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A Pilot Study of Effects of Coloured Glazing Systems in a Daylit Office: Visual Comfort, Alertness, Mood and Wellbeing

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Abstract: Daylighting can significantly affect human health & well-being in buildings. This article presents an experiment of the impact of several coloured/neutral glazing systems on visual performance, alertness, mood and wellbeing of occupants in a daylit office in Beijing, China. From 10:00 to 16:50 in four days of spring 2016, a total of 15 participants (age: 28.53±5.07) attended the experiment. Both visual and non-visual performances have been assessed using subjective evaluation measures. In the meantime the daylighting/colour conditions were also recorded. It has been found: the bronze glazing was given the least preference when compared with the blue and clear glazing; the blue glazing can achieve similar visual and non-visual performance as the clear glazing, even though there were big differences of spectral transmittances in between. In addition, this study indicated that further investigations would be required to clarify the preference of glazing colour, taking into account human-beings' biological performances, cultural and ethnic backgrounds.

Keywords: Coloured glazing, Visual comfort, Alertness and mood, Human wellbeing, Daylit office

Introduction

In modern buildings the daylighting condition has been recognized as a critical environmental factor that significantly affects occupants' visual comfort and non-visual performances, e.g. circadian rhythm, mood, alertness, physical well-being, etc. (Aries et al, 2015). Some experiments have substantially exposed the link between daylighting and visual performance and alertness and mood in office buildings (Borisuit et al, 2015). Based on surveys of both winter and summer, a recent study enhanced the importance of daylight availability in offices in terms of its positive effects on the productivity, mood and sleep quality (Figueiro & Rea, 2016). More investigations will still be encouraged in order to find more proofs justifying how daylight regulates sleep and mood, especially in the indoor working places (Figueiro & Rea, 2016).

Currently coloured glazing systems have been broadly found in modern buildings across the world, due to increasing applications of coated and tinted glass (SLL, 2014). These applications are generally based on a basic aim of solar control (e.g. to reduce glare and overheating risk). Some research/practice activities pointed out that current coloured glazing products can possibly distort the colour appearances of daylight in modern buildings (Matusiak et al, 2012). With an aim to assess the relationship between glazing types and visual comfort and alertness, a physical model study preliminarily revealed that the bronze glazing receives more preferences than the blue and clear glazing (Arsenault et al, 2011).

However, few studies have been conducted to explicitly display detailed strategies relevant to the design of coloured glazing in terms of human performances in a real space. As we have noticed, on the other hand, the colour temperature of artificial lighting in working places does affect occupants' performance (Sahin & Figueiro, 2013). For example, the narrow long-wavelength / red light (2568K) can obviously increase alertness and working performance during the daytime (Sahin et al, 2014). How the broad-wavelength daylight combined with coloured glazing works on human's psychological and biological functions is still unclear. Therefore, it is necessary to carry on more surveys of this impact in real buildings (Figueiro, 2013).

This article presents the first results of a research project focusing on occupants' visual and non-visual performances in a daylit office room with various coloured/neutral glazing systems. Daylighting/colour measurements and subjective assessments were implemented. This research project has been planned to include three stages: 1) a pilot study in the spring (31 March --- 06 April 2016); 2) winter period (17 November 2016 --- 11 January 2017); 3) summer period (from May to August in 2017). Only main results from the first pilot study have been reported in this article.

Materials and Methods

Location, climate and office building

The office room used for the experiment is located at the 3rd floor of a university building in Beijing (Lat: 39.9042° N, Long: 116.4074° E), China. Beijing has a temperate and continental monsoon climate. On average there are 2707 hours of sunshine per year.

Figure 1. (A): Plan and dimensions of the office room; (B): Window configurations and dimensions (left), and interior views (bronze and blue glazing) (right).

Figure 1 shows the plan, dimensions, window and interior view of the room. It has only one south-facing window. The room has the dimensions of 6.3m (L) × 3.2m (W) × 3.6m (H) and the surface reflectances including: 0.3 (floor), 0.88 (wall), and 0.88 (ceiling). The room has been divided into two spaces: one is for working and testing (length 4.6m) and the other is used as the preparation room (length 1.7m). The working and testing space (office room) has five sitting positions (A – E) where the participants can stay and work. With a total dimension of 2.3×2.3m, the window has a two-layer structure. The external layer is composed of single clear glazing and dividers, while the internal layer adopts a removable structure with easily installed/dismantled glazing and dividers. Two pictures display the interior appearances with bronze and blue glazing respectively (Figure 1).

