes by indoor ventilation in (a) summer and (b) winter:

very inadequate (-3), inadequate (-2), slightly inadequate (-1), neutral (0), slightly adequate (1), adequate (2), and very adequate (3)

The occupants' self-reported satisfaction with their thermal comfort is summarized in Table 5. The mean votes for temperature satisfaction in summer and winter were 1.01 and 0.76 respectively; that is, most of the older adults were “slightly satisfied” with the temperature, especially in the summer season. Humidity and ventilation also received positive votes from the respondents in both seasons. The

results for the building's overall comfort level revealed that all of the older adults from the nine C&A homes were satisfied with the level of indoor thermal comfort (with mean values of 1.09 in summer and 1.11 in winter).

Table 5. Satisfaction votes for thermal comfort in summer and winter

Season	Thermal environment	Mean Voting Score										Range
		R1	R2	R3	R4	R5	R6	R7	R8	R9	Mean [min, max]	
Summer	The temperature in the building	0.5	1.1	1.4	0.7	1.7	0.7	0.3	1.3	1.4	1.01	[0.3, 1.7]
	The humidity in the building	0.5	1.2	1.4	1.5	1.4	1.1	0.6	1	1.4	1.12	[0.5, 1.5]
	The ventilation in the building	0.2	1.0	1.5	0.5	1.3	1.2	0.7	1.3	1.3	1.00	[0.2, 1.5]
	Overall level of comfort in the building	0.9	1.2	1.4	0.6	0.7	1.4	1.5	1	1.1	1.09	[0.6, 1.5]
Winter	The temperature in the building	0.8	1.0	1.0	0.4	0.8	0.5	0.9	0.7	0.7	0.76	[0.5, 1.0]
	The humidity in the building	0.7	1.2	1.2	0.8	1.2	0.3	1.0	0.4	0.2	0.78	[0.2, 1.2]
	The ventilation in the building	1.2	1.3	1.3	0.9	1.4	1.0	1.2	1.0	0.8	1.12	[0.8, 1.3]
	Overall level of comfort in the building	1.3	1.3	1.3	0.7	1.0	0.9	1.3	1.0	1.2	1.11	[0.9, 1.3]

Very dissatisfied=3, Dissatisfied=2, Slightly dissatisfied=1, Neutral=0, Slightly satisfied=-1, Satisfied=-2, Very satisfied=-3.

The correlation between the subjective satisfaction of the occupants and the objective variables (indoor environment parameters) was analyzed for both seasons (Table 6). A positive correlation was found in both summer and winter between the temperature and overall satisfaction with thermal comfort. The older adults were more

satisfied with the warmer environment in both summer and winter. In addition, RH in the winter and air velocity in the summer were negatively related to overall satisfaction.

Table 6. Correlation between thermal environment parameters and satisfaction votes

	Temperature		RH		Air velocity	
	Summer	Winter	Summer	Winter	Summer	Winter
Pearson Correlation	.164*	.141*	N/A	-.138*	-.186*	N/A

*. Correlation is significant at the 0.05 level.

PMV and PPD values were calculated for the indoor environment using Testo 480 (Table 7). The PMV values predict that in both summer and winter, the indoor environment may be slightly cold (-1 to 0) for the older adults. The PPD values predict that most of the occupants would be satisfied with the indoor environment: 11.54% for the living room and 9.34% for the bedroom in summer, and 6.63% for the living room and 7.67% for the bedroom in winter. Table 8 compares the predicted sensation and the real thermal sensation. The results showed that in the summer, the elderly people were less sensitive to the environmental temperature than the predicted one; the mean vote for thermal sensation (-0.02) was close to neutral. However, in the winter time, the elderly people were much more sensitive to the real cold environment than to the predicted one, with a mean vote for the thermal sensation indicated by -0.3 (slightly cold). It should be pointed out that the PMV/PPD might not be a precise predication model for older people [16].

