Study on the Effect of the Layout of Daytime Activity Space on the Annual Vertical Daylight Exposure on the Eye in Elderly Facilities

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Abstract

Lighting has been identified as a significant environmental attribute responsible for promoting physical and mental health of the elderly. However, present guide and standard focuses mostly on horizontal illumination requirements for specific tasks, but less on vertical lighting. This study attempts to evaluate lighting quality of the daytime activity space in Beijing's elderly facilities from the configuration of vertical daylighting on the eye by DAYSIM simulation based on dynamic climate, and to analyze the influence of position orientation on vertical daylight exposure on the eye so as to explore the possibility and design technology to optimize the non-visual based lighting quality.

Keywords: daylight; vertical daylight exposure; activity space; elderly facilities;

1. Introduction

With the discovery of ipRGCs (intrinsically photosensitive retinal ganglion cells, a type of neuron in the retina of the mammalian eye) (Berson, Dunn et al., 2002), the effect of light on human physiological and psychological health has become research hotpot in the lighting field. Light causes circadian, hormonal and other behavioral responses, from shifting sleep timing, jet-lag and melatonin suppression to pupil constriction, light adaptation and physiological activation (Price and Peirson, 2014), and then influences alertness, tension and sleep quality (Münch, Kobialka et al., 2006).

Lighting has been identified as a significant environmental attribute responsible for promoting physical and mental health of the elderly (Shikder, Mourshed et al., 2012).With the growth of age, the elderly suffer from evident overall optical changes that can cause one or more visual diseases and result in reduced visual performance (Weale, 1992). Besides, with the discovery of non-visual biological effects, light can help the elderly defeat depression, circadian sleep-wake disorder and behavioral disturbances among elderly (Sloane, Figueiro et al., 2008). Therefore, specialized lighting for the elderly was urgently considered to satisfy their physical needs and to enhance their psychophysical health and well-being (Shikder, Mourshed et al., 2012).

With non-visual biological effects, researches on elderly's lighting for physiological and psychological health (alertness, mood, performance and sleep quality) is taken more seriously. Several studies were made and the effects of light on alertness and mood has been found that the high-light regime always results in better alertness and mood than control group (Boyce, Beckstead et al., 1997). Meanwhile it was investigated that lighting during daytime hours can influence the sleep quality during the night (Riemersma-van der Lek, Swaab et al., 2008). A significant positive correlation between vertical illuminance at the eye level and sleep quality was shown (Aries, 2005). Many studies, besides mentioned above, indicate that lighting levels of at least 1000 lux on the eye are needed for biological stimulation (van Bommel, 2006). Besides, the influences of CCT (Correlated Color Temperature) of light on mental performances was also aimed that the blue-enriched white light experimented within an office has improved the subjective measure of alertness, mood, performance and other indicators of wellbeing (Viola, James et al., 2008). The efficiency of good natural light in the architectural context has also been investigated in several studies (Beauchemin and Hays, 1996).

It has been evident that non-visual biological effect of light is not directly governed by the illuminance on the

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working plane, but by light entering the eye (van Bommel, 2006), namely vertical light exposure at the eye level, which means that both vertical illuminance at the eye level and its time should be counted. The light entering the eye causes non-visual biological effect and provides the time information (the moment when the light exposure exists and its lasting time) at the same time (Bierman, Klein et al., 2005), which will influence the former. However, levels of illumination for various tasks and spaces are widely discussed in guides and specific values are suggested in lux (CIEUK, 1997, Light, 2002), while detailed recommendations for vertical illumination and vertical light exposure at the eye level are lacking in most guides (Shikder, Mourshed et al., 2012).

Therefore, in this study it was suggested that investigation into the effect of vertical light exposure at the eye level on the elderly's physiological and psychological health should be carried out on the base of acknowledgement of the difference of vertical daylight condition in elderly facilities, and then help optimize the non-visual based lighting quality.

Since China entered an aging society in 1999, aging trend has been presented the characteristics of the huge elderly population, fast speed of growth and the increasing proportion of the oldest old. People over the age of 60 account for 16.15% of the country's population of 1.37 billion in 2015, up from 10.3% in 2000, and will be 33.6% in 2050, according to the National Bureau of Statistics of China (2016). The ageing population has already been recognized as one of the greatest challenges of the 21st century for housing on both side of quantity and quality. A number of new elderly facilities for not only housing and health care but also social care services need to be built and the quality of those existing need to be updated to accommodate the increased service levels the ageing population will require.

As one of the biggest cities in China, Beijing has many typical conditions and was selected as the location of the model in this study. Daytime activity space was taken due to its various vertical daylight conditions. Therefore, this study attempts to evaluate lighting quality of the daytime activity space in Beijing's elderly facilities from the configuration of vertical daylighting on the eye and the illuminance on the working plane (UDI) by DAYSIM simulation (Reinhart, 2011) based on dynamic climate, and to analyze the influence of position orientation on vertical daylight exposure on the eye so as to explore the possibility and design technology to optimize the non-visual based lighting quality. It must be illustrate that as a simulation the spectrum of light could not be considered, and in the simulation the element of time has been simplified.

