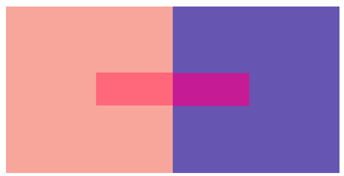
Colour shifts behind modern

GLAZING



Final Report Barbara Matusiak, Karin Fridell Anter and Kine Angelo June 2012

SYN-TES report 7

The Mies van der Rohe Pavilion in Barcelona. Photo by Kine Angelo

Preface

The trans disciplinary research project SYN-TES. Human colour and light synthesis: Towards a coherent field of knowledge has been carried out at University College of Arts, Crafts and Design (Konstfack) in Stockholm during 2010-2011, financed by the Swedish Knowledge Foundation (ref. nr 2009/0195). The project has involved around fifteen Nordic specialists on colour and light, from industrial companies and different academic disciplines. Apart from the involvement in SYN-TES, all participants have worked with other research or development work regarding colour and/or light issues. Within the SYN-TES project the group has held a number of joint seminars and workshops, where different knowledge traditions were brought closer to each other and where the group jointly formulated the foundations for a coherent field of knowledge including both colour and light. In addition, a number of subprojects on specific questions have been carried out.

The subproject presented in this report deals with glazing and its impact on the colours and colour contrasts perceived in interiors behind different kinds of transparent and translucent glazing materials. It has been carried out at the Norwegian University of Science and Technology (NTNU) in Trondheim, in conjunction with the project Translucent façades financed by Forskningsrådet (The Norwegian Research Council), Norway, project number 200557.

Trondheim june 2012

Professor Barbara Matusiak
Head of Department of Architectural Design, Form and Colour Studies
Faculty of Architecture and Fine Art, NTNU, Norway

Project manager of the GLAZING subproject.

NTNU
Norwegian University of
Science and Technology

Project group GLAZING

Barbara Matusiak, Architect, Professor, Norwegian University of Science and Technology (NTNU), Trondheim (Project Manager)

Karin Fridell Anter, Architect, Docent, University College of Arts, Crafts and Design (Konstfack) Stockholm

Kine Angelo, Interior Architect, Researcher, Norwegian University of Science and Technology (NTNU), Trondheim

Julie Guichard, Architect, Student in Civil Engineering, L'École nationale des travaux publics de l'État (ENPE), France

Additional observers

Magdalena Stós, Architect

Pawel Matusiak, Student

Special discussion partners

Tommy Pettersson, Lighting and glass consultant, Stockholm

Oskar Storm, Sales manager, Saint-Gobain Emmaboda Glas AB, Emmaboda Sweden

Partners

Forskningsrådet

I SAMARBETE MED KK·stiftelsen

EMMABODA GLAS GLASSOLUTIONS SAINT-GOBAIN

Konstfack University College of Arts, Crafts and Design

Reference Group = SYN-TES seminar group

Harald Arnkil, Artist, Senior lecturer, Aalto University School of Art, Design and Architecture, Helsinki

Leif Berggren, Independent senior light expert, Stockholm

Monica Billger, Assistant Professor, Department of Architecture, Chalmers University of Technology, Gothenburg

Pär Duwe, Technical sales manager, Alcro-Becers AB, Stockholm

Johanna Enger, Light designer MSc, University College of Arts, Crafts and Design (Konstfack) Stockholm

Anders Gustafsson, Technical Director, Alcro-Beckers AB, Stockholm

Cecilia Häggström, Interior Designer, PhD' University College of Arts, Crafts and Design (Konstfack) Stockholm

Yvonne Karlsson, Colour designer, Alcro-Beckers AB, Stockholm

Ulf Klarén, Illustrator, MA, University College of Arts, Crafts and Design (Konstfack) Stockholm

Thorbjörn Laike, Assistant Professor of Environmental Psychology, University of Lund, Sweden

Johan Lång, Sales director, Philips AB, Lighting, Stockholm

Anders Nilsson, Head of the colorimetric department of NCS Colour AB, Stockholm, Sweden

