Colour shift of interior surfaces with advanced glazings

Shabnam Arbabm, Barbara Szybinska Matusiak and Christian A. Klöckner[1]

Department of Architecture and Technology, Norwegian University of Science and Technology, Trondheim, Norway

[1]Department of Psychology, Norwegian University of Science and Technology, Trondheim, Norway

Email: shabnam.arbab@ntnu.no

The present paper reports the findings from a scale model (scale 1:5) laboratory experiment about the effect of coloured light created by imitated daylight of various colour temperatures passing through different glazing types on colour perception and the tendency of colour shift for interior surfaces. The building glass functions as an optical filter with a specific spectral transmittance. We set up an experiment to improve the method to evaluate the colour shift of interior surfaces based on people perception with the help of a questionnaire and the measurements from SpectraScan PR-655. Twenty-six participants evaluated colour perception impacted by two systematically varied variables: glazing types and CCTs of light. Exploring the effects on the visual experience of the indoor environment (based on the colour perception) was a secondary aim of this study. Results from linear regression are showed that CCT 2700 had an impact on all rooms and CCT 8000 on the blue and red rooms. The results testify that all glazing types separately had a significant impact on the hue perception of the yellow room, the red room and the violet room. On the other hand, it is difficult to find a general rule for nuances perception.

Received 15 September 2017; revised 9 January 2018; accepted 15 January 2018

Published online: 26 March 2018

Introduction

The knowledge about how coloured materials will appear under different spatial conditions is a prerequisite for working consciously with colours, and reaching the intended results [1]. Architects, interior designers, and others professionals will need to have a sufficient understanding of the actual appearance of coloured materials in buildings. This skill is normally gained through experience (trial and error), which can be costly and the risks of error in architectural design are often high.

Several factors are involved in a complex perception situation that a room represents. Among all factors, colours play an important role in giving a room its character, atmosphere, and form; which together are referred to as a room's gestalt.

The way that colours appear in a certain situation depends on a combination of various features in a room, such as:

- areas
- shape, size, and illumination of the room
- properties of the material (gloss, texture, pigment, etc.)
- qualities of the colours (hue and nuance)

In this regard, the different spectral composition of light could be one of the interesting issues, because it may have an impact on colour shift and colour perception. The window glazing is one of the building elements that change the spectral composition of light and therefore may have a significant impact on the perception of colour in the interior.

Previous research

The relationship between colour appearance and daylight/artificial light has been studied for a long time. Different methods and approaches in a full scale room or scale model were used in such studies.

One of the pioneers of colour-light interaction research, Michel Eugène Cheuvreul, compared colour appearance of surfaces when illuminated by sunlight, against when illuminated by sunlight transmitted through coloured glasses, which is coloured-light. He used materials with different colours; each with different degrees of chromaticness. According to Birren, Cheuvreul noticed that the impacts of coloured light on coloured surfaces is not exactly the same as expected in additive mixture or pigment mixtures. [2-3]. However, Billger concluded that most of the mixes between light and surface colours resulted in colours closer to the one that a mix of pigments would give, even if there were notable differences [1].

Billger studied spacious interaction between surface colours. She resolved that surface colours interact by contrast and by reflections; both types operate in a room, and they have a contradictory impact on colour appearance. Contrast effects enhance the difference between the colours involved, whereas reflections make the coloured surfaces blend with each other. Especially, reflections had strong influence on colour appearance in experimental rooms [1].

According to Liljefors [4], the colour of the surfaces will affect the light character (perceived level of light and perceived colour of light) in a room to a high extent. In other words, the reflections of the coloured surfaces in a room can affect the perceived colour of light in the room. Moreover, he states that reflection from the surfaces has a greater effect on the perceived level of light in a room, than intensity of the illumination.

Another example of the study on colour appearance was performed by Maud Hårleman who focused on daylight from different orientations [5-9]. She pointed out that all colours appear more chromatic and yellowish in sunlight; while with diffuse daylight from the sky pale yellow colour appeared to be less yellow. The blue and greenish blue changed slightly toward green in sunlight while they changed toward elementary blue in the diffuse light from the sky.

In a study carried out by Matusiak et al. [10], the impact of different transparent and translucent glazing on the perception of colour samples positioned behind the glass were studied. One of the findings was that glazing may contribute to colour shift in the same direction with colour samples exposed against both, white and black, backgrounds but the effect is slightly stronger when the colour is seen against the black background. The most apparent colour shift was registered behind the three layers low-energy glass (coating on two glass panes). One layer glazing caused no colour shift, also two layers clear glazing, without any coating, caused barely noticeable shift. Moreover, it was found that transparent glazing tends to give quite strong colour distortions compared to unfiltered daylight (e.g. open window), and that the translucent glazing had a similar effect, although a weaker colour shift was registered [11].

Actually, there are few documented experiments dealing with the effect of "coloured light" on the perceived colour of interior surfaces. Michele Zinzi [12] studied people preferences of electrochromic windows; the intention was to collect information concerning user behaviour in response to the actual luminosity conditions of the working space. The main issues were: visual comfort, system operation, and perception and/or alteration of both indoor and outdoor environments; the main consideration was connected to the visual perception of lighting rather than colours.

In a previous study [13] the impact of advanced glazing on outdoor view and colour perception was studied and it was concluded that all glazing types separately had a significant impact on exterior colour perception. We also found that the colour with reddish tint were more sensitive to change.

Even though research [12] gives a clue about the impact of electrochromic glazing on the perception of interiors, we still lack the knowledge to predict how different glazing materials and colour of light influence colour appearance in interiors.

Aim and scope

The current study was motivated by the following primary research question:

How do colour of light, created by choosing different CCTs of artificial daylight, and different advanced glazing materials affect the perceived colour of interior surfaces?

A secondary research question is:

How do different glazing and CCT of light impact the perceived architectural quality?

The project is an experimental study designed to provide a deeper understanding of colour appearance in space and consequently the atmosphere of a room and its quality.

By colour appearance, we mean how it appears to human observers (perceived colour) and by coloured surface we mean the surface has a colour that is defined in a colour system (NCS or Munsell) in strictly defined reference conditions (nominal colour).

More specifically, the first aim of the study was to describe shifts in hue and nuances in the presence of the different glazing materials and CCT conditions, something which could help to create a colour design with the desired outcomes. The second aim was to identify a good way to evaluate the impact of filtered light on the perception of interior surfaces (in other words how light and colour interact).

Method

The approaches described by Billger [14], Hårleman [6] and Matusiak [10] are very interesting starting points for defining the methodology of our study because they represent two different methodological perspectives. The method in this study was based on their experience, but some improvements were made based on the experiences described in the original papers.

Experimental design

Since it is easier to change the glazing in a small model rather than a real room, scale models were used in the present study.

A model with two rooms of equal dimensions in scale 1:5 was used (60×60×60cm representing a large office 3×3×3m); the rooms had identical openings to let in light and for observer to look in (Figure 1).

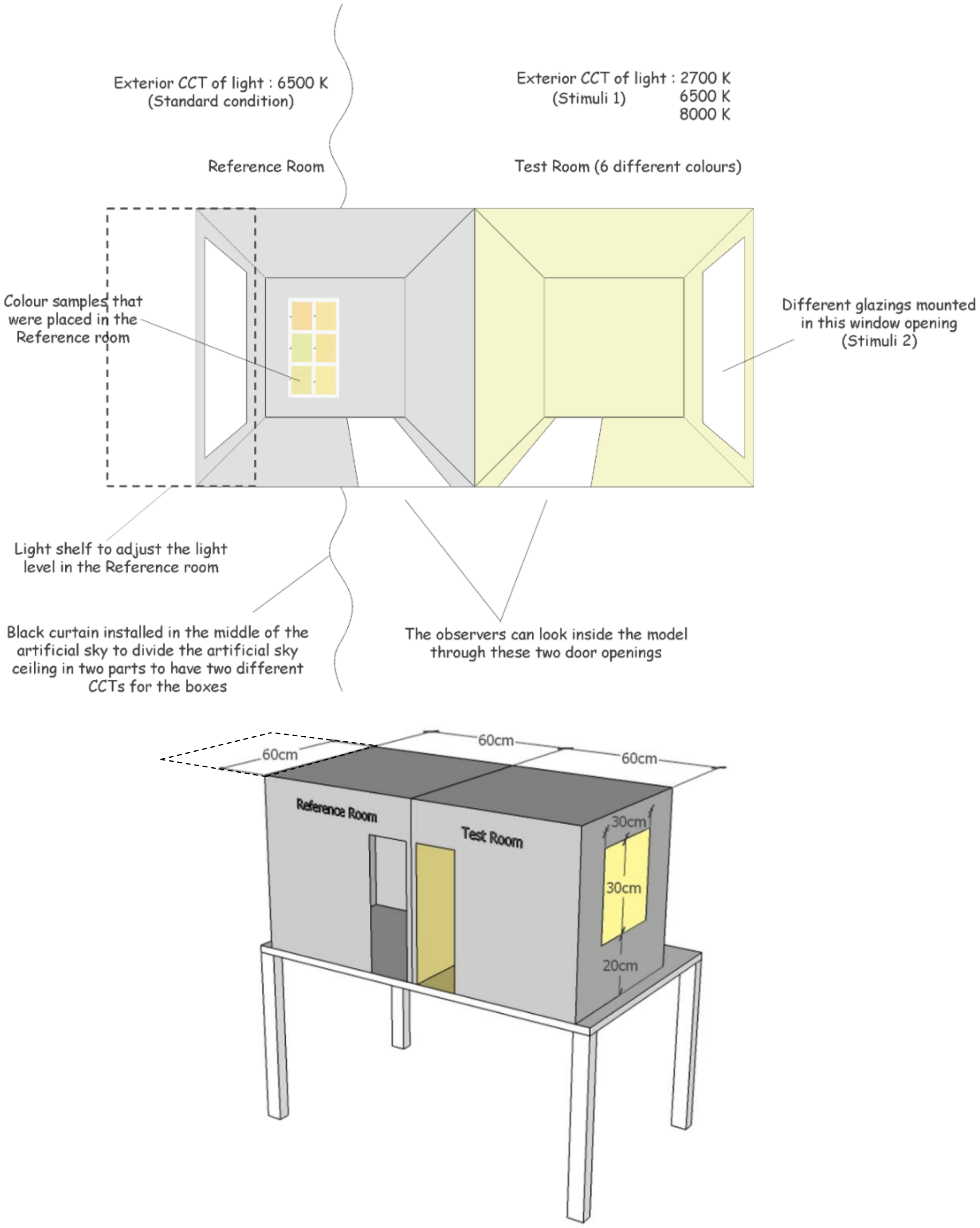

Figure 1: Experimental set-up. Above: top view, below: perspective view of the model.

One of the rooms functioned as a Reference room and the other one as the Test room; in practice 6 alternative versions of the Test room were created, each having a different colour of the interior surfaces (Table 1).

Box1: Yellow	Box 2: Blue	Box 3: Grey	Box 4: Red	Box 5: Green	Box 6: Violet
S1020-Y	S1020-R90B	S1000-N	S1020-R	S1020-G	S1020-R60B

Table 1: Selected colours to paint the interior surfaces of the boxes.

All the surfaces in the Test room were painted with the same inherent colour[1], one at the time. From the outside the models were painted in black to reduce undesired light reflections in the artificial sky. The model was also covered externally by black textile to reduce the light penetration from the artificial sky.

It would have been possible to create a white anchor e.g. white ceiling or grey floor in the Test room but we chose to use the same paint on all the surfaces in the Test room to strengthen the effect of colour around and intentionally make it more complex for the people.