Lighting conditions and glazing types

All measurements and subjective assessments have been carried out only under daylighting conditions (during the working time: 9:00 --- 17:00). No artificial lighting was used during the experiment even if the daylight illuminance was lower than the requirement at the working plane (e.g. 300 lux).

This study includes four various glazing systems of the window: Clear1 (neutral), Blue (coloured), Bronze (coloured) and Clear2 (neutral), which are typically found in current Chinese window market. Overall visible transmittances (VT) of the glazing are 0.91 (Clear1), 0.55 (Blue), 0.37 (Bronze), and 0.92 (Clear2). Figure 2 shows the transmission spectrum of Clear1, Blue and Bronze. According to the feedback from the glazing manufacturer the overall spectral response of Clear2 has little difference from Clear1.

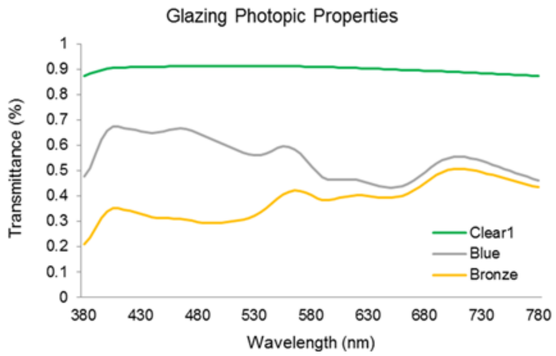

Figure 2. Transmission spectrum of window glazing systems used in the office.

Participants and Procedures

Using an online post the experiment has recruited fifteen Chinese participants (female number: seven; male number: eight.) from students and staffs of the University. The mean (±SD) age of all participants is 28.53 (±5.07) years. The basic requirement of the recruitment is: participants should not have any medical and psychiatric diseases, and sleep disorders. When attending the experiment they have been asked to carry out their regular office work (e.g. reading, writing, etc.) at the five positions mentioned above. The pilot study was conducted in four spring days (31 March, 01, 05 & 06 April, 2016). In each day, one of the four glazing systems was installed at the internal layer of the window and three time periods were measured as follows: 10:00-11:50, 13:00-14:50, and 15:00-16:50.

Lighting and colour measurements

During the experiment, a portable Illuminance Colour Spectral meter (SPIC-200BW) was adopted to get the illuminance (lux) and Correlated Colour Temperature (CCT, K) values at the vertical plane in front of participants' eyes. Each meter reading was recorded every 10 minutes.

Subjective assessment

The visual and non-visual performances were evaluated using two questionnaires. A paper-based VAS (Visual Analogue Scale) (Monk, 1989) was a measurement tool for each question (scale range: 0-100mm). Six questions for the visual assessment include: Q1, Lighting is comfortable? (0mm, extremely comfortable; 100mm, extremely uncomfortable); Q2, Room is bright? (0mm, OK; 100mm, very bright); Q3, Room is dark? (0mm, OK; 100mm, very dark); Q4, Glare? (0mm, no; 100mm, intolerable); Q5, Light colour is comfortable? (0mm, extremely comfortable; 100mm, extremely uncomfortable); Q6, Colour appearance is proper? (0mm, perfect; 100mm, absolutely not). Four questions for the non-visual assessment are: Q1, Alertness (0mm, extremely alert; 100mm, extremely sleepy), Q2, Mood (0mm, very good; 100mm, very bad), Q3, Physical well-being (0mm, very comfort; 100mm, very discomfort), Q4, Relaxation (0mm, very relaxed; 100mm, very tense). Each participant was asked to complete the two questionnaires every 40 minutes. The feedbacks were statistically analysed using IBM_SPSS(v23).