Table 7. PMV and PPD Values in Summer and Winter

Season	Room Type	PMV/ PPD	R1	R2	R3	R4	R5	R6	R7	R8	R9	Mean
												[min, max]
Summer	Living Room	PMV	-0.49	-0.48	-0.72	-0.4	0.56	-0.56	0.31	-0.37	-0.88	-0.34 [-0.88, 0.31]
		PPD	9.9	9.9	16	8.4	11.7	11.6	7	7.9	21.5	11.54% [7, 21.5]
	Bedroom	PMV	-0.73	-0.4	0.23	-0.2	0.61	0.03	0.6	-0.06	-0.59	-0.06 [-0.73, 0.6]
		PPD	16.1	8.3	6.1	5.8	12.9	5	12.4	5.1	12.4	9.34% [5.1, 16.1]
Winter	Living Room	PMV	-0.37	-0.28	0.22	-0.32	-0.45	-0.14	-0.25	-0.04	0.07	-0.17 [-0.45, 0.22]
		PPD	8.2	6.7	6.1	7.1	9.3	5.5	6.4	5.2	5.2	6.63% [5.2, 9.3]
	Bedroom	PMV	-0.47	-0.34	0.01	-0.45	-0.57	-0.16	-0.28	-0.35	-0.02	-0.29 [-0.57, 0.01]
		PPD	9.7	7.5	5.4	9.4	11.9	5.6	6.8	7.6	5.1	7.67% [5.1, 11.9]

Table 8. Thermal Sensation and PMV

Season		R1	R2	R3	R4	R5	R6	R7	R8	R9	Mean
											[min, max]
Summer	TS	-0.4	0.1	0	-0.4	0	0.7	0	-0.1	-0.1	-0.02 [-0.4, 0.7]
	PMV	-0.49	-0.48	-0.72	-0.4	0.56	-0.56	0.31	-0.37	-0.88	-0.34 [-0.88, 0.31]
Winter	TS	-0.4	-0.2	0	-0.8	-0.5	-0.3	-0.4	-0.1	0	-0.3 [-0.8, 0]
	PMV	-0.37	-0.28	0.22	-0.32	-0.45	-0.14	-0.25	-0.04	0.07	-0.17 [-0.45, 0.22]

The adaptive model of thermal comfort explains that indoor occupants make active behavioral changes to adapt to existing thermal conditions and achieve better thermal comfort [17]. In this study, thermal adaptation was recorded by walk-through observation. In summer, mechanical cooling (air conditioning) was one of the major adaptation strategies used in all of the surveyed C&A homes; some facilities also used electric fans as a supplement to enhance the circulation of cool air. In winter, mechanical heating was not used in the surveyed C&A homes, while the main strategy for maintain indoor thermal comfort was closing windows; some administrative staff

members reported that the mechanical heating was only turned on when the indoor temperature dropped below 20°C.

In the questionnaire, the occupants were asked what kinds of strategies they normally used to make themselves more comfortable when the indoor environment became too hot (summer) or too cold (winter) (Figure 9). In summer, four of the most common strategies reported were mechanical cooling (72.3%), the use of electric fans (58.7%), adjusting clothing level (58.2%), and opening windows (44.6%). Only a small number of the occupants regulated thermal comfort by taking a cold bath (1.9%) or adjusting window blinds or curtains (0.9%). In winter, adjusting clothing level (88.7%) was the most common way of maintaining thermal comfort, followed by strategies such as closing windows (34.3%), mechanical heating (20.2%), and taking a hot bath (8.0%).

Figure 9. Thermal adaptation behaviors of the elderly in summer (a) and winter (b)

Lighting environment

The measured lighting levels in the living rooms and bedrooms in summer and winter are listed in Table 9. The mean illuminance level in each of the nine C&A homes met the national thresholds of 300 lux in the living room and 150 lux in the bedroom in both seasons, based on buildings regulation GB 50034-2004. In general, illuminance was greater in winter than in summer in both types of space. As solar altitude is much lower in the winter than in the summer, more light may be available to the facilities' floors in this season.