During the experiment, the window opening in the Test room was successively covered by different glazing samples which were provided by GESIMAT manufacture and the Institute for Energy Technology (IFE).[2]

Keeping the same light level in both boxes for all different alternative combinations was an important setting of the experiment. Equal light level on the colour samples in the Reference room and in the corresponding place in the Test room was important to secure as accurate results as possible. For this purpose, an external moveable light shelf was prepared for the Reference room on the top of the window opening. For each box-glazing alternative, the interior illuminance was measured in the Test room at the point on the floor in 18.2cm distance from the window wall and the same illuminance was created at the corresponding point in Reference room by moving the light shelf.

The objective of the experiment was to visually evaluate the impact of the correlated colour temperature (CCT) of exterior artificial daylight and different glazing and the combination of both on the perceived colour of a room.

The Reference room had the same CCT (6500K) as the light sources applied under the NCS reference conditions (D65) and the colour samples were exposed on a white background (as in NCS lab), so we assume that our subjects observed "nominal colours" as in the NCS lab.

Two stimuli were manipulated in the experiment:

Stimulus 1: Correlated Colour temperature of the exterior light manipulated in three alternative specifications: 2700K – 6500K – 8000K

Stimulus 2: Glazing types. Three different glazings were used to create the following alternatives.

ET-on	Clear Electrotopic
ET-off	Milky Electrotopic
PC	Photochromic
EC-coloured	Electrochromic fully coloured
EC-midpoint	Electrochromic middle-point
EC-uncoloured	Electrochromic fully bleached (transparent)

Dependent Variable: Colour of interior surfaces

Based on the previous study conducted by Matusiak et al. [10], it was found that the colour shift for pale colours are more liable, both in hue and nuances, than strongly chromatic and darker colours. Additionally such colours are more often used on interior surfaces. Thus, the same pale colours were used in this experiment for the interior surfaces (Table 1).

---

[1]As Monica Billger mentioned in 1999 [1] inherent colour means the property of the material that does not change because of different lightings and conditions. Nominal colour is another term that was proposed to be used instead of inherent colour.

[2]The specification of the glazing types are available from the corresponding author upon request.

Participants

The total sample consisted of 26 participants (14 male, 12 female), between 20 and 59 years of age (mean age: 30 years); they had different educational backgrounds and professions as well as different nationalities and cultural backgrounds. All of them had good colour vision, tested by the Farnsworth-Munsell D-15 colour vision test and Ishihara colour test. Participation was voluntary and they were recruited via email, visual advertisement on the Norwegian University of Science and Technology (NTNU), through internet site of the university and Facebook group of the university.

Colour samples selection

Matusiak et al. [10] concluded in their studies involving glazing that there is a tendency for a hue-shift clockwise for colours with a dominating blueness and/or greenness and in the opposite direction for colours with redness and/or yellowness. For the colours between yellow and green as well as between red and blue it was difficult to find a conclusive pattern. Maud Hårleman [5-6] made similar observations. In our study, we used a two-step procedure for the participants to identify the hue and nuance they perceived in the Test room: First, they were asked to select among colours adjacent to the nominal colour of the Test room on the NCS circle. After choosing the comparison sample that appeared as having the same hue as the one in the Test room, a new set of comparison samples was presented depending on the selected hue. To find the nuance participants were asked to perform a similar selection procedure, however this time with blackness and chromaticness of the same hue, that is selecting adjacent colours from the NCS triangle.

Reference room

In the Reference room we kept constant light, similar to daylight, and no filtering glass was installed. Colour temperature of the exterior light was 6500K and walls were painted with neutral grey, with a luminous reflection factor of 50-60%. This corresponds to NCS 2500-N. The background of the samples was white. The reason for this choice is that it corresponds as much as possible with the NCS standard observation procedure, as described in the comprehensive report on NCS [15-16].

No additional light sources were provided for Reference room; it was illuminated only by 6500K exterior light from the Artificial Sky. The same illuminance as in the Test room was created at the corresponding point in Reference room by moving the light shelf.

The luminance level on the Reference room at specific point (mentioned earlier in Experimental Design Section) was between 27 and 170 cd/m². Figure 2 shows the spectral power distribution measured at Reference room surfaces.

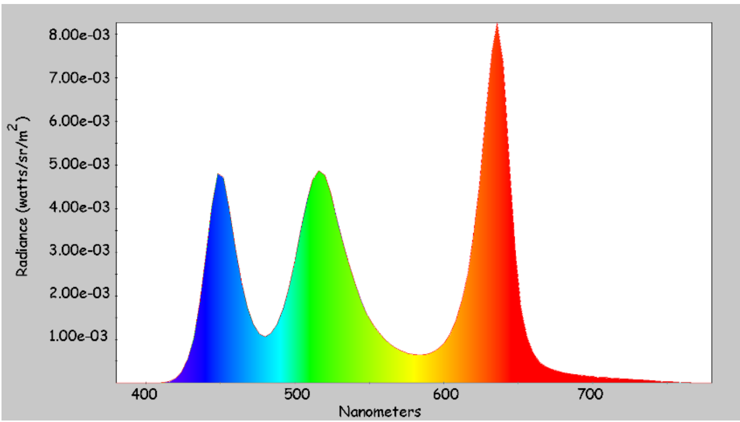

Figure 2: The spectral power distribution measured at Reference room surfaces.

The luminance level on the colour samples in the Reference room was between 85 and 218 cd/m^2, which we tried to adjust it to the light level of Test room with light shelf.

Experimental procedure

A pilot study was performed in the daylight laboratory (Figure 3), under an Artificial Sky at the laboratories of the Norwegian University of Science and Technology (NTNU). It enabled us to simulate different daylight conditions and to get stable and equal illumination in the whole room [17].

The Artificial Sky installation simulates a standard model of a perfectly cloudy sky, the CIE Overcast Sky. The light is produced by LED-chips. LED technology gives new possibility to change correlated colour temperature (CCT) from 2000K to 18000K in three illuminance levels: 100%, 50% and 25% of the maximum power. Referring to Matusiak and Braczkowski's study, It is possible with this type of light source to achieve colour rendering index around 85% in the range of 2000-10000K [18].

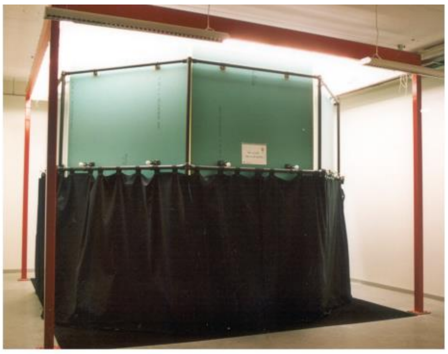

Figure 3: Artificial sky.

To study shifts in hue and nuance, for each box (Test room), certain colour samples were presented in the Reference room in two rounds. In the first round the nominal colour of interior was presented together with slightly different hues and in second round based on the choice of observer, the different nuances of the same hue were presented.

In a three hour-long session of visual evaluation, the observers started with a holistic view of the room, and then evaluated the colour of the room by shifting their focus between the Test room and the Reference room trying to select the colour sample from the Reference room, which appeared most similar to the colour of the Test room. The procedure was repeated for all combinations of CCT and glazing.

The participants had short break (~3 minutes) meanwhile the experimenter changed to next box with another colour. After first three boxes, they had longer break as 30 minutes.

The experimenter asked the subjects to look into the models from the outside through two vertical openings. To reduce the penetration of the light from the outside, the participants were asked to cover their heads with a black textile, which was totally opaque.

We put first box with identical NCS colour code and then we systematically changed the samples in the Reference room until the participants found a match to the colour of the box; the procedure was repeated for all six boxes. The Test room colour was selected completely in a randomised order.[3]

Due to all variables the experiment was time consuming, the whole procedure have taken on average 3 hours per participant. On the other hand, we did not push the subjects to finish soon and they could take their time until they feel confident to answer the questions.

[3]Details of the colour samples, which were presented in the Reference room are available from the corresponding author upon request.

Figure 4: Box 1 (yellow box) through ET-on glazing and 2700K (left), 6500K (middle) and 8000K (right).

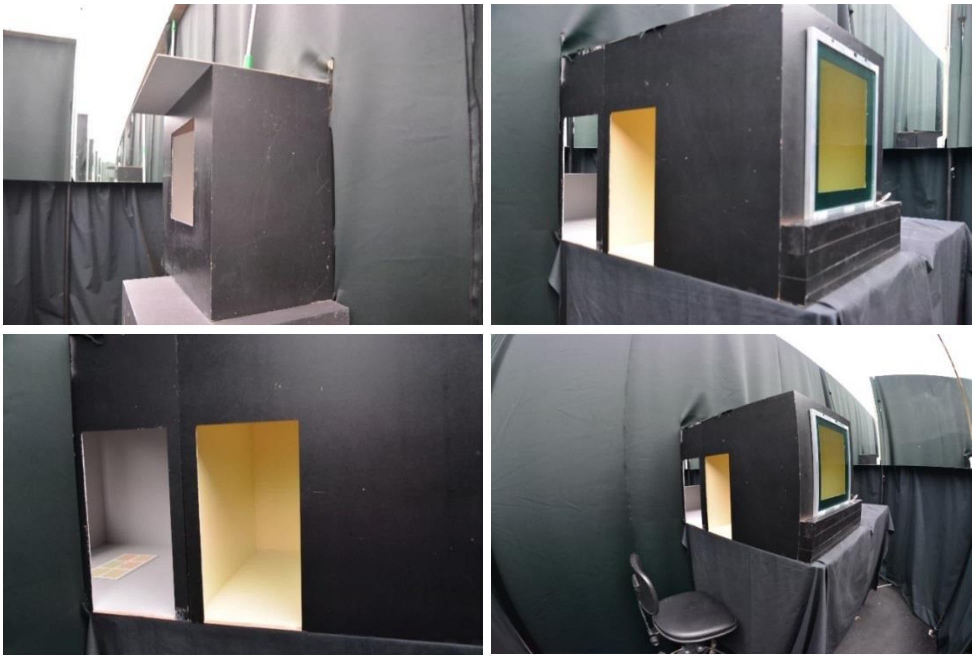

Figure 5: Experimental setup used in the study.

Questionnaires

The participants were asked to evaluate the interior colour of each combination of box and glazing by writing down the number of the most similar colour sample from the Reference room.

In addition, they were asked to evaluate if they liked or disliked the room colour and if they perceive it as boring or exciting (see Figure 6).

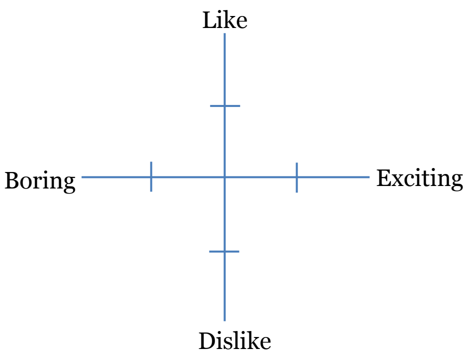

Figure 6: Evaluating scale that used in the questionnaire.

Results and discussion

The aim was to detect the colour shift tendencies due to advanced glazings in the test rooms with different colour of interiors. The results of questionnaire were analysed based on the NCS system to figure out the colour shift direction and then the overall impression of perceived architectural quality of each box. Statistical analysis was the last step of analysing the findings.

One important discovery was that the EC-coloured glazing gave a greenish effect to almost all boxes in combination with 2700K and a bluish tint in combination with 6500K. Because of that, it was difficult for participants to find the closest colour match in these scenarios.

When EC-fully coloured glazing was positioned as a window glass in the red room, the room colour got a distinctly different colour, more toward bluish, and it was difficult for subjects to pick the matching colour sample from the Reference room, which were different hue and nuances around red; the room acquired more blue colour and became for instance more Bluish.