2. Methodology

2.1 Building model and simulation

The building model was a unit of the activity room in the elderly facilities located in the urban area of Beijing (39.80 N/ 116.47 W), where there were no obstructions all around. According to the survey of the content and characteristics of the elders' activity in elderly facilities in Beijing, the model was built on the widely used standard column grid of 8.4m×8.4m, with the floor height of 3.6m (Fig. 1). The basic unit was formed as Fig. 1 shows, with the available space of 16m×16m×2.8m excluding the space occupied by beam, column and other facilities. According to the survey, the unit consisted of two rooms separated by a hallway. Considering the elders' requirement of daylight, the depth of the south room (8m) was larger than the north (6m), between which was a 2m-wide hallway to ensure that two wheelchairs could pass through meantime. And French window was used for more daylight.

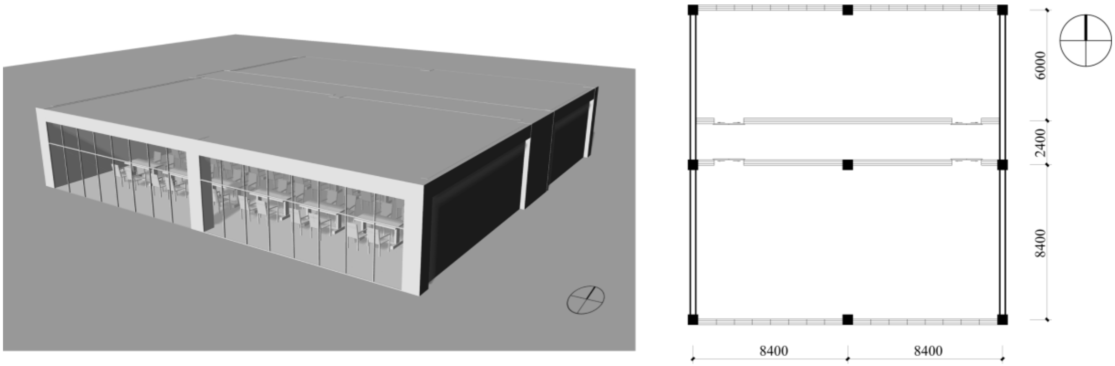
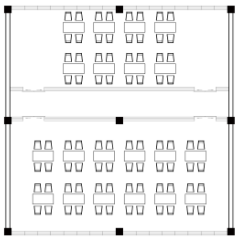
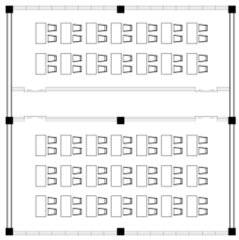
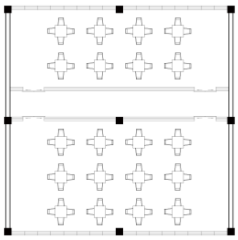


Fig. 1 perspective view and plan of the model

In the unit there were 3 typical furniture layout representing 3 common daytime activities in the elderly facilities (Tab. 1). The reflectances of the room surface are in Tab. 2.

Tab. 1 the three typical furniture layout

Type	1. Reading Room or Public Living Room	2. Classroom	3. Dining Room or Chess and Card Room
Plan			
Activity samples			

Tab. 2 Parameters for simulation

Room orientation	South	North
Moulded dimension (Wide/Depth/Height)	16m/8m/2.8m	16m/6m/2.8m
Site description	Beijing_CHN(39.80 N/ 116.47 W)	
Hourly occupancy schedule	8:00-18:00 per day	
Obstructions	None	None
Mutual occlusion of the elderly	None	None
the Eye height of the elderly	1.15m	1.15m
the Height of work plane for UDI	0.8m	0.8m
Material reflectance		
Interior white wall	0.5	0.5
Furniture (wood)	0.3	0.3
Ceiling	0.7	0.7
Floor	0.2	0.2
Ground	0.2	0.2
Material Visual Transmittance		
Glazing DoublePane LowE Argon	0.65	0.65
Parameters of simulation precision		

ambient bounces	5	5
ambient divisions	1000	1000
ambient accuracy	0.1	0.1
direct sampling	0.2	0.2
direct relays	2	2

2.2 Daylight simulation

The relative daylight metrics were obtained by annual dynamic daylighting simulation software DAYSIM based on dynamic climate, with three typical furniture layout and simulation period of 8:00-18:00, according to the survey of elderly facilities. Two daylight metrics were used: the annual vertical daylight exposure on the eye (simplified as H_v in this paper) and Useful daylight illuminance (UDI).