Results and discussions

Lighting levels and CCT

Figure 3 displays the variations of mean illuminance and CCT (near eyes) in terms of times. Generally, two clear glazing systems have a higher illuminance at most times than the blue and bronze glazing. With the lowest transmittance (see Fig 2) the bronze glazing gives rise to the lowest illuminance across the working time. Interestingly, the light colour with all glazing systems did not substantially vary with the changing time. The bronze glazing sees lower CCT values than two clear systems; although the differences between them are not big (the average is around 500K). The highest CCT (around 6600K) can be found at the blue glazing at any time. The similar CCT variations of two clear systems also respond to the fact that they have the same overall spectral transmission mentioned above.

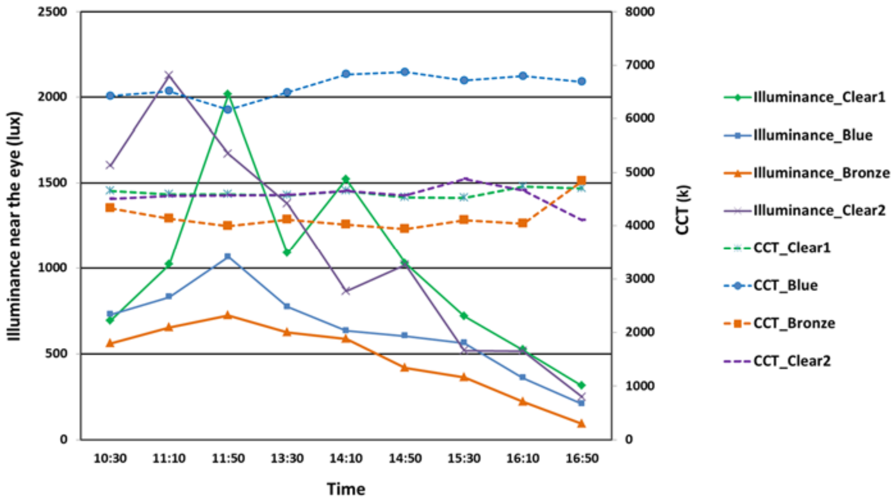

Figure 3. Mean illuminances and CCT measured near the eyes of participants.

Moreover, Table 1 shows the mean (±SD) of illuminance and CCT. It is not surprising that two clear glazing systems achieved the highest mean illuminance while the lowest value was based on the bronze glazing. The blue glazing has a medium value in between. These results well reflect the differences of glazing transmittances. Under variable daylight conditions, the blue glazing brings in the cold/bluish light colour (around 6600K); however bronze and clear glazing systems have the white/neutral light colour (4000 – 4600K). The two clear glazing systems achieve a very similar performance.

Table 1. Measured mean ±SD illuminance and CCT near the participants' eye.

	Mean ±SD			
	Clear 1	Blue	Bronze	Clear2
Illuminance(eye) (lux)	991.1 ±733.2	641.3 ±369.0	471.9 ±315.7	956.7 ±634.1
CCT (K)	4628.3 ±124.5	6609.6 ±453.5	4166.4 ±462.9	4563.8 ±511.0

Visual performances

Comparisons between various glazing systems

According to Table 2, the performance differences of various glazing systems in terms of six visual questions and relevant mean values of all feedbacks were analysed using a two-tailed paired t-test. The value of 'Mean' was defined as the mean difference of each question between two glazing systems. The significance was achieved when p<0.05. The sample correlations and effect size have been assessed (not presented in the article). Only the results of Clear1, Blue and Bronze glazing are discussed here.

Table 2. Two-tailed paired glazing types t-test of visual performances (six questions: Q1-6).

Pair	Mean	t	df	Sig.(2-paired)
Q1: (Clear1 – Blue)	-2.66667	-1.015	44	0.316
Q1: (Clear1 – Bronze)	-15.11111	-4.209	44	0.000
Q1: (Blue – Bronze)	-12.44444	-3.206	44	0.003
Q2: (Clear1 – Blue)	-1.33333	-0.453	44	0.652
Q2: (Clear1 – Bronze)	-4.44444	-1.431	44	0.160
Q2: (Blue – Bronze)	-3.11111	-1.069	44	0.291
Q3: (Clear1 – Blue)	-0.69767	-0.203	42	0.840
Q3: (Clear1 – Bronze)	-13.33333	-2.772	44	0.008
Q3: (Blue – Bronze)	-11.86047	-2.633	42	0.012
Q4: (Clear1 – Blue)	-2.00000	-0.942	44	0.351
Q4: (Clear1 – Bronze)	-6.00000	-1.789	44	0.081
Q4: (Blue – Bronze)	-4.00000	-1.198	44	0.237
Q5: (Clear1 – Blue)	-7.55556	-2.761	44	0.008
Q5: (Clear1 – Bronze)	-20.00000	-5.300	44	0.000
Q5: (Blue – Bronze)	-12.44444	-2.862	44	0.006
Q6: (Clear1 – Blue)	-8.88889	-3.546	44	0.001
Q6: (Clear1 – Bronze)	-23.11111	-6.457	44	0.000
Q6: (Blue – Bronze)	-14.22222	-3.489	44	0.001