While we asked the subjects to mark the closest colour sample in hue and nuance for each scenario, we also asked them to write down their comments and explain what they experienced as difficult for each scenario. It is interesting to analyse these spontaneous explanations of their decisions, so it was kind of mixed method approach. A summary of these comments can be found in Table 2.

Box	+ glazing	+CCT	Result
Box 1, Yellow room	EC-coloured	2700	Much more chromatic green-blueish
	EC-coloured	6500/8000	No close match
Box 2, Blue room	PC	2700	Looks more greenish
	EC-coloured	2700	More greenish
	EC-coloured	6500/8000	More blueish
	EC-midpoint	2700	More greenish
	ET-on	2700	More whitish
Box 3, Grey room	EC-coloured	2700	Much more greenish
	EC-coloured	6500	More blueish
	EC-midpoint	8000	More blueish
Box 4, Red room	EC-coloured	2700	More blue-green
	EC-coloured	6500/8000	More blueish
Box 5, Green room	EC-coloured	2700	More greenish
	EC-coloured	6500	More blueish
	EC-coloured	8000	Much more vivid blue
	EC-midpoint	2700	Vivid green
	EC-uncoloured	2700	Vivid green-yellow
	PC	2700	Much more greenish
	ET-off	2700	More yellow-green
Box 6, Violet room	EC-coloured	2700	More pure strong greenish
	EC-coloured	6500	Pure blue
	EC-coloured	8000	Pure strong blue
	EC-midpoint	2700	More yellowish
	EC-midpoint	8000	Pure blue
	EC-uncoloured	2700	Moe white-yellowish

Table 2: Summary of subjects' comments throughout the experiment.

Results on the NCS graphs

Figure 7 shows the principal (pattern) of colour shifts for each box, except for box 3 which is a grey room, seen behind different glazings and CCT of exterior light. The results for the grey room will be discussed further later in this chapter as they are structurally different from the coloured boxes.

We found that the colour shifts were slightly larger for colours seen behind the EC glazing, especially EC-coloured. This result was expected because the transmittance of EC is not equal for all wavelengths, i.e. the levels in the red part of the spectrum passed through are close to zero.

ET and PC glazings showed the same pattern for hue shift in all colours except for the red room where we could not find any tendencies for the hue shift through ET glazing.

The results from the questionnaire indicate some small but consistent differences between glazings. For example, EC-coloured glazing enhance the perceived blueness in 6500K and more greenness in 2700K.

For the nuances, it was very difficult to register any stable pattern. Effects varied between different areas and we could only highlight the impact of EC glazings on all CCTs in the NCS triangle in Figure 7 with the exception of the violet room. For a yellow hue, the nuances shift towards increased blackness. For the rooms with blue and green hue, the nuances tended to get increased towards chromaticness whereas it was reduced for the red room.

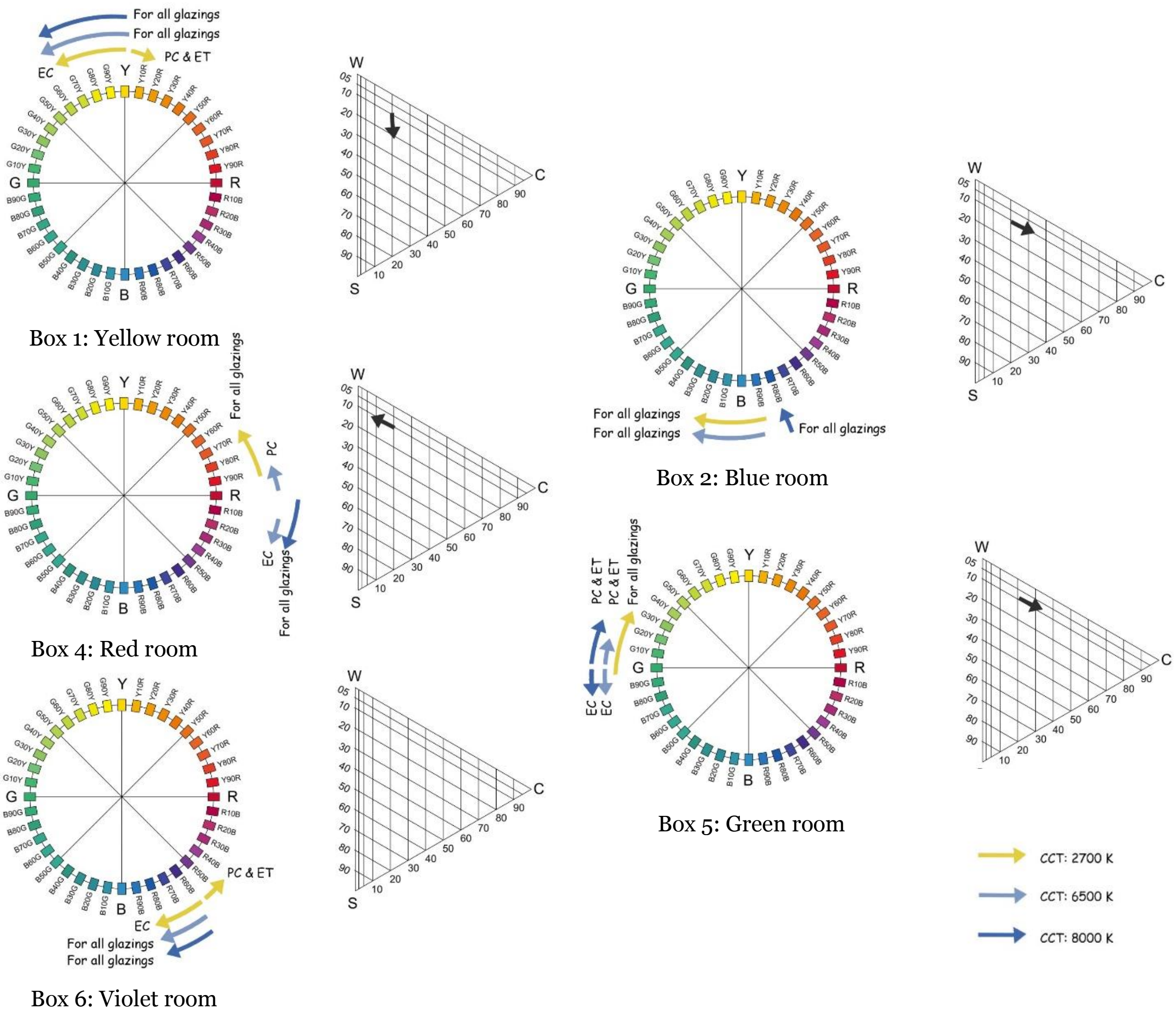

Figure 7: Colour shift tendencies for all the boxes except grey room.

For the violet hue, the results of nuances were identical for PC and ET glazings. It was shown that the nuance did not shift much and people mainly chose the same nuance as the violet room had; only in 2700K chromaticness was reduced by 10%.

It was not possible to identify any rule for the grey room, especially since participants needed to evaluate the whole room not only a small sample. The grey colour is very sensitive for changing to different directions. It is also very much dependent on the observer. A study conducted by Fridell Anter and Klarén [19] showed the complexity of the ‘greyness and spatial experience’. These authors pointed out that “paints or other materials made with the aim of being neutral grey are very sensitive to different light sources, and only a slight variation of the spectral distribution can make them be perceived as “warm” or “cold” ”. Even very small changes would be visible to our eyes. Consequently, the grey colour is very tricky. In this experiment, there was a small deviation from the strictly neutral, large enough to be perceived but too small to specify any pattern in hue or nuances.

We have three different types of receptors in our eyes, which they supposed to recognise the colours, in addition to the *What* system in our brain which is responsible for colour perception [20]. However, for grey colours, its absolute lack of hue and chromaticness and so there is no stimulation for these two levels in our brain and eye.

Results for the grey box are shown in Figure 8. As can be seen, it is difficult to find any pattern for hue in the grey box with different CCTs. We may conclude that the impact of colour temperature of light is visible only for 2700K, e.g. for PC and ET glazing, the perception was shifted towards yellow, and for EC-coloured and EC-midpoint which have a bluish tint the hue shifted towards green since the combination of blueish glass with yellowish light yield a greenish mixture. Surprisingly, the nuance shifts indicate decreased chromaticness for all CCTs. The details of distribution of answers will be available for the researchers upon the request

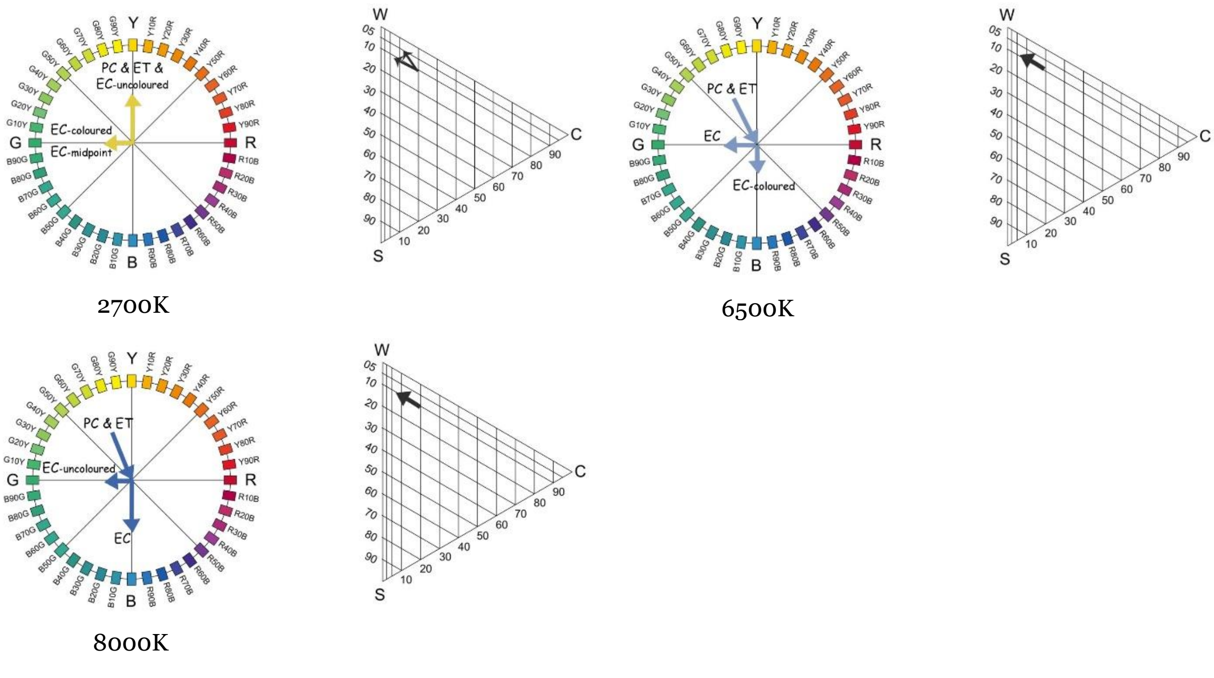

Figure 8: Colour shift tendencies for grey box at different colour temperatures.

Evaluation of architectural quality

Another part of this experiment was to evaluate the subject’s visual impression of each scenario, which is if they like/dislike the atmosphere of the room and if they perceived it as exciting/boring

(Figures 9-11). We present an example of the three glazings, ET-on, EC-coloured and PC, in 2700K. The details of the other scenarios are available upon the request. We chose 2700K since it was tricky in combination with blueish glazing and whitish glazing. These analyses are about subjective evaluation rather than more objective characteristics. Therefore, we cannot expect precise answers from the subjects. In general, from an application perspective it is preferable to have exciting and liked rooms or at least liked rooms.