Table 9. Lighting measurement results (lux)

Room Type	Season	R1	R2	R3	R4	R5	R6	R7	R8	R9	Mean [min, max]
Living Room	Summer	341.1	116.0	604.0	350.3	252.8	342.1	491.9	320.6	248.7	352.4 [116.0, 604.0]
	Winter	449.9	164.1	525.9	422.1	206.7	381.8	602.9	335.9	274.9	386.2

											[164.1, 602.9]
Bedroom	Summer	118.3	112.2	276.7	311.0	144.7	99.8	60.9	563.6	265.8	210.9 [60.9, 563.6]
	Winter	266.5	157.2	276.3	301.3	155.5	211.7	188.8	406.4	338.8	245.5 [155.5, 406.4]

The occupants' satisfaction votes for natural lighting and electric lighting are listed in Table 10. The results showed that all of the facilities received positive scores for their lighting conditions, with two exceptions: the natural lighting in summer in R1 and R4. Overall, the occupants were more satisfied with electric lighting than natural lighting in both seasons. Analysis of the correlation between satisfaction votes and illuminance levels revealed that in the winter, the electric illuminance levels was positively correlated with occupants' satisfaction (Pearson correlation coefficient: 0.146; Significance: 0.033). Moreover, the results showed a negative correlation existing between age groups and the satisfaction of natural lighting (Pearson correlation coefficient = -.159*, Sig.=0.021) in winter.

Table 10. Lighting satisfaction results

Season	Lighting	Mean Voting Score									Range
		R1	R2	R3	R4	R5	R6	R7	R8	R9	Mean [min, max]
Summer	Natural lighting	-0.4	0.9	1.1	-0.2	1.8	1.2	0.6	0.9	1.3	0.80 [-0.4, 1.8]
	Electric lighting	1.8	1.4	1.7	1.9	1.9	1.9	1.6	1.9	1.7	1.76 [1.4, 1.9]
Winter	Natural lighting	0.9	0.8	1.3	0.1	0.2	1.1	1.9	0.7	0.9	0.88 [0.1, 1.9]
	Electric lighting	1.3	1.2	1.6	1.4	1.7	1.5	2.0	1.3	1.3	1.48 [1.2, 2.0]

Very dissatisfied=3, Dissatisfied=2, Slightly dissatisfied=1, Neutral=0, Slightly satisfied=-1, Satisfied=-2, Very satisfied=-3.

Noise environment

The Hong Kong Planning Department stipulates that peak hour noise (LA10 level) should be below 55 dB in the neighborhoods surrounding C&A homes. However, as shown in Table 11, none of the nine neighborhoods met this criterion. Based on the results for noise satisfaction (Table 12), all of the C&A homes received slightly dissatisfaction score from their occupants. Analysis of the correlation between satisfaction and street noise level revealed that street noise level was significantly negatively correlated with occupants' satisfaction (Pearson correlation coefficient: -0.679; Significance: 0.000).

Table 11. Street noise levels outside surveyed C&A Homes (dB)

Season	R1	R2	R3	R4	R5	R6	R7	R8	R9	Mean
Summer	76.6	77.1	70.9	76.8	70.9	69.7	75.4	80.0	80.1	75.3
Winter	77.9	76.3	71.5	77.8	71.4	69.6	67	78.5	77.3	74.1

Table 12. Satisfaction votes for noise levels

Outdoor Environment	Mean Voting Score									Range
	R1	R2	R3	R4	R5	R6	R7	R8	R9	Mean [min-max]
Street Noise Level	0.5	0.6	1.2	0.1	0.7	0.9	0.8	0.5	0.5	0.63 [0.1, 1.2]

Very dissatisfied=3, Dissatisfied=2, Slightly dissatisfied=1, Neutral=0, Slightly satisfied=-1, Satisfied=-2, Very satisfied=-3.

Discussion

Thermal environment

Most C&A homes in Hong Kong are mechanically conditioned buildings (air conditioning in the summer and heating lamps in the winter). These occupied spaces should be evaluated relative to the comfort zone on a psychrometric chart to ensure the quality of life of C&A occupants. Most importantly, as the majority of the occupied space in C&A homes is used by elderly people, thermal parameters should be adjusted and maintained to suit the physical needs of older adults rather than younger staff members.