In this study, the vertical daylight exposure on the eye instead of vertical illuminance on the space's surface of the elderly facilities was selected to reflect the distribution of vertical lighting. This is because the latter of the seats in space changes between different moments, which cannot be used as an evaluation standard, while the former is more objective (it considered the effect of time although it supposes that person always sit here). And it was suggested that higher vertical daylight exposure on the eye is recommended under consideration of UDI

Considering the complexity of vertical daylight situation which changes by time, situation, and orientation, only the positions of the elderly's eyes when they sat in the seat instead of the whole room were considered in this paper. And it was supposed that the elderly would sit on the same seat and look at the front during the whole daytime activity in a year, so that the vertical daylight exposure the elderly received could be represented by vertical daylight metrics of the positions of the elderly's eyes when they sat on the seat.

There's some point must be illustrate that the position of the elderly, namely the seats and tables' usage periods in different position, is far more complex than supposed, which are related to the seasons, weather, the horizontal illumination, layout of activities, etc, and there will significantly influence vertical daylight exposure on the eye. Therefore, the annual daylight exposure can proximately reflect this phenomenon but not totally.

Useful daylight illuminance (UDI) was invoked to be comparatively analyzed with the annual vertical daylight exposure on the eye. UDI evaluates luminous environment with the effective horizontal illumination (from 100 lux to 2000 lux) in work plane, which is irrelevant to the face orientation. Therefore, the simulation of the study, which presents health concept, was treated as an addition to UDI to some extent.

In order to get H_v, a series of vertical working planes including the seats' position were chosen as calculation plane, on which the points of 1.15m above the floor (the eye position of a sitting elderly) were finally considered. As for UDI, the calculation position in the model was at a horizontal working plane height of 0.8m above the floor. A calculation grid with 1600 points was evenly distributed across the plane. Other detailed parameters for the simulation were shown in Tab. 2.

2.3 Data analysis

Data analysis paid attention to the effect of position, orientation on H_v, the difference between H_v and UDI, and the difference between the glass hallway and opaque hallway. Besides, the material of walls, which are the solid wall (opaque, and reflectance is 0.5) and the glass wall (visual transmittance is 0.65), on both sides of the hallway was also compared to find how much it would influence the daylight environment.

Statistical analyses were performed using SPSS version 23.0 for Windows (IBM SPSS Inc., Chicago, IL). A two-sided p value<0.05 was considered significant. One-Way ANOVA (one-way analysis of variance, a technique that can be used to compare means of two or more samples) (Howell, 2002) was adopted to determine whether H_v of different groups (columns or rows) have a significant difference. When comparing H_v with UDI, as for the seats at one table, visual task happened mainly on the tabletop, so the average UDI of tabletop was calculated to approximately reflect the level of visual task lighting of the seats at the table. In order to compare easily, the average H_v of the seats at one table was also calculated similarly.

In order to analysis conveniently, each table and seat in the 3 type of plans was numbered as Tab.3 showed.

Tab. 3 numbers of tables/seats

<table>
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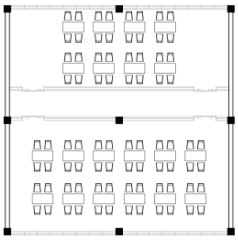
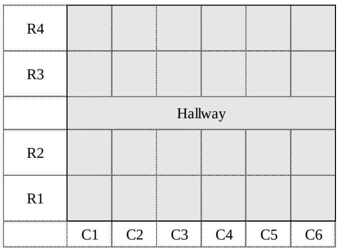
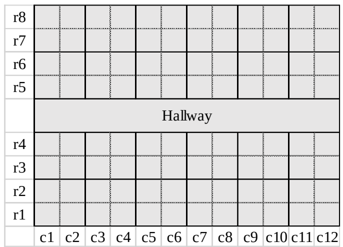
<tr><td>1</td><td></td><td>
</td><td>
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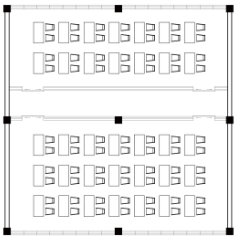
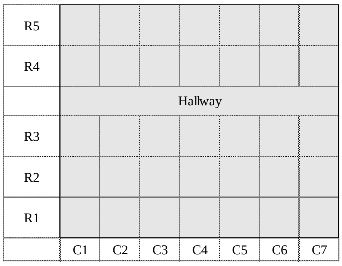
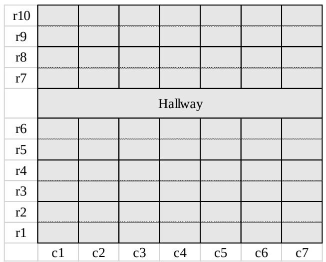
<tr><td>2</td><td></td><td>
</td><td>
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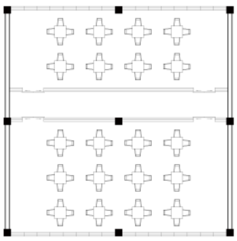
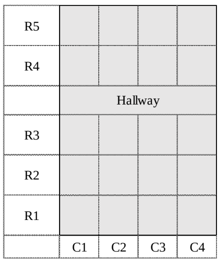
<tr><td>3</td><td></td><td>
</td><td>None</td></tr>
</table>

3. Results

3.1 Position and orientation

In this part, it was found that position orientation has a significant influence on annual vertical daylight exposure on the eye (H_v). For analyzing, position and orientation were discussed separately. Position was divided into the differences of the same row, the same column and whether in south or north, while orientation paid attention to whether facing or back to windows. And it is similar between the two different material of hallway, so in this part only the opaque hallway was discussed while the difference between the two hallway was shown in part 3.3.