The numbers show how many people rate within a specific quadrant of the graph. Since each axis has two sides, the answers on the axis counted for both sides, which have that axis in common.

If we compare the rate of liking and excitement, we could see that with ET-on, all the rooms were liked by people and were exciting for them except the grey room, which was liked but was boring as well. Yellow room was liked most compare to other rooms. With EC-coloured, the blue and the violet room was more preferred than the rest. With PC glazing, almost all the rooms were rated highly, both in liking and in excitement.

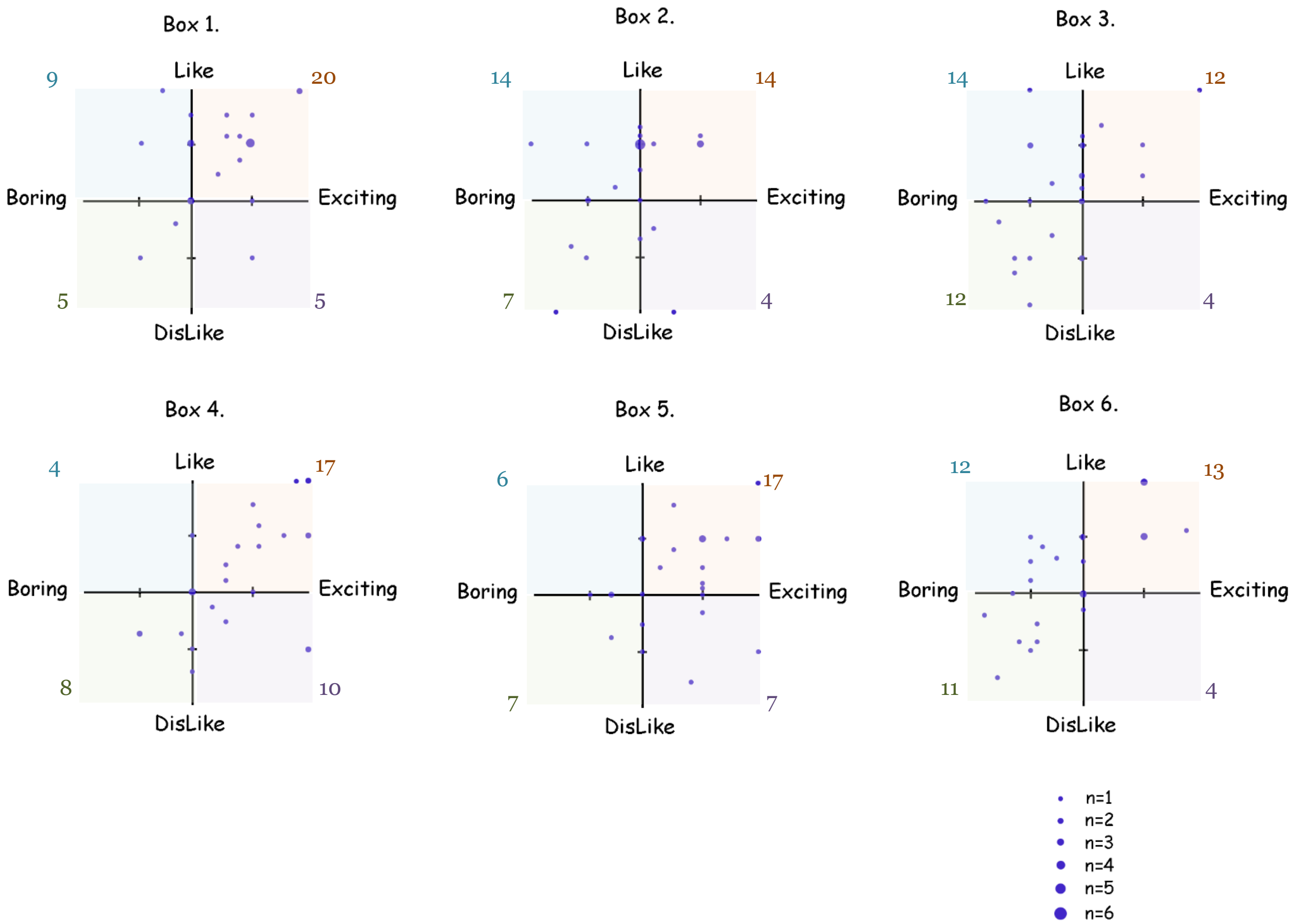

Figure 9: Electrotopic in clear state (ET-on) in combination with 2700K.

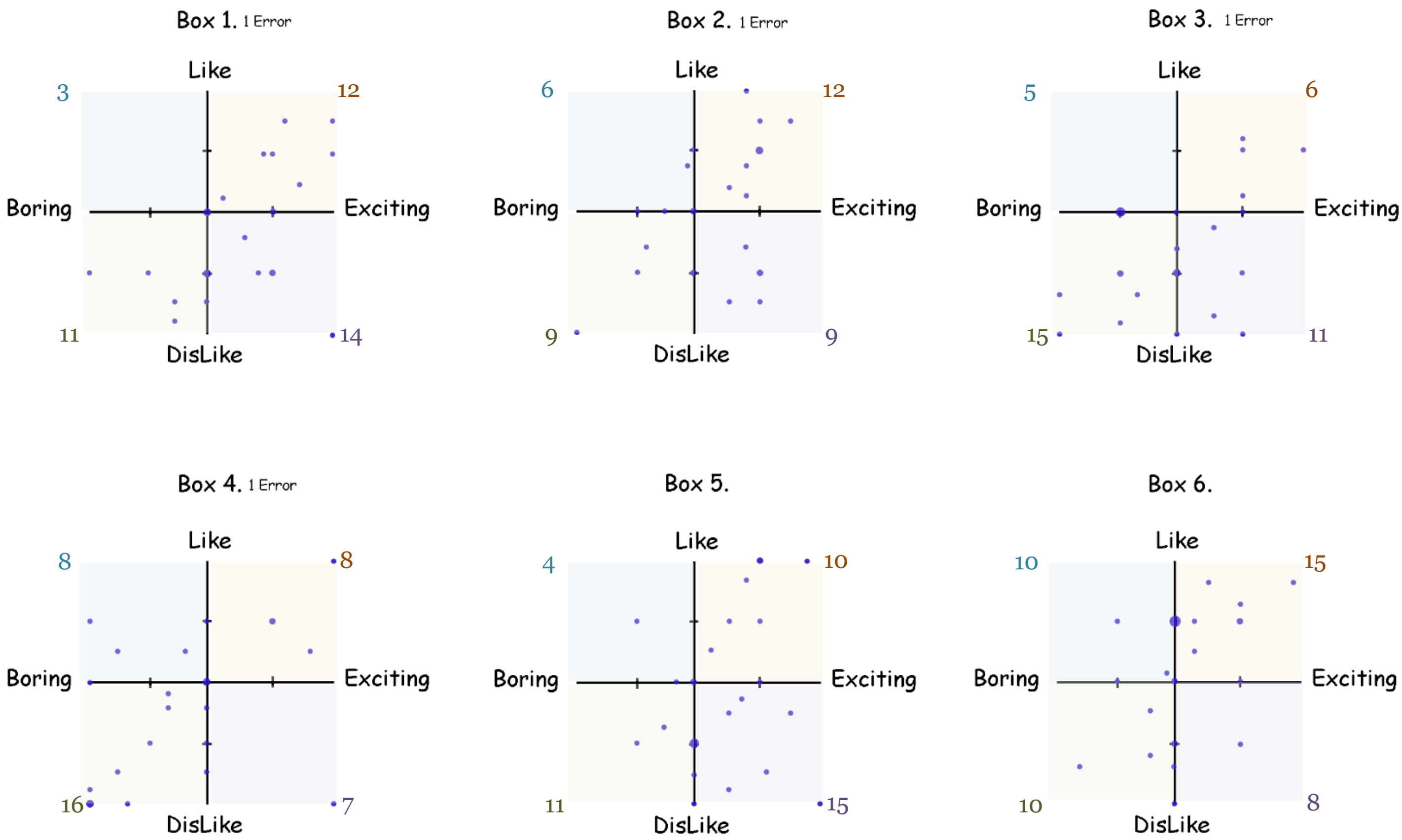

Figure 10: Electrochromic in coloured state (EC-coloured) in combination with 2700K.

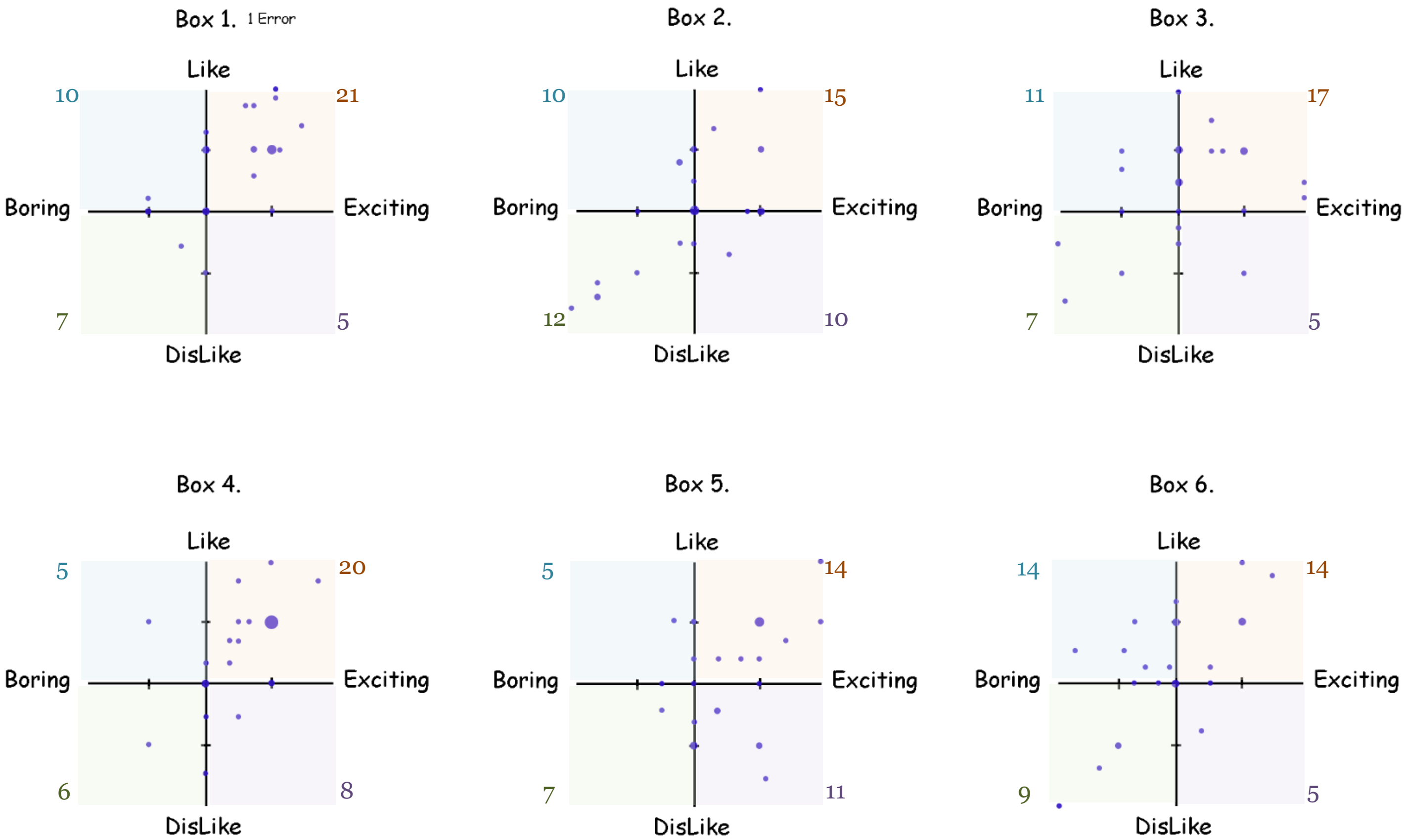

Figure 11: Photochromic glazing (PC) in combination with 2700K.