Svante Pettersson, Light designer, Philips AB, Lighting, Stockholm

Helle Wijk, Assistant Professor, Department for Health and Care Sciences, University of Gothenburg, Sweden

GLAZING
Daylight Laboratory/NTNU 2010-2012

Funded by Forskningsrådet, Norway, project number 200557and KK-stiftelsen, Sweden, project number 2009/0195
Project Manager GLAZING: Barbara Matusiak
Project Manager SYN-TES: Karin Fridell Anter
Layout and graphic design: Johanna Enger and Kine Angelo
Photographs: Barbara Matusiak, Alex Booker, Kine Angelo and Johanna Enger
Illustrations: Barbara Matusiak, Julie Guichard and Kine Angelo

Innehåll

SYN-TES REPORTS

1. OPTIMA. Metodstudie om färg, ljus och rumsupplevelse
2. PERCIFAL. Perceptiv rumslig analys av färg och ljus
3. Ljus- och färgbegrepp och deras användning
4. Ljusförstärkande färgsättning av rum
5. SYN-TES 2010-2011. Interdisciplinära studier om färg – ljus – rum.
6. Rumslig samverkan mellan färg och ljus. En översikt över aktuell forskning.
7. Colour shifts behind modern GLAZING

More reports are planned.

1 Abstract

The necessity of a dramatic reduction of energy consumption in the building sector causes the need for much higher energy efficiency. Regarding facades, the easiest way to obtain this goal in many European countries, e.g. Norway, is to reduce the size of windows. On the other side occupants need a considerably high daylight level, visual comfort and a nice view out. How to meet those contradictory goals?

New glazing technologies and new translucent materials are under development, for example the nanogel material that has an exceptionally high thermal insulation capacity and a moderate light transmittance. Can those new materials and/or technologies help us to meet the goal?

In the scientific project Translucent Facades a number of new glazing types equiped with especially designed low-energy coatings and new translucent materials were studied regarding: light transmittance, light distribution and glare. During the work with the glazing samples a clear color difference between the outside and the inside appearance of samples was observed. This was a cue to regard glazing samples as a sort of color filters and triggered the research group to test color shift in interiors situated behind such glazing; the "colour shift" project was defined.

The main goal of the colour shift project was to explore in which direction (hue? chromaticness? backness?) and how much do different colours change their visual appearance due to a given glazing type. The NCS colour system was used for the choice of test colours as well as for analysis of test results. Five hues in addition to the achromatic grey scale were chosen; 5 different nyances were chosen for each hue. The study was carried by expert observers in a specially designed scale modell 1:5 consisted of two chambers: a reference chamber and the test chamber to which the respective glazing types were fixed. The project was carried in the Artificial Sky, NTNU, the overcast sky simulator, were the correlated colour temperature is 6000 K.

Results shows that the tested transparent glazings tend to give quite obvious colour distortions compared to the open chamber (open window), which let in unfiltered daylight. Results for the translucent materials show a similar pattern, although not as strong as for the transparent glass.

Surfaces with pale colours, which have only little blackness and are not strongly chromatic, showed very liable to shifts both in hue and nuance, whereas strongly chromatic, intense colours and dark colours tended to be much more stable.

The typical pattern was that hues shifted towards yellowish green when seen behind the tested glazings, in comparison with how they looked in unfiltered daylight. When the nominal hue had a dominating blueness and/or greenness (hues between approximately R50B and G50Y), there was a tendency for a hue shift clockwise in the NCS model. Colours with nominal hues dominated by a redness and/or yellowness instead tended to be shifted counter clockwise in the model.

Nuance shifts varied between different areas of the colour circle. Pale samples with nominally yellowish or greenish hues tended to get increased chromaticness and reduced blackness when seen behind glazing. This was true also for light grey samples that assumed an obvious green-yellow hue when seen behind the glass. For samples with their nominal hue between red and blue the opposite was found and chromaticness was typically reduced. The very lightest nominally blue sample instead assumed a distinct chromaticness in a hue between yellow and green.