According to H_v in all 3 types (Fig. 2.1 to 2.3), generally type-1 has the best evaluation (with MN of 4.2×10^6 lux ħ) while type-2 has the worst (with Mean, simplified as MN, of 3.4×10^6 lux ħ). And the distribution of H_v among the seats in type-2 is most uniform (with Standard Deviation, simplified as SD, of 2.5×10^6 lux ħ) while the type-3 varies most (with SD of 4.4×10^6 lux ħ).

Meanwhile, it was found that orientation of the room makes obvious effect on H_v. Generally the H_v of the seats in south room is higher than that in north room (with the MN of 5.5×10^6 lux ħ in south vs 3.0×10^6 lux ħ in north in type-1, 4.1×10^6 lux ħ vs 2.4×10^6 lux ħ in type-2, and 5.2×10^6 lux ħ vs 2.4×10^6 lux ħ in type-3), and varies more (with the SD of 5.8×10^6 lux ħ in south vs 2.6×10^6 lux ħ in north in type-1, 3.0×10^6 lux ħ vs 9.8×10^5 lux ħ in type-2, and 5.2×10^6 lux ħ vs 1.9×10^6 lux ħ in type-3).

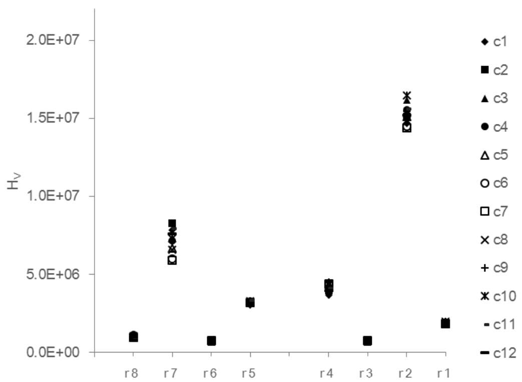
the North	1.01	1.00	1.13	1.14	1.00	0.95	0.94	0.99	1.04	1.07	0.97	0.99
	7.86	8.28	7.34	7.18	6.67	6.02	5.89	6.57	7.16	7.32	7.94	7.61
	0.72	0.70	0.75	0.75	0.75	0.75	0.75	0.75	0.74	0.74	0.70	0.71
	3.05	3.24	3.32	3.30	3.24	3.25	3.20	3.29	3.29	3.23	3.32	3.11
Hallway	solid wall											
the South	3.69	3.97	4.19	4.16	4.37	4.35	4.40	4.37	4.52	4.43	4.12	3.96
	0.70	0.70	0.69	0.71	0.77	0.77	0.77	0.77	0.74	0.70	0.72	0.74
	14.68	15.09	16.19	15.56	15.10	14.49	14.37	14.88	15.46	16.47	15.58	15.20
	1.89	1.92	1.94	1.93	1.87	1.82	1.83	1.89	1.97	2.00	2.01	2.03

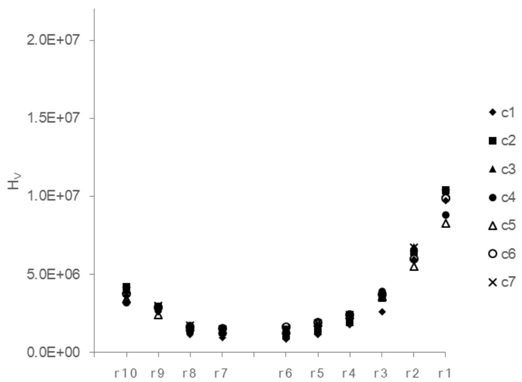
the North	3.6	4.2	4.0	3.2	3.4	3.8	4.0
	2.6	2.9	3.0	2.7	2.4	2.9	3.0
	1.2	1.4	1.7	1.7	1.7	1.7	1.7
	1.0	1.3	1.5	1.6	1.4	1.6	1.5
Hallway	solid wall						
the South	0.9	1.1	1.3	1.5	1.5	1.7	1.6
	1.2	1.4	1.5	1.7	1.9	1.9	1.9
	1.8	1.9	2.2	2.5	2.4	2.4	2.4
	2.6	3.5	3.8	3.9	3.6	3.7	3.6
	6.0	6.5	6.8	6.6	5.5	6.0	6.7
	9.7	10.4	10.4	8.8	8.3	9.9	10.2