Statistical analysis

So far, the analysis presented have been purely descriptive. However, to test if we might have obtained the results just by chance, we also conducted an inference statistical analysis of the main findings. Two predictors act as independent variables in these analyses: Correlated Colour Temperature of light (CCT) and Glazing types. The data were analysed by regression analysis in STATA to predict the value of colour shift (both hue and nuance) based on the value of the independent variables for all boxes except the grey box. The grey box was excluded since it was not possible to register different hues of Grey around the NCS circle and it was not possible to conduct a multinomial logistic regression due to low numbers of participants.

See Tables 3-4 for distribution of answers of hues and nuances for each stimulus for Box 1. A full analysis for each box is available from the corresponding author upon request.

Hue	**CCT (K)**			**Glazing types**					
Colour sample	**2700**	**6500**	**8000**	**EC-coloured**	**EC-midpoint**	**EC-uncoloured**	**PC**	**ET-on**	**ET-off**
G70Y	38	52	45	72	58	5	0	0	0
G80Y	10	23	34	6	16	38	4	3	0
G90Y	21	63	59	0	4	16	47	43	33
Y	44	17	18	0	0	16	12	19	32
Y10R	36	0	0	0	0	3	11	11	11
Y20R	7	0	0	0	0	0	4	2	1

Table 3: Dominating answers for hues with different stimuli of Box 1.

Hue	**CCT (K)**			**Glazing types**					
Colour sample	**2700**	**6500**	**8000**	**EC-coloured**	**EC-midpoint**	**EC-uncoloured**	**PC**	**ET-on**	**ET-off**
0520	22	66	68	17	23	27	36	34	19
1010	20	29	19	2	2	4	18	13	29
1015	13	11	12	10	4	9	6	4	3
1020	1	2	7	3	2	1	2	0	2
1030	37	16	14	4	7	23	9	16	8
2020	63	31	36	42	40	14	7	11	16

Table 4: Dominating answers for nuances with different stimuli of Box 1.

Tables 5-8 present the results for domination answers for hue and nuances of each box. In these tables, the first column shows the box number, the second column show the samples number and the rest of columns show the number of answers for each scenario.

The effect of the CCT of light and glazing types and their interactions on the responses were tested by multiple linear regression for continuous values. Since the independent variables CCT and glazing were categorical, we need to define one of the categories in each of these variables as a reference category to have some point to compare differences of the other categories to. Therefore, we assume EC-uncoloured and a CCT of 6500K as references in Tables 5-8 and all the effects of the other categories are compared to them. We chose 6500K since it represents white, neutral overcast sky, which occurs more often in the North. On the other hand, EC-uncoloured was chosen as reference because it is nearly identical to standard clear glazing.

		1= EC-Coloured			2= EC-midpoint			3= EC-uncoloured			4= PC			5= ET-on			6= ET-off		
Box		**2700**	**6500**	**8000**	**2700**	**6500**	**8000**	**2700**	**6500**	**8000**	**2700**	**6500**	**8000**	**2700**	**6500**	**8000**	**2700**	**6500**	**8000**
1	-3	26	26	20	12	24	22	0	2	3	0	0	0	0	0	0	0	0	0
	-2	0	0	6	10	2	4	0	17	21	0	2	2	0	2	1	0	0	0
	-1	0	0	0	4	0	0	7	7	2	4	22	21	3	21	19	3	13	17
	0	0	0	0	0	0	0	16	0	0	7	2	3	10	3	6	11	12	9
	1	0	0	0	0	0	0	3	0	0	11	0	0	11	0	0	11	0	0
	2	0	0	0	0	0	0	0	0	0	4	0	0	2	0	0	1	0	0
2	-2	0	3	4	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0
	-1	0	6	10	0	5	1	1	0	2	0	0	4	0	1	1	1	1	2
	0	0	14	12	0	5	20	0	4	12	0	3	11	1	12	20	2	7	15
	1	0	2	0	0	5	2	5	14	9	8	18	9	12	11	5	13	15	8
	2	26	1	0	26	11	3	20	8	3	18	5	1	12	2	0	10	3	1
4	-3	1	0	1	8	0	0	21	0	0	20	0	0	19	0	0	19	0	0
	-2	1	0	0	10	0	0	1	0	0	3	4	0	3	0	1	5	4	0
	-1	10	4	1	6	3	2	2	4	0	1	11	3	0	10	1	1	2	1
	0	2	1	0	0	1	0	0	9	5	1	8	15	2	12	5	0	18	19
	1	4	6	8	1	4	6	0	10	15	0	3	3	0	3	15	0	1	4
	2	8	15	16	1	18	18	2	3	6	1	0	5	1	1	4	1	1	2
5	-1	4	23	21	0	21	23	0	10	10	0	2	4	0	4	3	0	0	3
	0	9	1	4	2	5	3	1	9	15	0	5	8	1	10	13	4	10	10
	1	9	0	0	16	0	0	6	4	1	9	12	12	7	9	7	5	9	10
	2	2	1	1	6	0	0	6	3	0	11	7	2	5	3	3	5	7	3
	3	2	1	0	2	0	0	13	0	0	6	0	0	13	0	0	12	0	0
6	-2	0	0	0	0	0	0	2	0	0	4	0	0	2	0	0	6	0	0
	-1	0	0	1	0	0	0	6	0	0	11	0	3	14	4	3	8	10	2
	0	0	2	1	1	0	2	7	4	7	6	19	19	5	18	21	8	14	21
	1	1	11	9	1	4	12	8	20	16	5	6	3	4	4	2	4	2	3
	2	2	6	10	7	8	7	1	1	3	0	1	1	1	0	0	0	0	0
	3	23	7	5	17	14	5	2	1	0	0	0	0	0	0	0	0	0	0

Table 5: Dominating answers for hues with interaction of stimuli for Boxes 1, 2, 4, 5 and 6.

		1= EC-Coloured			2= EC-midpoint			3= EC-uncoloured			4= PC			5= ET-on			6= ET-off		
Box		2700	6500	8000	2700	6500	8000	2700	6500	8000	2700	6500	8000	2700	6500	8000	2700	6500	8000
1	-3	1	9	7	2	12	9	6	9	12	6	18	12	4	12	18	3	6	10
	-2	1	1	0	2	0	0	3	1	0	5	5	8	2	7	4	7	15	7
	-1	0	5	5	0	1	3	1	4	4	5	1	0	4	0	0	3	0	0
	0	0	0	3	0	1	1	0	1	0	1	0	1	0	0	0	0	0	2
	1	2	1	1	4	0	3	9	7	7	5	2	2	11	4	1	6	2	0
	2	22	10	10	18	12	10	7	4	3	4	0	3	5	3	3	7	2	7
2	-3	3	0	2	5	2	4	6	6	4	3	3	9	3	6	11	7	5	7
	-2	0	0	0	0	2	0	4	3	2	3	5	2	7	1	1	1	1	3
	-1	0	0	0	0	2	0	0	0	1	2	0	0	4	1	0	6	3	2
	0	5	6	2	12	8	8	14	5	10	12	7	8	8	8	6	4	4	7
	1	17	20	22	8	12	14	0	7	4	4	1	1	2	3	4	4	7	2
	2	1	0	0	1	0	0	2	5	4	2	10	6	2	7	4	4	6	5
	3	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0
4	-3	0	0	1	4	3	0	10	13	13	4	10	12	2	16	11	4	12	10
	-2	19	20	14	10	17	19	0	1	1	0	0	0	0	0	0	0	0	0
	-1	1	0	2	8	2	5	2	5	3	0	2	1	1	1	0	0	0	1
	0	2	3	2	4	2	2	6	6	8	7	11	6	4	9	10	6	8	11
	1	2	2	3	0	2	0	7	1	0	14	1	6	18	0	3	16	6	4
	2	2	1	4	0	0	0	1	0	1	1	2	1	0	0	2	0	0	0
5	-3	2	2	2	2	5	6	5	8	7	6	8	13	8	11	10	7	11	2
	-2	0	6	8	0	0	1	0	0	0	0	0	1	0	0	1	2	0	0
	-1	0	0	0	0	0	0	0	1	0	0	0	2	0	2	6	0	2	0
	0	1	6	10	1	5	10	6	7	14	10	12	8	7	9	9	7	8	1
	1	21	12	3	23	16	9	15	10	5	10	6	2	11	4	0	10	5	21
	2	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2
6	-3	7	1	0	4	4	5	1	6	6	3	10	5	3	8	7	4	5	4
	-2	0	0	0	3	0	0	20	3	0	20	4	1	14	1	0	12	4	1
	-1	3	0	1	13	0	0	5	2	1	3	4	1	6	0	0	8	2	1
	0	11	3	1	4	10	8	0	10	11	0	8	15	3	16	14	2	15	15
	1	3	22	24	1	12	13	0	4	7	0	0	3	0	1	5	0	0	5
	2	2	0	0	1	0	0	0	1	1	0	0	1	0	0	0	0	0	0

Table 6: Dominating answers for nuances with interaction of stimuli for Boxes 1, 2, 4, 5 and 6.

		1= EC-Coloured			2= EC-midpoint			3= EC-uncoloured			4= PC			5= ET-on			6= ET-off		
Box		**2700**	**6500**	**8000**	**2700**	**6500**	**8000**	**2700**	**6500**	**8000**	**2700**	**6500**	**8000**	**2700**	**6500**	**8000**	**2700**	**6500**	**8000**
3	1	0	0	0	1	0	0	1	4	3	7	10	19	4	17	20	3	13	15
	2	1	0	0	2	0	0	25	0	0	18	8	0	21	5	0	22	8	1
	3	0	0	0	0	0	0	0	0	0	1	1	0	1	1	2	1	2	1
	4	1	25	25	1	7	20	0	4	9	0	1	1	0	2	2	0	0	7
	5	24	1	1	22	19	6	0	18	14	0	6	6	0	1	2	0	3	2

Table 7: Dominating answers for hues with interaction of stimuli for Box 3.

		1= EC-Coloured			2= EC-midpoint			3= EC-uncoloured			4= PC			5= ET-on			6= ET-off		
Box		**2700**	**6500**	**8000**	**2700**	**6500**	**8000**	**2700**	**6500**	**8000**	**2700**	**6500**	**8000**	**2700**	**6500**	**8000**	**2700**	**6500**	**8000**
3	1	0	0	0	1	0	0	0	0	0	2	3	11	2	7	6	1	6	4
	2	1	2	0	2	0	4	20	6	8	18	9	3	17	5	5	14	10	5
	3	0	0	0	0	0	0	1	4	3	4	6	8	1	9	13	1	6	10
	4	23	19	22	22	26	21	5	15	15	2	8	4	6	5	2	9	4	7
	5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	6	2	5	4	1	0	1	0	1	0	0	0	0	0	0	0	1	0	0

Table 8: Dominating answers for nuances with interaction of stimuli for Box 3.