2 Background

The use of glass in sustainable architecture

Until rather recently, most windows were made of double layer glazing. Focus on sustainable architecture and the demands for low energy consumption have, however, lead to a more widespread and accepted use of triple layer glazing.

During the last decades, there has been a trend to use large glass façades on official buildings, but due to the demands for energy efficiency there is a need for solutions that provide better heat insulation. In the global discussions about climate change and energy-efficiency, architecture has moved to centre-stage. Governments around the world are becoming aware that buildings offer the biggest energy-saving potential. The process of reformulating the standards for new buildings towards zero-carbon is underway in most European countries.

At the same time there is an ambition to utilize daylight in buildings for optimal daylight conditions, visual comfort and the nicest possible view. To meet these seemingly conflicting needs, new materials and technologies are being developed to be used in transparent windows or in translucent façades.

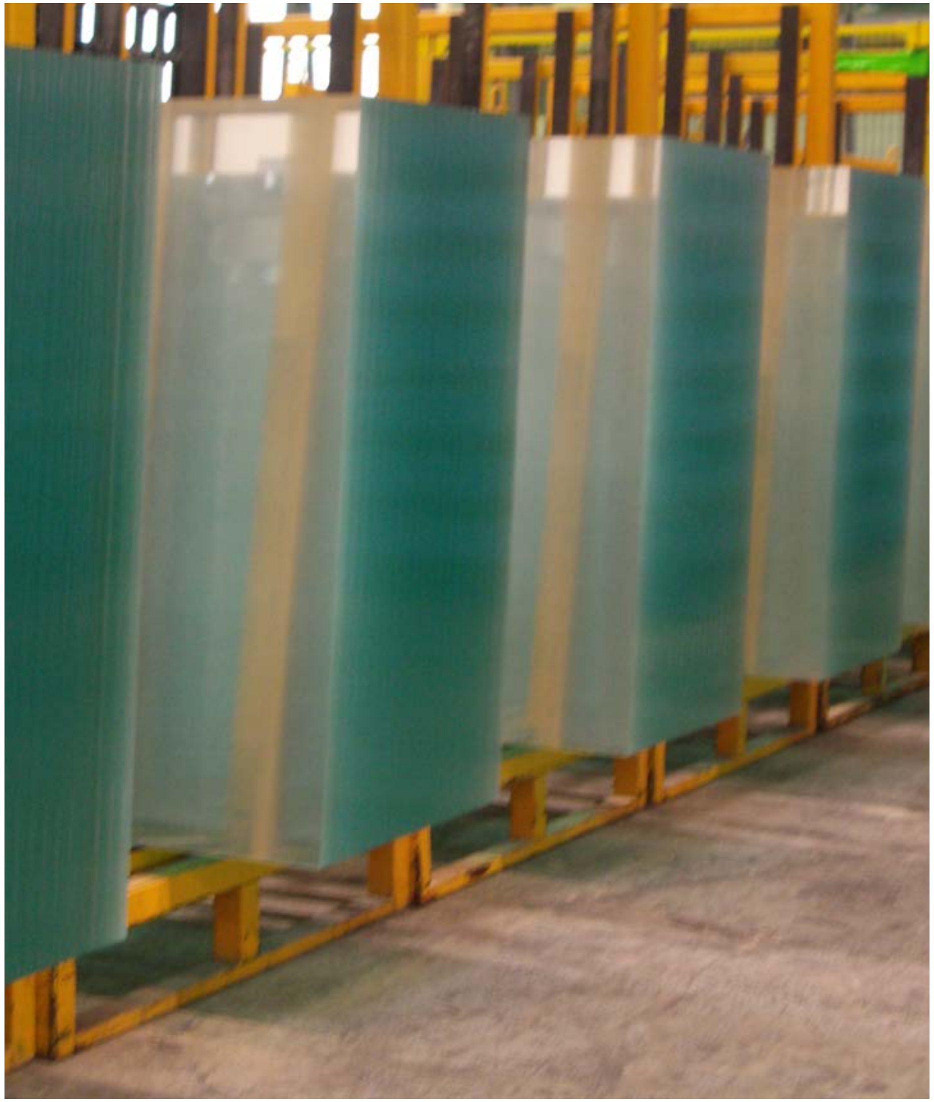
The energy saving functions of such glazings is of basically two types: In warm climate or on façades reached by high sun radiation, the option is to reduce the need for cooling by stopping long-wave solar radiation to enter the building. In cool climate the option is instead to minimize the need for heating, and consequently the glazing is designed to hinder heat loss by reflecting long wave radiation back into the building.[1]