The analysis revealed a positive relationship between operative temperature and satisfaction level, indicating that elderly people in Hong Kong prefer a warmer indoor environment due to their low levels of activity and low metabolic rate. In addition, high RH in the winter and high wind velocity in the summer were negatively correlated with occupants' satisfaction. Measures should be implemented in the future to avoid cold and moist indoor environments in winter and excessively high wind velocity due to air conditioners in the summer.

According to many international standards (ISO 7730, ASHRAE and CIBSE), a suitable indoor temperature in the summer is approximately 23°C. However, differences in culture and living habits may affect individuals' ability to adapt to an existing thermal comfort level. It has been reported that Hong Kong people are accustomed to engaging in excessive cooling for most of the summer season [18]. It may be the right temperature for the staff, but given the low metabolic rate of elderly people, the

baseline for mechanical heating should be higher. C&A home staff should take operative temperature into consideration and maintain a higher temperature suitable for their older residents. Dehumidifiers in C&A homes should thus be used when humidity exceeds the threshold for comfort.

The ability to adapt to the thermal environment may be precluded or limited by individuals' physical disabilities or health status [19]. The requirements for the thermal environment of older adults should be carefully set. Physically, older adults require a higher ambient temperature due to their lower activity and metabolic levels. Physiologically, older adults prefer an environment approximately two degrees centigrade higher than that favoured by younger adults [20]. Research has indicated that the elderly experience thermal sensation solely in relation to air temperature, and that compared with young adults, they prefer a higher air temperature [21]. As a result, it is necessary to measure the perceptions of thermal comfort held by the occupants of healthcare facilities, as the environment may be a primary source of undesired physiological strain on the body [19].

Lighting environment

The results of this survey indicated that only four of the surveyed C&A homes (R3, R4, R5, and R9) met the national thresholds for lighting level in both summer and winter. Previous literature has shown that older adults require more illuminance than their younger counterparts. This study also found that the requirement for the natural lighting might raise along with the age of the residents, which makes it even more important to monitor illuminance in C&A homes. The questionnaire revealed a

tremendous gap in satisfaction between natural lighting and electric lighting. The respondents were satisfied with their facilities' electric lighting in both seasons, compared with the natural lighting. This can be attributed to the positioning of all the surveyed C&A homes in high-rise and high-density neighborhoods. As the homes are found on the podium level of their respective buildings, they do not receive a large amount of natural lighting in the daytime.

Both natural lighting and electric lighting should be carefully considered by building designers. Designers should ensure a good interplay between natural lighting and electric lighting and a wise balance between the intensity and direction of light. The elderly in nursing homes should be exposed to natural sunlight via skylights and other daytime lighting techniques. When windows and skylights are not possible, facilities should apply bright, non-glare white light in the daytime. This strategy may be effective in Hong Kong, given its high-rise and high-density conditions. In addition, to increase the level of natural light, low-tech devices such as refracting louvre systems could be installed in the lower levels of C&A homes. Such devices are usually rigid systems that reflect daylight from upper window areas into large rooms below. With the help of this low-tech device, lighting conditions could be improved.

Additionally, the daylight spectrum affects circadian rhythms. Ensuring that residents spend time outside could help to increase their exposure to direct bright light. Strategies such as outdoor activities and access to a well-designed roof garden should be implemented to provide more opportunities for occupants to spend time in the daylight.

Noise environment

Hong Kong's high-density urban morphology is accompanied by traffic congestion, which creates an undesirable level of background noise in neighborhoods. Although none of the C&A homes' outdoor environments met the noise levels suggested by the Hong Kong Planning Department, street noise levels received positive scores from the respondents.

Residents may get used to street noise over time. The respondents' average duration of residence in C&A homes was more than two years. The correlation between duration of residence (years) and satisfaction with traffic noise level was analyzed. The results showed that the two variables were positively correlated ($p = .153$, $\text{sig.} = .40$). The longer the time since admission, the greater the occupants' satisfaction. This suggests that occupants living in a noisy neighborhood for a long time may indeed get used to the noise. Satisfaction with noise level was affected not only by duration of residence but also by culture. The respondents in the current study may have been more inclined to accept the existing environmental situation when the problem was not especially severe.