To have a better understanding of their impact, we ran the analysis also with different reference categories which are available upon request. The results are summed up in Tables 9-13 for hues and Tables 14-18 for nuances for all the boxes except Box 3, the grey room (values of $p<0.05$ indicate a statistically significant difference between the perception of colours). Since the grey colour is not on the NCS circle, the way of analysing it was different from other boxes. As it is apparent from the low probability values, all alternatives of both stimuli (the glazing types and the correlated colour temperatures of light), separately have significant effects on perception of Box 4 (the red room); It is while for the other boxes, only some of them were significant. Moreover, the standardised regression coefficients were calculated using Beta, and are reported in Tables 9-13 for the hues and Tables 14-18 for the nuances. This value serves as standardised effect size statistics and allow you to compare the relative strength of the various predictors within the model; they can be compared to one another. For example for the hue of the Box 2, blue room, between the two stimuli, EC-coloured has the largest Beta coefficient, -0.530 (in absolute value), and PC has the smallest Beta, -0.028. The maximum Beta value for each box was highlighted with blue colour in Tables 9-18. If we want to compare, the CCT of 2700K possessed a strong effect in the evaluation of the hue of Box 1, yellow room, while PC glazing had the biggest impact on the evaluation of the nuance of the Box 1.

Stimuli		**Coef.**	**p**	**95% conf. interval**		**Beta**
				min	**max**	
CCT	1-2700	1.654	<0.001	1.326	1.982	0.583
	3-8000	-0.231	0.060	-0.472	0.011	-0.081
Glazing	1-EC-coloured	-1.192	<0.001	-1.426	-0.959	-0.333
	2-EC-midpoint	-1.115	<0.001	-1.357	-0.873	-0.311
	4-PC	0.808	<0.001	0.547	1.068	0.225
	5-ET-on	0.846	<0.001	0.545	1.147	0.236
	6-ET-off	1.288	<0.001	0.985	1.590	0.357
Interaction (CCT + Glazing)	1 * 1	-1.654	<0.001	-1.982	-1.326	-0.284
	1 * 2	-1.038	<0.001	-1.525	-0.552	-0.178
	1 * 4	-0.077	0.736	-0.541	0.387	-0.013
	1 * 5	-0.231	0.349	-0.729	0.267	-0.040
	1 * 6	-0.749	0.003	-1.223	-0.276	-0.128
	3 * 1	0.461	0.009	0.128	0.795	0.079
	3 * 2	0.308	0.032	0.028	0.587	0.053
	3 * 4	0.269	0.116	-0.071	0.609	0.046
	3 * 5	0.385	0.024	0.054	0.715	0.066
	3 * 6	0.097	0.529	-0.216	0.409	0.017

Table 9: Hue results for Box 1: S1020-Y.

Stimuli		**Coef.**	**p**	**95% conf. interval**		**Beta**
				min	**max**	
CCT	1-2700	0.538	0.018	0.099	0.977	0.247
	3-8000	-0.654	0.001	-1.002	-0.306	-0.300
Glazing	1-EC-coloured	-1.461	<0.001	-1.885	-1.038	-0.530
	2-EC-midpoint	-0.308	0.196	-0.784	0.169	-0.112
	4-PC	-0.077	0.633	-0.404	0.251	-0.028
	5-ET-on	-0.615	<0.001	-0.925	-0.306	-0.223
	6-ET-off	-0.385	0.033	-0.735	-0.034	-0.140
Interaction (CCT + Glazing)	1 * 1	1.769	<0.001	1.232	2.306	0.395
	1 * 2	0.615	0.050	-0.001	1.232	0.137
	1 * 4	0.077	0.736	-0.387	0.541	0.017
	1 * 5	0.231	0.322	-0.239	0.701	0.051
	1 * 6	-0.077	0.795	-0.681	0.527	-0.017
	3 * 1	0.269	0.292	-0.245	0.784	0.060
	3 * 2	0.0769	0.812	-0.581	0.734	0.017
	3 * 4	-0.231	0.307	-0.686	0.224	-0.051
	3 * 5	0.269	0.191	-0.143	0.682	0.060
	3 * 6	0.192	0.503	-0.390	0.774	0.043

Table 10: Hue results for Box 2: S1020-R90B.

Stimuli		Coef.	p	95% conf. interval min	max	Beta
CCT	1-2700	-2.885	<0.001	-3.515	-2.254	-0.767
	3-8000	0.577	0.004	0.206	0.948	0.154
Glazing	1-EC-coloured	0.769	0.009	0.207	1.331	0.162
	2-EC-midpoint	0.961	<0.001	0.550	1.373	0.203
	4-PC	-1.077	<0.001	-1.596	-0.557	-0.227
	5-ET-on	-0.654	0.018	-1.186	-0.121	-0.137
	6-ET-off	-0.731	0.019	-1.330	-0.131	-0.154
Interaction (CCT + Glazing)	1 * 1	1.846	<0.001	0.985	2.707	0.239
	1 * 2	-0.346	0.461	-1.298	0.606	-0.045
	1 * 4	1	0.003	0.362	1.637	0.130
	1 * 5	0.637	0.101	-0.134	1.408	0.081
	1 * 6	0.615	0.078	-0.074	1.305	0.080
	3 * 1	-0.423	0.066	-0.876	0.303	-0.055
	3 * 2	-0.461	0.022	-0.851	-0.071	-0.060
	3 * 4	0.423	0.148	-0.161	1.007	0.055
	3 * 5	0.385	0.234	-0.264	1.033	0.050
	3 * 6	-0.038	0.900	-0.659	0.583	-0.005

Table 11: Hue results for Box 4: S1020-R.

Stimuli		Coef.	p	95% conf. interval min	max	Beta
CCT	1-2700	2.192	<0.001	1.659	2.726	0.793
	3-8000	-0.346	0.161	-0.839	0.147	-0.125
Glazing	1-EC-coloured	-0.692	0.023	-1.283	-0.101	-0.198
	2-EC-midpoint	-0.808	0.001	-1.243	-0.372	-0.231
	4-PC	0.923	<0.001	0.459	1.387	0.264
	5-ET-on	0.423	0.091	-0.073	0.919	0.121
	6-ET-off	0.885	0.001	0.386	1.383	0.253
Interaction (CCT + Glazing)	1 * 1	-0.923	0.011	-1.611	-0.235	-0.162
	1 * 2	-0.077	0.787	-0.658	0.504	-0.014
	1 * 4	-1.231	0.002	-1.970	-0.492	-0.216
	1 * 5	-0.461	0.081	-0.985	0.062	-0.081
	1 * 6	-1.115	0.006	-1.872	-0.358	-0.196
	3 * 1	0.308	0.254	-0.235	0.851	0.054
	3 * 2	0.269	0.303	-0.258	0.797	0.047
	3 * 4	-0.115	0.730	-0.797	0.566	-0.020
	3 * 5	0.308	0.423	-0.471	1.086	0.054
	3 * 6	-0.038	0.892	-0.614	0.537	-0.007

Table 12: Hue results for Box 5: S1020-G.

Stimuli		Coef.	p	95% conf. interval min	max	Beta
CCT	1-2700	-0.731	0.009	-1.258	-0.20.3	-0.257
	3-8000	-0.115	0.458	-0.430	0.200	-0.041
Glazing	1-EC-coloured	0.731	0.001	0.318	1.143	0.203
	2-EC-midpoint	1.423	<0.001	1.111	1.735	0.396
	4-PC	-0.654	<0.001	-0.960	-0.347	-0.182
	5-ET-on	-0.961	<0.001	-1.280	-0.643	-0.268
	6-ET-off	-1.269	<0.001	-1.567	-0.971	-0.353
Interaction (CCT + Glazing)	1 * 1	1.884	<0.001	1.223	2.546	0.322
	1 * 2	0.885	0.018	0.164	1.605	0.151
	1 * 4	-0.115	0.662	-0.653	0.422	-0.020
	1 * 5	0.269	0.419	-0.405	0.943	0.046
	1 * 6	0.423	0.178	-0.205	1.052	0.072
	3 * 1	0.077	0.799	-0.538	0.692	0.013
	3 * 2	-0.692	0.006	-1.169	-0.216	-0.118
	3 * 4	-0.115	0.566	-0.524	0.293	-0.020
	3 * 5	0.077	0.697	-0.325	0.479	0.013
	3 * 6	0.461	0.006	0.148	0.774	0.079

Table 13: Hue results for Box 6: S1020-R60B.

Stimuli		Coef.	p	95% conf. interval min	max	Beta
CCT	1-2700	0.615	0.226	-0.406	1.637	0.137
	3-8000	-0.346	0.446	-1.269	0.577	-0.077
Glazing	1-EC-coloured	0.192	0.591	-0.535	0.919	0.034
	2-EC-midpoint	0.192	0.721	-0.906	1.290	0.034
	4-PC	-1.731	<0.001	-2.598	-0.863	-0.305
	5-ET-on	-0.846	0.148	-2.014	0.322	-0.149
	6-ET-off	-0.988	0.040	-1.928	-0.047	-0.173
Interaction (CCT + Glazing)	1 * 1	1.461	0.017	0.279	2.644	0.158
	1 * 2	1.038	0.098	-0.207	2.284	0.113
	1 * 4	1.038	0.159	-0.436	2.513	0.113
	1 * 5	0.961	0.153	-0.383	2.306	0.104
	1 * 6	0.834	0.176	-0.401	2.068	0.090
	3 * 1	0.654	0.265	-0.527	1.835	0.071
	3 * 2	0.577	0.346	-0.661	1.815	0.063
	3 * 4	1.077	0.060	-0.051	2.205	0.117
	3 * 5	-0.231	0.769	-1.832	1.370	-0.025
	3 * 6	0.872	0.160	-0.368	2.113	0.095

Table 14: Nuance results for Box 1: S1020-Y.

Stimuli		Coef.	p	95% conf. interval min	max	Beta
CCT	1-2700	-0.577	0.293	-1.682	0.528	-0.164
	3-8000	0.192	0.734	-0.960	1.344	0.055
Glazing	1-EC-coloured	1.038	0.012	0.253	1.823	0.233
	2-EC-midpoint	0.269	0.529	-0.598	1.137	0.060
	4-PC	0.346	0.522	-0.751	1.444	0.078
	5-ET-on	0.115	0.852	-1.145	1.376	0.026
	6-ET-off	0.231	0.674	-0.887	1.349	0.052
Interaction (CCT + Glazing)	1 * 1	0.192	0.714	-0.874	1.259	0.027
	1 * 2	0.385	0.477	-0.714	1.483	0.053
	1 * 4	0.154	0.836	-1.362	1.670	0.021
	1 * 5	-0.077	0.908	-1.429	1.275	-0.011
	1 * 6	-0.038	0.961	-1.645	1.568	-0.005
	3 * 1	-0.346	0.584	-1.631	0.939	-0.048
	3 * 2	-0.115	0.839	-1.269	1.039	-0.016
	3 * 4	-0.961	0.238	-2.601	0.678	-0.133
	3 * 5	-0.923	0.243	-2.514	0.668	-0.127
	3 * 6	-0.808	0.218	-2.124	0.509	-0.111

Table 15: Nuance results for Box 2: S1020-R90B.

Stimuli		Coef.	p	95% conf. interval min	max	Beta
CCT	1-2700	0.846	0.048	0.009	1.683	0.251
	3-8000	0.115	0.782	-0.734	0.965	0.034
Glazing	1-EC-coloured	0.346	0.336	-0.380	1.072	0.081
	2-EC-midpoint	0.077	0.814	-0.591	0.745	0.018
	4-PC	0.692	0.140	-0.244	1.629	0.162
	5-ET-on	-0.154	0.697	-0.957	0.650	-0.036
	6-ET-off	0.577	0.200	-0.326	1.480	0.135
Interaction (CCT + Glazing)	1 * 1	-0.731	0.160	-1.769	0.307	-0.105
	1 * 2	-0.731	0.120	-1.666	0.204	-0.105
	1 * 4	0.346	0.546	-0.817	1.510	0.050
	1 * 5	1.478	0.009	0.405	2.552	0.209
	1 * 6	0.461	0.415	-0.686	1.609	0.067
	3 * 1	0.423	0.396	-0.586	1.432	0.061
	3 * 2	-0.115	0.817	-1.132	0.901	-0.017
	3 * 4	-0.192	0.781	-1.603	1.219	-0.028
	3 * 5	0.769	0.164	-0.337	1.875	0.111
	3 * 6	0.000	1.000	-1.280	1.280	0.000

Table 16: Nuance results for Box 4: S1020-R.