[1] The technology of different glazing materials is further presented in section 4.

Whereas there are strictly formulated demands on the energy saving aspect of glazing, there are no regulations dealing with their impact on perceived light and colours inside the buildings. There are, however, a few recent studies discussing different impacts of coloured glazing types. C. Chain et al. show the influence of green and brown glazing on surface colours in buildings under the daylight illuminant at 6500 K in the numeric form.[2]

In the study carried by Hélène Arsenault et al. blue, bronze, and neutral glazings were tested by participants using a scale model. The study showed that the participant's level of arousal was slightly lower when the blue glazing was in use. Additionally, the study shows that there was a preference for daylight filtered through bronze window glazing.[3] In a master thesis, Israa Hussein has investigated how different glazing and lighting interact regarding colour rendering, and contributed to the methodological development.[4]

This report aims to contribute to the understanding of glazing materials' effect on perceived colours. The project has been carried out in conjunction with another project, dealing with daylight utilization, glare and visual communication when using translucent façades. That project is reported separately.[5]



[2] The considerations of daylight's colour, by Chain, Dumortier and Fontoynont (2001).
[3] Effects of glazing colour on perception of daylight quality are discussed in Arsenault, Hébert and Dubois

Light Level

The daylight level in interiors depends mostly on the quantity of light transmitted through the glazing. It depends on the size and colour of outside obstructions, the size of the glazing and the light transmittance (LT) of the glazing. All solar control glazings and energy saving glazings have significantly lover light transmittance than the traditional clear glazing.
The typical values of light transmittance for glazings with 3 layer of glass are:
Solar control glazing: LT= 30 - 60%.
Energy saving glazing: LT= 60 - 70%.
Glazing in the period 1970 - 2000 was made of two layers of clear glass, LT> 80%.

The effect of glazing on perceived colours in a room

The colours that we perceive in a room and the contrasts between them are essential for our perception of the room's atmosphere and visual clarity. And it is therefor, as a consequence of that, essential for how we experience the quality of light.[6] Colours are perceived as a result of a complex process in our brains, where the input signals are made up from the intensity and wavelength distribution of the radiation reaching our retina. This, in its turn, is a result of the same properties of the light source together with the reflection properties of the coloured surface.

A window glass or a translucent façade distorts the wavelength distribution of incoming daylight, and thus is likely to affect our perception of colours in the room. However, the human observer has a large capacity to adapt to different lighting situations, which results in what is called colour constancy. The perceived colour of an object – or a sensitive thing such as the human skin – changes much less between different light situations than what could be expected from the wavelength distribution or the intensity of light. It is an ecologically developed necessity for us to recognize the world and its objects irrespective of light situation.