the North	1.55 3.08 → ← 1.22 7.50	1.08 1.53 → ← 1.56 6.65	1.07 1.45 → ← 1.95 6.54	1.09 1.27 → ← 1.57 7.38
	0.79 1.63 → ← 1.36 3.48	0.91 1.66 → ← 1.67 3.65	0.90 1.62 → ← 1.59 3.54	0.78 1.34 → ← 1.65 3.47
Hallway	solid wall			
the South	3.58 1.63 → ← 1.14 0.70	3.88 1.51 → ← 1.48 0.83	3.71 1.54 → ← 1.60 0.82	3.78 1.15 → ← 1.93 0.71
	6.25 3.35 → ← 3.19 1.09	6.42 3.17 → ← 3.78 1.08	6.39 3.39 → ← 3.65 1.08	6.68 3.04 → ← 3.78 1.09
	20.04 9.49 → ← 10.62 2.70	18.57 7.69 → ← 10.74 2.48	18.22 9.36 → ← 8.51 2.47	20.27 9.50 → ← 10.51 2.73

Fig. 2.1 to 2.3 the annual vertical daylight exposure on the eye (H_v, 10^6 lux・h) of each seat with solid walls on the side of the hallway, layout type-1 to type -3

Besides, there is a big difference among the seats in the same column. From the result of One-way ANOVA (Tab. 4), it was shown that there is a significant difference of H_v among the column (F_7=2265.063, p<0.05 in type-1, F_9=312.153, p<0.05 in type-2, and F_4=571.305, p<0.05 in type-3). Among the seats of the same orientation in one column, H_v decreased with the raise of the distance to windows (Fig. 3.1 to 3.4).





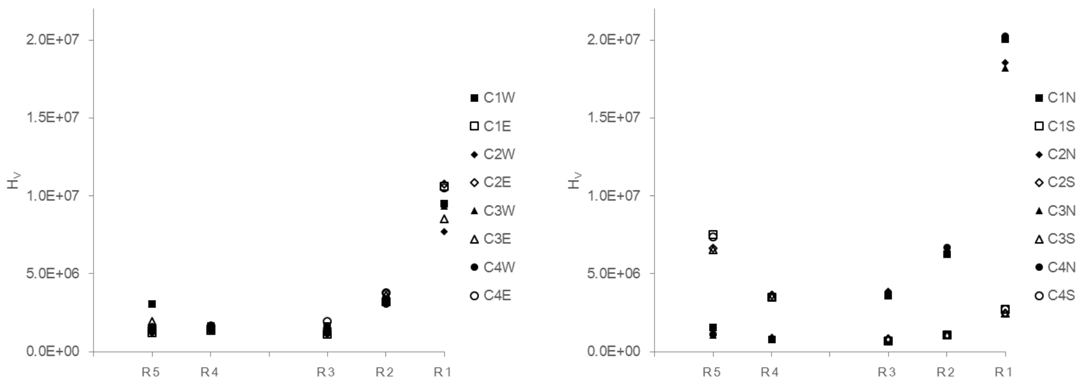


Fig. 3.1 to 3.4: the annual vertical daylight exposure on the eye of each seat (H_v, lux • h), layout type-1 to type -3

Note: 3.1 for type-1, 3.2 for type-2, and H_v in type-3 was divided into 2 parts: 3.3 includes seats westwards and eastwards, and 3.4 includes the north and south.

However, the H_v of the seats in the same row is similar according to One-way ANOVA result in Tab. 5 ($F_{11}=0.007$, $p>0.05$ in type-1, $F_6=0.068$, $p>0.05$ in type-2, and $F_3=0.006$, $p>0.05$ in type-3). In type-2, H_v among the seats in the row near the window varies more than those away from the window, and the conclusion is tenable in type-1 and type-3 when considering seat orientation (facing or back to windows). That is to say, within the 3 type plan, positions perpendicular to windows have more effect on H_v than positions parallel to windows.

Tab. 4 one-way ANOVA results (between columns)

		Sum of Squares	df	Mean Square	F	Sig.
Type-1	Between Groups	2053885838252480.000	7	293412262607497.000	2265.063	.000
	Within Groups	11399366119749.400	88	129538251360.789		
	Total	2065285204372230.000	95			
Type-2	Between Groups	449089154852403.000	9	49898794983600.300	312.153	.000
	Within Groups	9591226811834.930	60	159853780197.249		
	Total	458680381664238.000	69			
Type-3	Between Groups	197368045712237.000	4	49342011428059.300	571.305	.000
	Within Groups	1295508725153.260	15	86367248343.551		
	Total	198663554437390.000	19			

Notes: df: degree of freedom; F: F-test; Sig.: Statistical significance

Tab. 5 One-way ANOVA Results (between rows)

		Sum of Squares	df	Mean Square	F	Sig.
Type-1	Between Groups	2005104461408.360	11	182282223764.397	.007	1.000
	Within Groups	2063280099910820.000	84	24562858332271.700		
	Total	2065285204372230.000	95			
Type-2	Between Groups	2950000602991.090	6	491666767165.181	.068	.999
	Within Groups	455730392694777.000	63	7233815757059.960		
	Total	458680393297769.000	69			
Type-3	Between Groups	226823208655.060	3	75607736218.353	.006	.999
	Within Groups	198436731228735.000	16	12402295701796.000		
	Total	198663554437390.000	19			