Stimuli		Coef.	p	95% conf. interval min	max	Beta
CCT	1-2700	0.577	0.120	-0.161	1.314	0.166
	3-8000	-0.038	0.917	-0.788	0.711	-0.011
Glazing	1-EC-coloured	0.346	0.364	-0.425	1.118	0.079
	2-EC-midpoint	0.615	0.151	-0.240	1.471	0.140
	4-PC	-0.115	0.769	-0.916	0.685	-0.026
	5-ET-on	-0.615	0.098	-1.352	0.121	-0.140
	6-ET-off	-0.577	0.133	-1.341	0.188	-0.131
Interaction (CCT + Glazing)	1 * 1	0.385	0.487	-0.738	1.507	0.054
	1 * 2	0.038	0.929	-0.844	0.921	0.005
	1 * 4	-0.192	0.709	-1.240	0.855	-0.027
	1 * 5	0.115	0.832	-0.991	1.221	0.016
	1 * 6	0.000	1.000	-1.175	1.175	0.000
	3 * 1	-0.346	0.468	-1.312	0.620	-0.048
	3 * 2	-0.423	0.414	-1.471	0.625	-0.059
	3 * 4	-0.846	0.089	-1.831	0.139	-0.118
	3 * 5	-0.231	0.658	-1.293	0.831	-0.032
	3 * 6	-0.154	0.800	-1.389	1.082	-0.021

Table 17: Nuance results for Box 5: S1020-G.

Stimuli		Coef.	p	95% conf. interval min	max	Beta
CCT	1-2700	-1.077	0.003	-1.745	-0.409	-0.350
	3-8000	0.385	0.178	-0.186	0.956	0.125
Glazing	1-EC-coloured	1.5	<0.001	0.771	2.229	0.385
	2-EC-midpoint	0.769	0.069	-0.064	1.603	0.197
	4-PC	-0.846	0.005	-1.413	-0.280	-0.217
	5-ET-on	-0.192	0.540	-0.830	0.445	-0.049
	6-ET-off	-0.192	0.586	-0.910	0.525	-0.049
Interaction (CCT + Glazing)	1 * 1	-0.308	0.550	-1.354	0.738	-0.049
	1 * 2	0.000	1.000	-0.871	0.871	0.000
	1 * 4	0.692	0.031	0.068	1.316	0.109
	1 * 5	0.385	0.226	-0.254	1.023	0.061
	1 * 6	0.346	0.403	-0.493	1.185	0.055
	3 * 1	-0.231	0.472	-0.882	0.420	-0.036
	3 * 2	-0.461	0.318	-1.394	0.471	-0.073
	3 * 4	0.731	0.072	-0.072	1.533	0.115
	3 * 5	-0.038	0.910	-0.732	0.655	-0.006
	3 * 6	0.192	0.586	-0.526	0.910	0.030

Table 18: Nuance results for Box 6: S1020-R60B.

For the grey box, instead of the linear regression analysis a Chi square test with adjusted residuals was used to see which stimuli had the biggest impact.

With chi square we could see if there is a significant difference between the perceived distribution of answers as compared to the expected distribution if all columns in Table 19 for hue and Table 20 for nuances had the same distribution. It tells furthermore how much does the number of answers in one category contribute to the difference, which means that if the number is higher (either more positive or more negative), the impact of this category in the general significant result is higher. By looking at the columns with largest numbers in the last line we can see which combination makes the largest contribution.

Figures 12-16 displays the average "disagreement" between colour samples chosen by participants in degrees on the NCS Colour Circle for yellow, blue, red, green and purple rooms respectively, along with their 95% CIs. "Missing" bars indicate complete agreement between all 26 participants. We could see that among all the rooms, there is a significantly greater degree of agreement among the consultants regarding the colours samples selected for the yellow room.

	1= EC-Coloured			2= EC-midpoint			3= EC-uncoloured			4= PC			5= ET-on			6= ET-off		
Hue	**2700**	**6500**	**8000**	**2700**	**6500**	**8000**	**2700**	**6500**	**8000**	**2700**	**6500**	**8000**	**2700**	**6500**	**8000**	**2700**	**6500**	**8000**
1	-3.029	-3.029	-3.029	-2.563	-3.029	-3.029	-2.563	-1.165	-1.631	0.233	1.631	5.826	-1.165	4.893	6.292	-1.631	3.029	3.961
2	-2.451	-2.926	-2.926	-1.977	-2.926	-2.926	8.935	-2.926	-2.926	5.614	0.870	-2.926	7.037	-0.554	-2.926	7.512	0.870	-2.451
3	-0.775	-0.775	-0.775	-0.775	-0.775	-0.775	-0.775	-0.775	-0.775	0.620	0.620	-0.775	0.620	0.620	2.016	0.620	2.016	0.620
4	-2.338	9.272	9.272	-2.338	0.564	6.853	-2.822	-0.887	1.532	-2.822	-2.338	-2.338	-2.822	-1.854	-1.854	-2.822	-2.822	0.564
5	7.779	-2.711	-2.711	6.867	5.499	-0.431	-3.167	5.043	3.218	-3.167	-0.431	-0.431	-3.167	-2.711	-2.255	-3.167	-1.799	-2.255
sum	16.372	18.713	18.713	14.52	12.793	14.014	18.262	10.796	10.082	12.456	5.89	12.296	14.811	10.632	15.343	15.752	10.536	9.851

Table 19: The results of Chi square test with adjusted residuals for the hue of grey room.

	1= EC-Coloured			2= EC-midpoint			3= EC-uncoloured			4= PC			5= ET-on			6= ET-off		
Hue	**2700**	**6500**	**8000**	**2700**	**6500**	**8000**	**2700**	**6500**	**8000**	**2700**	**6500**	**8000**	**2700**	**6500**	**8000**	**2700**	**6500**	**8000**
1	-1.669	-1.669	-1.669	-0.970	-1.669	-1.669	-1.669	-1.669	-1.669	-0.272	0.427	6.016	-0.272	3.221	2.523	-0.970	2.523	1.126
2	-2.785	-2.333	-3.237	-2.333	-3.237	-1.430	5.796	-0.527	0.376	4.893	0.828	-1.882	4.441	-0.979	-.979	3.086	1.280	-0.979
3	-2.126	-2.126	-2.126	-2.126	-2.126	-2.126	-1.546	0.193	-0.387	0.193	1.353	2.513	-1.546	3.092	5.412	-1.546	1.353	3.672
4	4.477	2.857	4.072	4.072	5.692	3.667	-2.812	1.237	1.237	-4.027	-1.597	-3.217	-2.407	-2.812	-4.027	-1.192	-3.217	-2.002
5	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
6	1.337	4.774	3.628	0.191	-0.955	0.191	-0.955	0.191	-0.955	-0.955	-0.955	-0.955	-0.955	-0.955	-0.955	0.191	-0.955	-0.955
sum	12.394	13.759	14.732	9.692	13.679	9.083	12.778	3.817	4.624	10.34	5.16	14.583	9.621	11.059	13.896	6.985	9.328	8.734

Table 20: The results of Chi square test with adjusted residuals for the nuance of grey room.

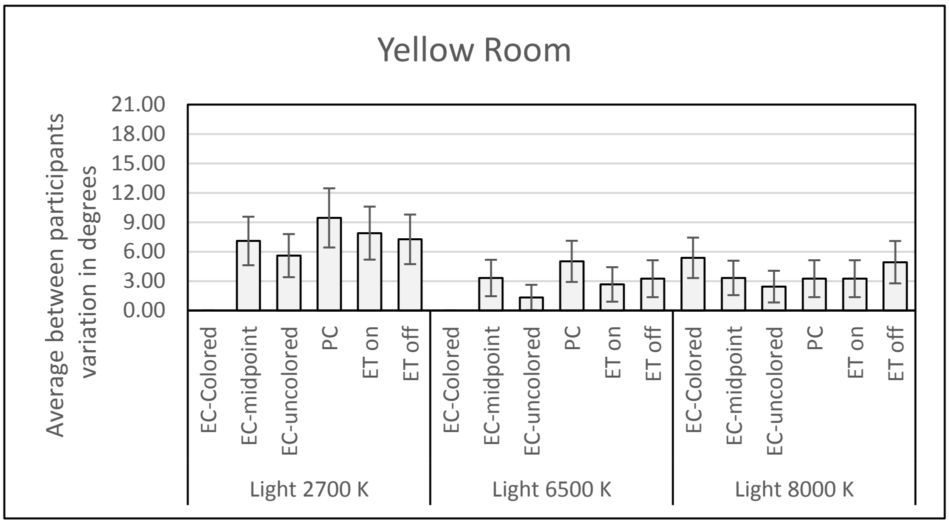

Figure 12: Average dissimilarity between the colour samples selected for yellow room and the 95% CIs.

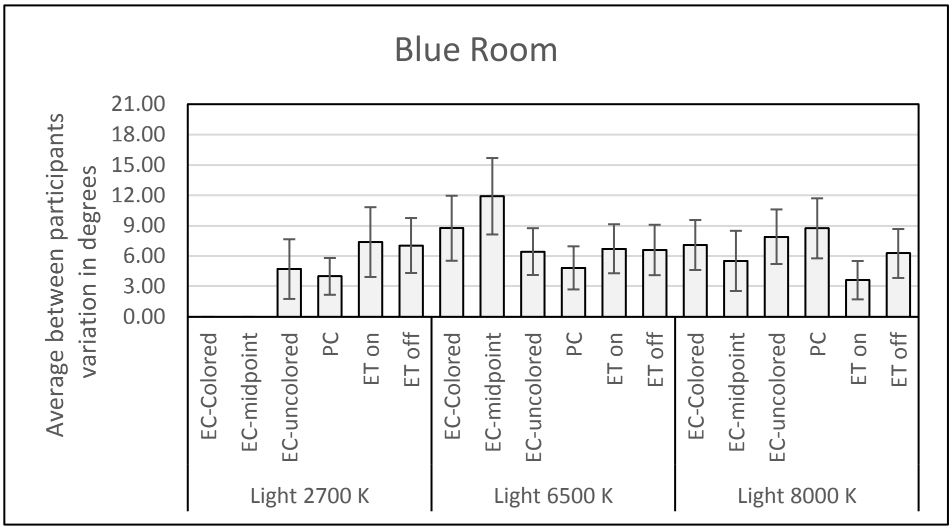

Figure 13: Average dissimilarity between the colour samples selected for blue room and the 95% CIs.