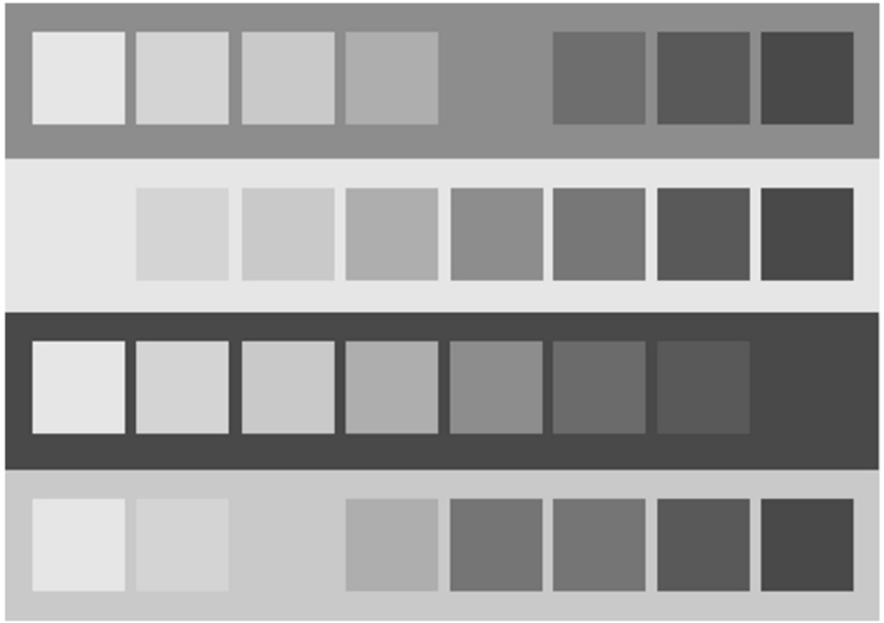


Figure 1. The importance of the colour of the background for the perceived lightness. Four physically identical rows of a grayscale (identical reflections) are surrounded by four different backgrounds. From Valberg 2005, figure 4.32, page 200.

[4] Hussein 2007.
[5] The Norwegian research Council (Forskningsrådet), project 200557; Translucent Façade. Research partners Asplan Viak AS, Lund Hagem Arkitekter AS, Atelier Oslo AS and NTNU. A guide for use of translucent façade will be published later this year.
[6] Recent studies of the spatial interaction between light and colour have been carried out within the trans disciplinary Nordic research project SYN-TES. See Fridell Anter 2011 and Häggström & Fridell Anter 2012.

Therefore the colour distorting effects of glazing or translucent materials are most important when there is no single lighting situation for our visual sense to adapt to, for example when a translucent glazing is combined with transparent glazing, or when some of the glazings are opened to let in full daylight. Thus, in a building with translucent glazing and transparent glazing that can be opened, there can be three co-existing light situations created by daylight.

An additional factor in our colour perception is the contrast between the sample to be judged and its background. Our ability to see small contrasts decreases with the increase of adaption luminance, which is the "average" luminance of the viewing field. With a black background, even the smallest change in a colour is visible. With a white background, our ability to detect changes in a colour decreases. [7]

[7] The function of white as an anchor for lightness and chromatic adaptation is discussed in Klarén & Fridell Anter 2009 and 2011.

3 Project objectives

The project is a pilot study exploring how different translucent materials and glazings can influence the colours that we perceive and therefore the atmosphere of a room. It has two main objectives

- to formulate relevant questions regarding the colour rendering properties of glass and to develop methods to find answers to those questions. This is meant to form the basis for further research and for future analyses of materials not yet existing.

- to present and analyze the colour rendering properties of a large number of transparent and translucent glazings available on the market in 2011. This is meant to provide guidance to architects and others who deal with selecting glass materials and/or work with the colour design of rooms lit with daylight filtered through such materials.

The new Deichman Library in Oslo. Illustration from Lund Hagem Architects and Atelier Oslo

4 A basic guide to glass materials

Glass is an amorphous solid material characterized by excellent visual transparency. It is brittle since its structure is non-crystalline. The most familiar type of glass, used for centuries in windows and drinking vessels, is soda-lime glass, composed of about 75% silica (SiO_2) plus soda (Na_2O), lime (CaO), and several minor additives, including iron oxide.