Considering orientation of seats, there is a significant difference in type-1 and type-3 (type-2 has only one orientation). In type-1 (Fig. 3.1) between the two orientation——facing (r8, r6, r3 and r1) or back to windows (r7, r5, r4 and r2), H_v of the former seats is obviously larger than the latter in general, with a difference of 6.4×10^6 lux ħ on average (7.5×10^6 lux ħ vs 1.1×10^6 lux ħ). As for the seats at the same table, H_v between facing and back to windows differs by 6.1×10^6 lux ħ (r7 vs r8), 2.5×10^6 lux ħ (r5 vs r6), 3.5×10^6 lux ħ (r4 vs r3), and 1.3×10^7 lux ħ (r2 vs r1), among which it showed that the difference between facing and back to windows enlarges with the distance to windows. Besides, the difference between the two orientations in south room is larger than that in south.

In type-3 (Fig. 3.3 and 3.4) among the 3 orientation——facing (R1N, R2N, R3N, R4S and R5S), side-facing (towards west or east) or back to windows (R1S, R2S, R3S, R4N and R5N), generally H_v of the seat facing windows (8.0×10^6 lux ħ) is the highest compared with side-facing (3.5×10^6 lux ħ) and back to windows (1.3×10^6 lux ħ). Meanwhile, within the seats side-facing windows, there is no significant difference between towards west or east generally (differs by 2.5×10^5 lux ħ, about 7.5%). Similar with type-1, in type-3 the difference between the different orientations increased with the distance to window, and the difference between the three orientations in south room is larger than that in south (R1 in type-3 is the largest of SD 6.0×10^6 lux ħ).

From the discussion it could be said that as for the elderly at the same table, the one facing windows has the highest H_v, and the one back to windows has the lowest, and that generally H_v of the elderly in south room is higher than the one in north. Thus, the elderly sitting in the seats close to and facing windows in south room (r2 in type-1, r1 in type-2 and R1 in type-3) can receive the most daylight, while the elderly in the seats away from and back to windows (r3 and r6 in type-1, r6 and r7 in type-2, and R3 and R4 in type-1) have the least daylight. Meanwhile, sitting at the same table, the elderly near windows have more individual differences than those away from windows.

3.2 Health evaluation by the annual vertical daylight exposure on the eye (H_v) vs Visual task lighting evaluation by UDI

Based on the comparison, Health evaluation (H_v) differs significantly from Visual task lighting evaluation (UDI). According to UDI in all 3 types (Fig. 4.1 to 4.3), generally type-1 has the best evaluation (with MN of 82.17%) while type-3 has the worst (with MN of 79.01%), which is a little different from H_v (type-2 is the worst). And the distribution of daylight among the seats in type-1 is most uniform (with SD of 9.18%) while the type-3 varies most (with SD of 17.15%), which is in common with H_v.

Meanwhile, according to UDI in all 3 types the north room is better than the south both in general evaluation (with MN of 87.04% in north vs 77.30% in south in type-1, 89.90% vs 75.51% in type-2, and 88.40% vs 72.75% in type-3) and uniformity (with SD of 4.01% vs 10.26% in type-1, 1.78% vs 15.18% in type-2, and 3.33% vs 19.62% in type-3). However, according to H_v the north has advantages in uniformity but disadvantages in general evaluation compared with the south (mentioned in Part 3.1).

the North	81.67	81.50	86.13	86.75	82.25	81.83
	90.17	90.88	91.00	91.00	91.00	90.33
Hallway	solid wall					
the South	88.11	88.58	87.42	87.50	87.67	85.78
	69.00	66.13	66.75	67.13	66.00	67.50

the North	4.53	4.20	3.66	3.60	4.15	4.38
	1.93	2.03	2.00	2.00	2.00	1.96
Hallway	solid wall					
the South	2.27	2.44	2.56	2.58	2.60	2.39
	8.40	8.91	8.32	8.24	8.97	8.71

the North	88.00	87.00	88.13	91.75	89.25	87.38	88.00
	90.50	91.50	91.75	91.50	91.75	91.50	90.63
Hallway	solid wall						
the South	85.83	87.67	88.67	88.50	88.17	87.83	85.17
	86.88	86.00	84.50	84.13	84.00	85.13	84.13
	55.50	53.33	53.33	57.00	54.50	52.50	53.00

the North	3.12	3.56	3.50	2.98	2.91	3.33	3.48
	1.07	1.36	1.57	1.64	1.54	1.61	1.61
Hallway	solid wall						
the South	1.02	1.20	1.42	1.59	1.70	1.78	1.73
	2.20	2.71	2.99	3.21	2.98	3.07	3.02
	7.84	8.43	8.58	7.71	6.89	7.93	8.48

the North	82.44	86.44	87.78	84.89
	91.33	91.67	91.67	91.00
Hallway	solid wall			
the South	87.83	89.17	88.83	87.17
	85.83	84.33	84.33	85.00
	43.56	47.44	46.89	42.67

the North	3.34	2.71	2.75	2.83
	1.81	1.97	1.91	1.81
Hallway	solid wall			
the South	1.76	1.92	1.92	1.89
	3.47	3.61	3.63	3.65
	10.71	9.87	9.64	10.75

Fig. 4.1 to 4.3 Results of UDI (on left, %) and H_v (on right, 10^6 lux・h), Layout Type-1 to Type -3

Note: UDI refers to the average UDI on each desktop; and H_v is the average of the 4 seats at the table.