As for the colour comfort and rendering (Q5 & 6), apparently, a significant difference can be found between the three glazing types (all p values <0.05). The clear glazing would deliver a more comfortable colour environment with a higher rendering ability than the coloured glazing systems. Compared with the bronze glazing, participants would choose the blue glazing (mean=-12.4 or -14.2; p<0.05). Interestingly, feedbacks of 'bright' (Q2) & 'glare' (Q4) have not brought in big differences between the three glazing systems (all p values >0.05), even though their transmittances are significantly different. With the bronze glazing, however, it has a higher possibility for the participants to feel darker and less comfortable than the clear and blue glazing (Q1 & 3) (each p-value <0.05); while the results of clear and blue glazing show no substantial differences (each p-value >0.05). The differences of comfort between bronze and clear glazing systems might be explained by the various illuminance levels near eyes. Surprisingly, the big gap of transmittance and illuminance levels between blue and clear glazing did not give rise to a significant divergence of visual performance. This finding would support that the glazing colour might be more critical than the visual transmittance of glazing and the illuminance level.

Time and glazing types

Figure 4 displays the effects of glazing types and daily times on the six questions of visual performances (two-way ANOVA). The significant can be achieved based on ‘p<0.05’.

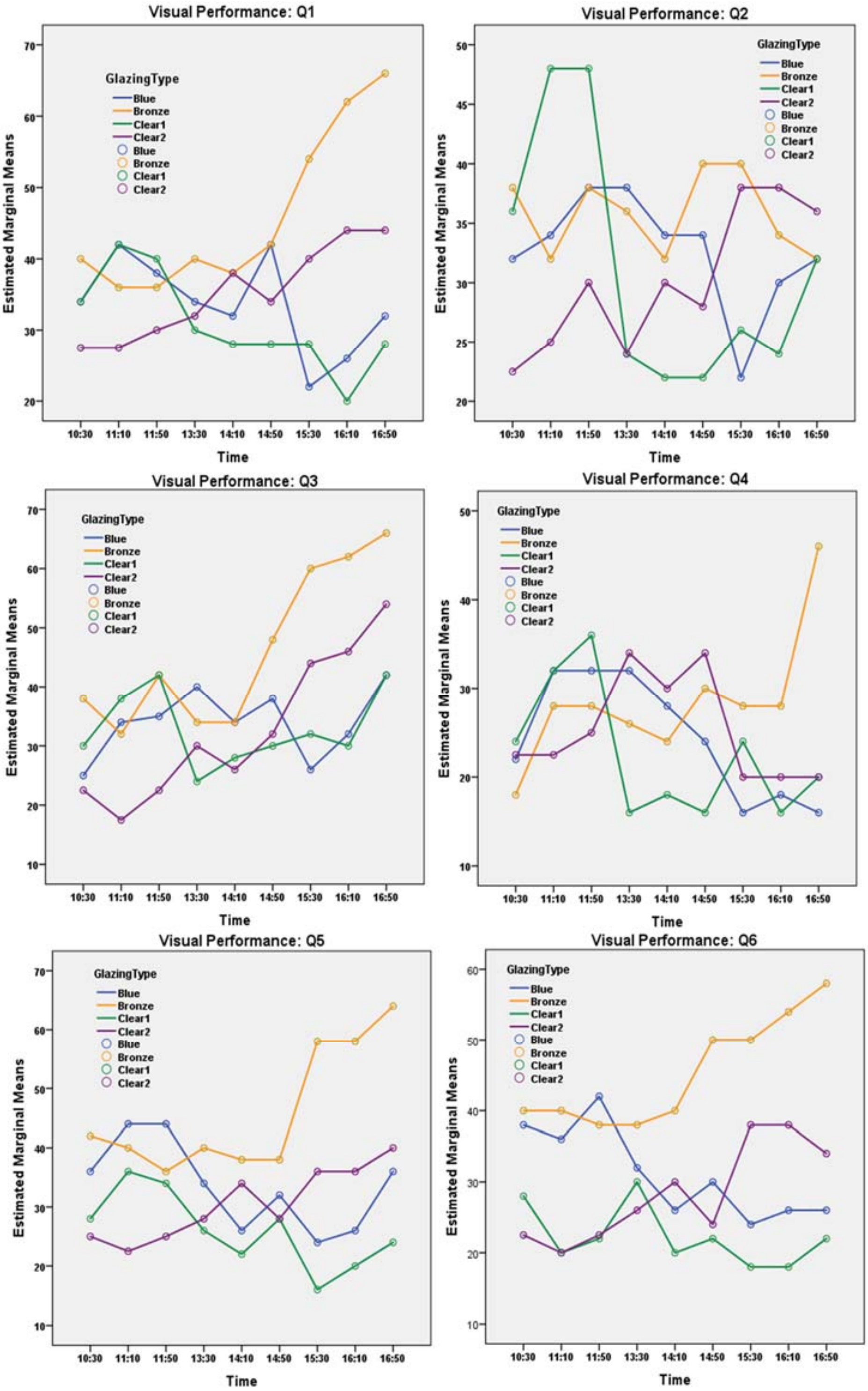

Figure 4. Subjective assessments of visual performance (Q1--6): the impact of glazing types and daily times.

A significant impact of time can be just found at the question ‘dark’ (Q3) [F(8, 139)=3.4; p<0.05]. Normally, the participants would feel darker in the late afternoon. Other questions concerning light/visual/colour comfort (Q1-2, 4-6) have no clear relationships with the time (p>0.05). With the varying time, the glazing types do clearly affect the Q1, 3, 5-6 (p<0.05). In the later afternoon (after 15:30), the bronze glazing sees a higher mean value than others, which indicates more complaints of discomfort. In addition, a clear interaction effect of time and glazing only occurs at Q1 [F(24, 141)=2.1; p=0.004)]. The visual comfort would be significantly linked to the interaction of time and glazing type.

Non-visual performances

Comparisons between various glazing systems

Table 3 shows a two-tailed paired t-test of the impact of glazing types in terms of four non-visual questions. The method of t-test analysis is the same as the mentioned above. The Clear2 is not included. According to the Q2 ('mood'), the glazing colour would significantly influence the participants' mood during the working time (each p-value <0.05). Both blue and bronze glazing systems have more negative effects on the mood than the clear glazing. Similar to the visual performance, the bronze glazing expresses a big difference of non-visual performance from the blue and clear glazing for the 'Alertness (Q1)', 'Physical well-being (Q3)', and 'Relaxation (Q4)' (each p-value <0.05). The blue glazing can, however, achieve a similar performance as the clear glazing (p>0.05).

Table 3. Two-tailed paired glazing types t-test of non-visual performances (four questions: Q1-4).

Pair	Means	t	df	Sig.(2-paired)
Q1: (Clear1 – Blue)	-3.77778	-1.107	44	0.274
Q1: (Clear1 – Bronze)	-14.88889	-4.115	44	0.000
Q1: (Blue – Bronze)	-11.11111	-3.052	44	0.004
Q2: (Clear1 – Blue)	-4.44444	-2.119	44	0.040
Q2: (Clear1 – Bronze)	-15.55556	-4.495	44	0.000
Q2: (Blue – Bronze)	-11.11111	-2.911	44	0.006
Q3: (Clear1 – Blue)	-3.77778	-1.544	44	0.130
Q3: (Clear1 – Bronze)	-16.44444	-3.733	44	0.001
Q3: (Blue – Bronze)	-12.66667	-2.637	44	0.012
Q4: (Clear1 – Blue)	-1.11111	-0.520	44	0.606
Q4: (Clear1 – Bronze)	-9.11111	-2.884	44	0.006
Q4: (Blue – Bronze)	-8.00000	-2.273	44	0.028

Time and glazing types

In Figure 5 & 6, the effects of glazing types and daily times on the mean variations of each non-visual question are given (two-way ANOVA).