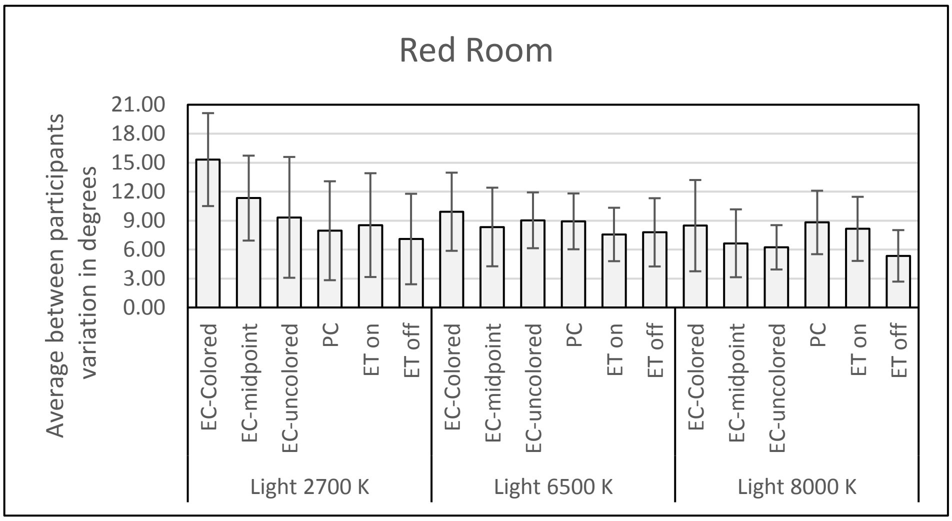

Figure 14: Average dissimilarity between the colour samples selected for red room and the 95% CIs.

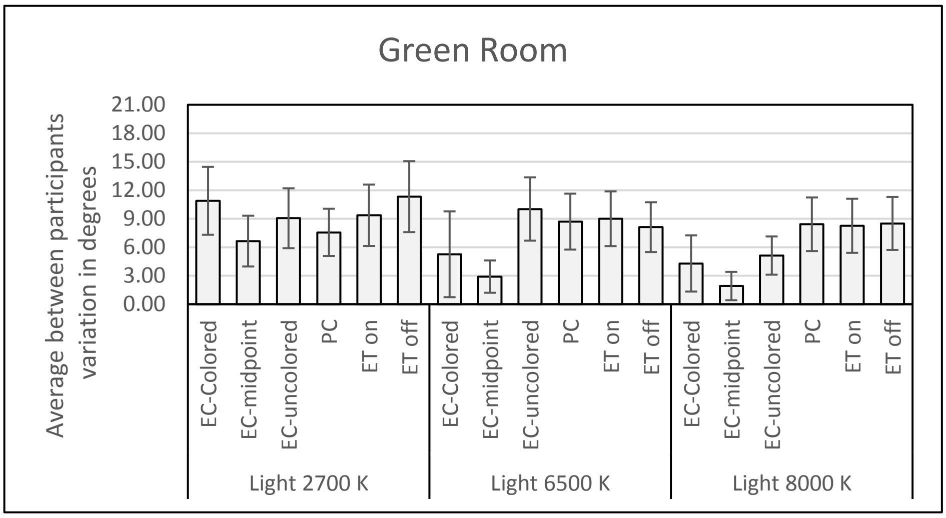

Figure 15: Average dissimilarity between the colour samples selected for green room and the 95% CIs.

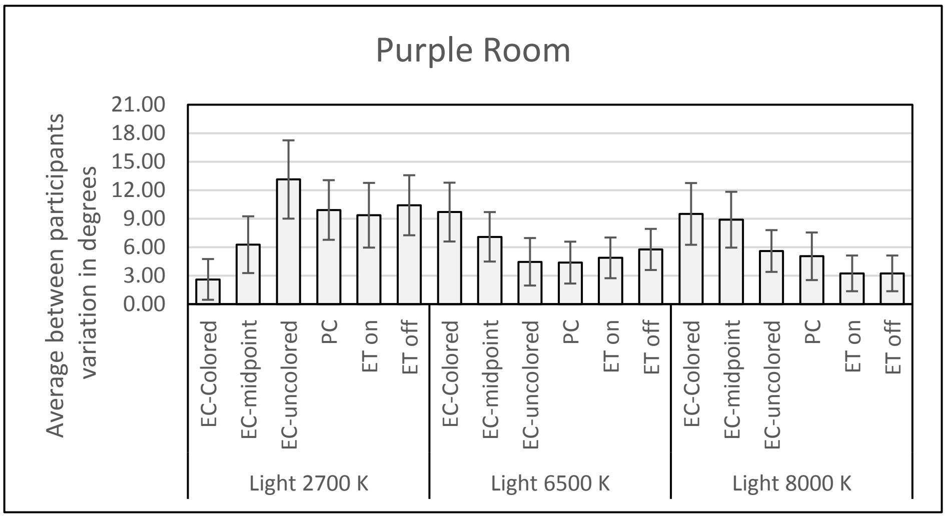

Figure 16: Average dissimilarity between the colour samples selected for purple room and the 95% CIs.

Conclusions

The study attempted to achieve a deeper understanding of how colour shift of different interior surfaces can be affected by different advanced glazings.

An experiment was carried out comparing a coloured target room with different glazings and colour temperatures to a reference room with constant conditions as close as possible to standard conditions. This experiment was performed in a specific laboratory situation; therefore, these results are fully valid for similar situations as in the test.

Although doing the experiment with a small colour sample might have been an easier task for evaluation of colour perception, we decide to paint the whole test room and ask participants to evaluate the impression of the full room. Thus, it was not accidental that all the surfaces were painted with the same colour. As a consequence though, it was difficult for subjects to know where exactly they should look to compare the colour of the Test room with the samples in the Reference room. This is, however, exactly what we would experience in everyday life, we see some parts of the room in shadow and some parts illuminated intensively, so while it might have been confusing for the participants, it was at the same time very realistic.

Even though it would be possible to evaluate the colour shift caused by glazing with spectrophotometric and/or colorimetric methods, thus on an objective level, we focused on people's perception because it is huge difference to look into a room as a human being or to do the measurements of the physical qualities of a room. Adaptation is an important factor that is difficult to include in physical measurements so we consider our results as carrying more perceptual reliability.

Our visual system can adjust to very different levels of illumination and can change its sensitivity to light over time. In this experiment, the light level was in the range of 15 to 150 cd/m2 during the whole experiment, therefore according to Valberg [21], only few seconds would be needed for the adaptation.

Regarding colour shift tendencies, see Figure 7, we can conclude that in 2700K with EC glazing there is a tendency for hue shift clockwise on the NCS circle for the nominal hues blue, green and violet i.e. blue -> green, green -> yellow-green and violet -> blue. Colours with nominal colour red and yellow tend to shift counter clockwise, i.e. red -> yellow and yellow -> yellow-green. These tendencies are the same for PC and ET except for yellow and violet hues. Moreover, EC glazing in 6500K and 8000K cause the clockwise hue shift for blue, red and violet hues while it is counter clockwise for yellow and green hues.

There is a clear difference between EC glazing and PC & ET glazings, especially in 6500K and 8000K. EC causes shift toward blue for hues: red and green; PC & ET causes shift toward yellow for the same hues.

The observations show that the grey hue was not perceived differently from its nominal hue in 6500K and 8000K for both PC glazing and ET glazing. This tendency shifted toward green with EC-uncoloured and toward blue with EC-coloured. However in 2700K, the shift was the result of mixing colour of light and glazing colour. For example in 2700K with EC coloured (bluish tint), the hue shifted toward green while with PC glazing shifted toward yellow.

The results show that the EC glazing caused strong colour distortions compared to a room without a window and other glazing types.

The statistical analyses show that CCT 2700 had an impact on the hue of all rooms and CCT 8000 on the blue and red rooms.

The results testify that all glazing types separately had a significant impact on the hue perception of the yellow room, the red room and the violet room; all besides the ET-on glazing had an impact on the green room; in the blue room EC-coloured, ET-on and ET-off glazing had an impact.

The interaction of CCT and glazing types was statistically significant for some interactions that are marked with grey colour in Table 9, the yellow box appear to be the most sensitive.

On the other hand, it is difficult to identify a general rule for nuances perception based on Table 10. It seems that in the setting with two variables we are much better in noticing hue differences than nuances. It means also that subjects were much more unsure and random in their answers to nuances.

Acknowledgements

This project consumed huge amount of work, research and dedication. Still, implementation would not have been possible if we did not have a support of many individuals and organisations. Therefore, we would like to extend our sincere gratitude to all of them.

The author is thankful to Institute for Energy Technology (IFE) especially Fredrik Aleksander Martinsen who provided the photochromic glass. The author would also like to thank Dr. Alexander Kraft, founder of Gesimat GmbH Company-Germany.

We would like to express our sincere thanks towards volunteer researchers who devoted their time and knowledge in the implementation of this project.

References

1. Billger M (1999), Colour combination effects in experimental rooms, *Color Research and Application*, **24** (4), 230-242.
2. Chevreul ME (1967), *The Principles of Harmony and Contrast of Colors and their Applications to the Arts*, Birren F (ed.), New York: Reinhold Publishing Corporation.
3. Chevreul ME (1854), *The Principles of Harmony and Contrast of Colours, and their Applications to the Arts*, Longman, Brown, Green and Longmans.
4. Liljefors A (1995), Lighting and colour terminology: visually–physically, *Proceedings of the Interim meeting of International Colour Association – Colour and Psychology*, 230-234, Goteborg (Sweden).
5. Hårleman M (2002), Color appearance in interior daylight: Observations of hue shifts in different compass orientations, *Proceedings of the Ninth Congress of the International Colour Association*, 68-71, Sydney (Australia).
6. Hårleman M (2007), Daylight influence on colour design: empirical study on perceived colour and colour experience indoors, *PhD Thesis*, Royal Institute of Technology (Sweden).
7. Hårleman M (2007), Study of colour shifts in various daylights: Dominantly reddish and greenish rooms illuminated by sunlight and skylight, *Colour: Design and Creativity*, **1** (1): 8, 1-15.
8. Hårleman M (2001), Colour appearance in different compass orientations, *Nordisk Arkitekturforskning*, **2**, 41-48.
9. Hårleman M, Werner I-B and Billger M (2007), Significance of colour on room character: study on dominantly reddish and greenish colours in north-and south-facing rooms, *Colour: Design and Creativity*, **1** (1): 9, 1-15.
10. Matusiak B, Fridell Anter K and Angelo K (2012), Colour shifts behind modern glazing, *SYN-TES Report #7* [https://www.konstfack.se/SYN-TES – last accessed 27 February 2018].
11. Angelo K, Matusiak B and Fridell Anter K (2012), Colour shift behind modern glazing, *Proceedings of the Interim meeting of International Colour Association – In Color We Live: Color and Environment*, 52-55, Taipei (Taiwan).
12. Zinzi M (2006), Office worker preferences of electrochromic windows: a pilot study, *Building and Environment*, **41** (9), 1262-1273.
13. Arbab S, Matusiak BS, Martinsen FA and Hauback BC (2017), The impact of advanced glazing on colour perception, *Journal of the International Colour Association*, **17**, 50-68.
14. Billger M (1999), Colour in enclosed space observation of colour phenomena and development of methods for identification of colour appearance in rooms, *Doctoral Dissertation*, Chalmers University of Technology, Göteborg (Sweden).
15. Hård A, Sivik L and Tonnquist G (1996), NCS natural color system—from concept to research and applications: Part I. *Color Research and Application*, **21** (3), 180-205.
16. Hård A, Sivik L and Tonnquist G (1996), NCS natural color system—from concept to research and applications: Part I. *Color Research and Application*, **21** (3), 206-220.
17. Matusiak B and Arnesen H (2005), The limits of the mirror box concept as an overcast sky simulator, *Lighting Research and Technology*, **37** (4), 313-327.
18. Matusiak BS and Braczkowski T (2014), Overcast sky simulator in the Daylight Laboratory at NTNU, Trondheim, *Lumen V4*, Visegrád (Hungary).
19. Fridell Anter K and Klarén U (2009), *Neutral grey–an abstraction?*, *Proceedings of the Ninth Congress of the International Colour Association*, 0909015final-00236, Sydney (Australia).
20. Livingstone MS (2008), *Vision and Art: The Biology of Seeing*, New York: Harry N. Abrams.
21. Valberg A (2007), *Light Vision Color*, John Wiley & Sons.