Besides, UDI showed that the tables near windows are more disadvantageous than others (with an average lack of 13.90% in type-1, 16.80% in type-2, and 22.88% in type-3), and those close to windows in the south-facing room (R1 in all 3 types) are the worst (with the MN of 67.08% in type-1, 54.17% in type-2, and 45.14% in type-3). On the contrary, as a result of H_v the seats close to window are more favorable than others, especially in the south-facing room (mentioned in Part 3.1). Moreover, even at the same table the elderly have a significant difference between each other because of the orientation of seats (mentioned in Part 3.1), which is not expressed by UDI, while discomfort and unwanted excessive levels of daylight such as glare is not considered in H_v.

3.3 Material of walls on both sides of the hallway

In general, solid walls on both sides of the hallway help increase the annual vertical daylight exposure (H_v), compared with glass walls. In type-1 and type-2, solid walls improve H_v on both sides of general level (by 5.8×10^4 lux ħ in type-1 and 1.4×10^5 lux ħ in type-2) and uniformity, while in type-3 the result is on the contrary (decrease 3.5×10^4 lux ħ in type-3) (Tab. 6). Meanwhile, in the north room of type-1 and type-2 the improvement of using solid walls is better that in south (8.5×10^4 lux ħ vs 4.1×10^4 lux ħ in type-1 and 2.0×10^5 lux ħ vs 9.4×10^4 lux ħ in type-2). And in the north room of type-3 using solid walls decreases H_v, while in the south it increased. Besides, in general when using solid walls instead of glass walls, there is no significant difference between facing and back to windows but on the contrary a difference between near and away from windows (1.4×10^4 lux ħ vs 1.0×10^5 lux ħ in type-1, 1.0×10^5 lux ħ vs 2.0×10^5 lux ħ in type-2 and -1.4×10^5 lux ħ vs 1.8×10^4 lux ħ in type-3).

Tab. 6 descriptive statistics of H_v with the solid wall and the glass wall (10^6 lux ħ), layout type-1 to type-3

			Solid wall	Glass wall	Difference				Solid wall	Glass wall	Difference
Type-1	MN	Whole	4.28	4.23	0.05	Type-2	MN	Whole	3.42	3.29	0.13
		North	3.04	2.96	0.08			North	2.38	2.18	0.20
		South	5.53	5.49	0.04			South	4.12	4.02	0.10
		Face	7.46	7.40	0.06			Face	/	/	/
		Back	1.10	1.05	0.05			Back	/	/	/
		Side-facing	/	/	/			Side-facing	3.42	3.29	0.13
	SD	Whole	4.65	4.66	-0.01		SD	Whole	2.53	2.59	-0.06
		North	2.57	2.61	-0.04			North	0.96	0.98	-0.02
		South	5.78	5.76	0.02			South	2.98	3.03	-0.05
		Face	4.75	4.76	-0.01			Face	/	/	/
		Back	0.49	0.55	-0.06			Back	/	/	/
		Side-facing	/	/				Side-facing	2.53	2.59	-0.06

			Solid wall	Glass wall	Difference

Type-3	MN	Whole	4.10	4.13	-0.03
		North	2.39	2.53	-0.14
		South	5.24	5.20	0.04
		Face	8.00	7.89	0.11
		Back	1.30	1.18	0.12
		Side-facing	3.55	3.73	-0.18
	SD	Whole	4.41	4.38	0.03
		North	1.93	1.90	0.03
		South	5.16	5.17	0.01
		Face	5.83	5.86	0.03
		Back	0.68	0.77	0.09
		Side-facing	3.13	3.06	0.07

Note: 'Whole' =all the seats in the type; 'North' and 'South' = the room orientations; the others= the seat orientations.

MN refers to Mean, and SD refers to Standard Deviation.

By comparison of H_v of each row in details, using solid walls instead of glass walls mainly changed seats in r6 (1.9×10^5 lux ħ) and r8 (-3.5×10^4 lux ħ) in type-1, seats side-facing windows in R4 in type-3 (1.3×10^6 lux ħ), and seats back to windows in R3 in type-3 (1.7×10^5 lux ħ). And remarkably the difference between type-3 and other types is caused by the large decreasing H_v of the seats side-facing windows in R4 (by 1.3×10^6 lux ħ).