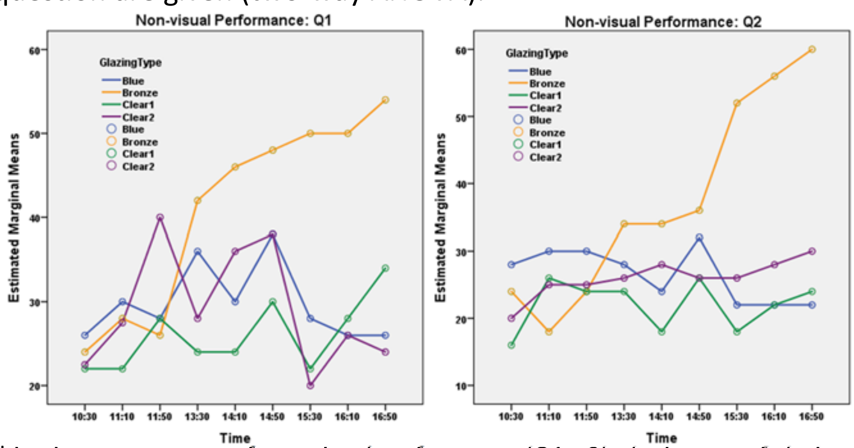

Figure 5. Subjective assessments of non-visual performance (Q1-- 2): the impact of glazing types and times.

Interestingly, no significant impact of time was found according to all non-visual performances (each p-value >0.05). On the contrary, the glazing type plays a clear role to affect the alertness [F(3, 141)=7.5; p<0.05], mood [F(3, 141)=12.3; p<0.05], physical well-being [F(3, 141)=9.9; p<0.05] and relaxation [F(3, 141)=5; p<0.05]. The big performance differences between the bronze glazing and others occur at 14:50, and then increase towards the late afternoon. The bronze glazing gives rise to a more negative impact on the non-visual performance. Except for the Q1 (p>0.05), the significant interaction effect of time and glazing can be found at other questions including mood [F(24, 141)=2.1; p<0.05], physical well-being [F(24, 141)=2.7; p<0.05] and relaxation [F(24, 141)=2.1; p<0.05].

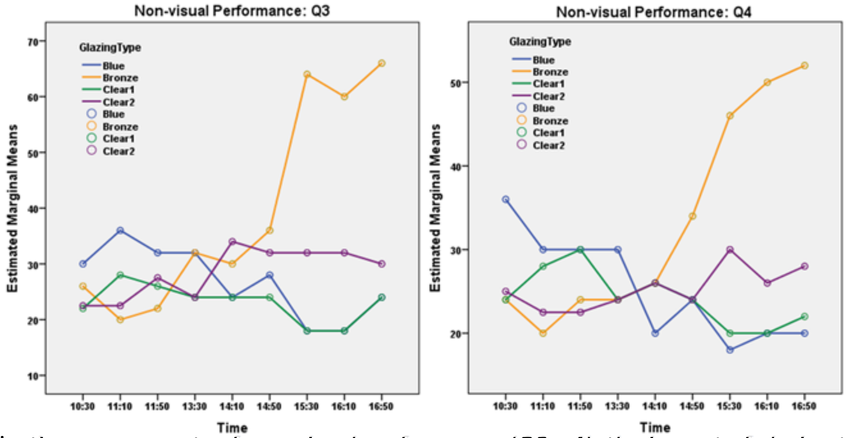

Figure 6. Subjective assessments of non-visual performance (Q3-- 4): the impact of glazing types and times.

Conclusions

Several findings could be concluded from the results as follows: 1) compared with the clear and blue glazing, the bronze glazing could be less acceptable based on the visual and non-visual feedbacks of occupants, especially at the late afternoon. This could be due to the combined effect of glazing's low transmittance and colour. 2) The blue glazing has no big differences of the impact on human performances (visual and non-visual) from the clear glazing, even though there is a significant transmittance divergence in between. This again enhanced the complexity of glazing design in office buildings. 3) Under daylighting conditions it could be hard to justify the relationship between human performances (visual and non-visual) and the light colour, especially when considering the fact that the colour preference is strongly linked to the cultural and ethnic backgrounds.

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