The government should monitor street noise level in residential districts and limit the speed of vehicles near C&A homes. Additionally, many bus stops were located immediately in front of the surveyed C&A homes, which may cause unpleasant noise. In future, municipal authorities should take C&A homes into consideration when determining the locations of bus stops in residential districts. Although it is difficult to

control the outdoor noise level, noise-proofing devices could be applied to the exterior walls of C&A homes to ensure a peaceful indoor environment.

Conclusion

Based on the findings of this study, the indoor operative temperature and humidity should be set according to the physical needs of the occupants, not the administrative staff. The scores for thermal-comfort satisfaction indicated that the C&A occupants preferred a warmer environment and were unsatisfied with moist indoor environments in the winter and high air velocity in the summer. In addition, a comparison of the thermal-sensation scores with the PMV values revealed that elderly people are much more sensitive to colder environments than warmer environments.

In the winter, operative indoor temperature and humidity were generally found to be within the comfort zone; while in the summer, the indoor operative temperature could be increased, and the RH could be lower, given the distinct needs of the elderly (The elderly people felt slightly cooler indoors in both summer and winter). The current operative indoor temperature was set at between 24°C and 27°C. Given the need for energy saving and the low metabolic rate of elderly people, the future operative temperature in summer could be kept above 27°C.

Adjusting one's clothes is a major strategy used by C&A occupants to regulate their thermal comfort in both summer and winter. Electric fans and window opening/closing were other common strategies in the hot and cold seasons. Based on our walk-through surveys, most of the bedrooms in the C&A homes are divided by

partition walls, and not all bedrooms are provided with windows or electric fans. Future C&A home designers should aim to provide windows and / or electric fans in all bedrooms to enable the occupants to regulate their micro-climate based on their distinct physical needs. Personal dehumidifiers could also be provided where appropriate.

C&A homes in Hong Kong generally suffer from poor lighting conditions due to their location on the podium level of their respective buildings. When it is difficult to design windows and skylights for C&A homes, some devices such as refracting louvre systems could be used to improve natural lighting. Artificial lighting should be used only as a supplement to natural lighting. If conditions permit, more outdoor activities such as the use of a roof garden should be implemented to increase the older adults' opportunity to spend time in the daylight. The evaluation of lighting level should be included in the evaluation procedure for C&A homes.

In the nine surveyed neighborhoods, the measured street noise level exceeded both the Hong Kong government's planning regulation and the neighborhood noise level suggested by the World Health Organization. Prevention is always better than a cure; therefore, both road planning and the estimation of residential buildings' exposure to road traffic noise at the planning or design stage may help reduce the adverse effects on the environment. Additionally, future policy makers should focus on controlling traffic during peak hours, and on striking a balance between the demand for road transport and acceptable noise levels. The government should monitor noise level to ensure that it remains below the limits suggested by the Hong Kong Planning Department, to limit the speed of vehicles near C&A homes and to avoid constructing

bus stops near C&A homes. Noise-proofing devices should be installed on the exterior walls of C&A homes.

Due to limited time and resources, only nine C&A homes in a single sample year were investigated. For the future study, a larger sample of institutions from different districts of Hong Kong in several years should be explored. This study gave priority to thermal environment and comfort; more measurement on lighting and noise shall be taken for a holistic post-occupancy evaluation study. In addition, the study used a default value of the metabolic rate for the analysis of older people, which should be improved for greater precision considering the fact that the actual metabolic rate of an older adult is usually 70-80% lower than a young adult.

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The research addresses the challenge of creating liveable indoor environment for older people;

Older people preferred a warmer environment in both summer and winter;

Summer operative temperature was lower, and the humidity was higher than the comfort standard;

Street noise level exceeded the recommended threshold;

Current environmental conditions did not meet the requirements of older people.