Therefore, in order to improve the daylighting quality of the elder away from windows especially in north-facing room, the solid walls on both sides of the hallway are recommended.

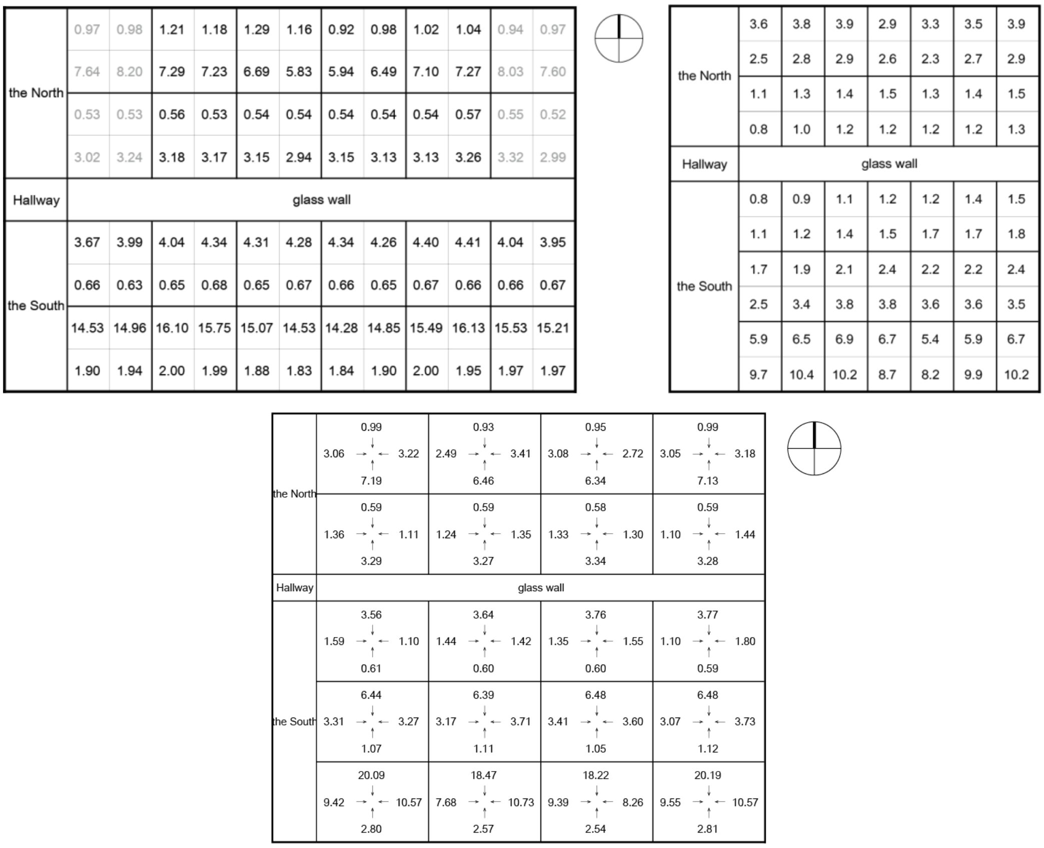


Fig. 5.1 to 5.3 the annual vertical daylight exposure on the eye (H_v, 10^6 lux・h) of each seat with glass walls on the side of the hallway, Layout Type-1 to Type-3

4. Conclusion

According to the discussion above, the main conclusions showed as follows:

- Position orientation has a significant influence on annual vertical daylight exposure on the eye (H_v);
- Health evaluation by the annual vertical daylight exposure on the eye (H_v) differs significantly from Visual task lighting evaluation by UDI, and both have shortage and need to be considered together;
- Compared with glass walls, solid walls on both sides of the hallway help improve the annual vertical daylight exposure (H_v) on both side of general level and uniformity.

All above can be applied to improve the daylight conditions for the elderly during activities. On one side, the layout of daytime activity space can be designed or redesigned to optimize the daylight quality based on non-visual effects. For example, a suitable room orientation and furniture layout of the space can be chosen according to the requirement of the activity. On the other side, the regulation of the elderly's activities can be optimized to realize the needs of the elderly and to avoid disadvantages.

Limitations and future work: in this paper, the regulation of the elderly's activities is simplified as a point, while actually it is more appropriate to describe it as a line. In other words, the movement of the elderly from one seat to another and from one room to another should be recorded so that the difference between different elderly will be more comparable. Some work has been made in this paper that if one always sit in the seat with the most/least vertical illuminance per hour, finally he will receive the H_v of 3.6×10^4 lux ·h /2.0×10^3 lux ·h in one day (for example in Sep. 23rd) and 1.8×10^7 lux ·h /5.3×10^5 lux ·h in a year (for example in type-1), which can somewhat reflect the influence of position on vertical daylight exposure on the eye in another view. With the real occupancy schedule of one's activities as well as his position record, specialized plan for improving his condition of vertical daylight exposure on the eye will be drawn up and the result of the improvement will be more efficient.

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