Throughout history window glass has been made with different methods, gradually allowing larger sheets of glass. The float glass method, developed in the 1950:s, gives the sheet uniform thickness and very flat surfaces. Nearly all modern windows are made from soda-lime float glass. The typical building glass is slightly polluted by the iron oxide, something that gives it a faintly greenish colour. This may be observed most clearly at the glass edges.
The window glass can be toughened by the use of controlled heating and cooling process. The toughened glass is 4-5 times stronger than ordinary glass of the same thickness. In addition, it will have significantly greater resistance to heat stress. The toughened glass does not break but it granulates into small pieces.

Glass can be also laminated to protect users against fall of broken glass, noise, burglar, explosions and different types of radiation This plastic film is glued in between two glass panes by a heat treatment. The laminated glass is much thicker and more greenish. If the glazing is broken the glass pieces are held in place by the film.
In recent years, the window glass producers are working on developing products that address the goals of sustainability and "zero carbon". The development goes in two directions: low-emissivity glass and solar control glass.

Low-emissivity glass (energy-saving glass)

The purpose of low-emissivity glass is to reflect long-wave radiation back into a building and thus to achieve much lower heat loss than ordinary float glass. There are two basic types of low-emissivity coating for glass, known as on-line and off-line coatings. On-line coatings are applied during the glass manufacture, whereas off-line coatings are applied afterwards.

Off-line coatings can generally give higher levels of thermal insulation than on-line coatings, and at the same time allow higher transmittance. Their disadvantage is that they require extra care in handling and processing. They can be supplied in toughened and laminated form by applying the coating to pre-processed glass, they can also be offered in some toughenable forms. On-line coatings are easier to handle and process, are more durable and can be toughened or laminated without difficulty.

The glass products used in buildings consist of glass sheet placed together in insulating glass units (IGUs). Here pieces of glass are separated by gas-filled chambers and sealed around the edges. IGUs can incorporate two or three panes of glass to give double or triple-glazing. Use of additional panes of glass (i.e. triple-glazing) enhances particularly the thermal insulation properties; therefore it becomes a standard in new energy-efficient buildings. Additionally, the choice of edge seal material between the panes of glass and the choice of gas used to fill the created cavity can enhance the overall thermal performance of the IGU and thus the window.

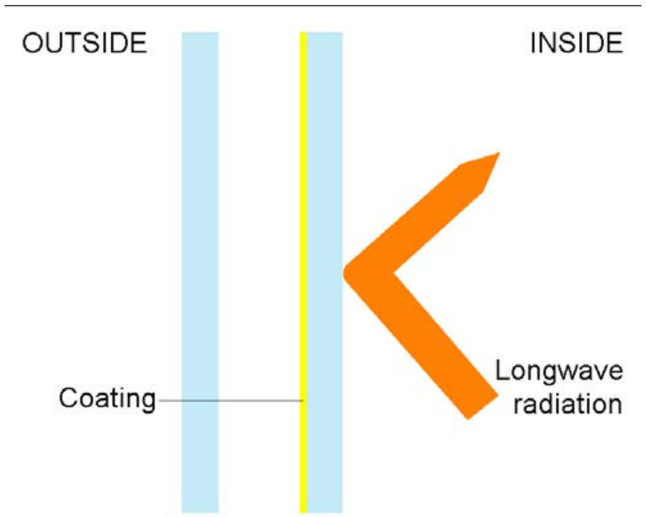


Figure 2. Insulating glazing incorporating low energy glass.

Solar control glass

Products from this group control solar radiation by reflectance, transmittance and absorptance. In hot climates, solar control glass can be used to minimise solar heat gain into the building and help to control glare. In temperate climates the solar control glass can be useful in situations where excessive solar heat gain is an issue, e.g. south oriented glazed façades or atria. Solar control can be achieved in a number of ways, including body-tinted glass, coated glass, laminated glass with tinted interlayers, screen printed glass and insulating glass units incorporating blinds.

The body-tinted glass is manufactured using the standard float glass process. Solar control properties and colour densities vary with thickness. The tints available are bronze, grey, green, blue-green, etc. The coated glass is typically manufactured using an off-line coating process. Coatings are produced in a range of colours.

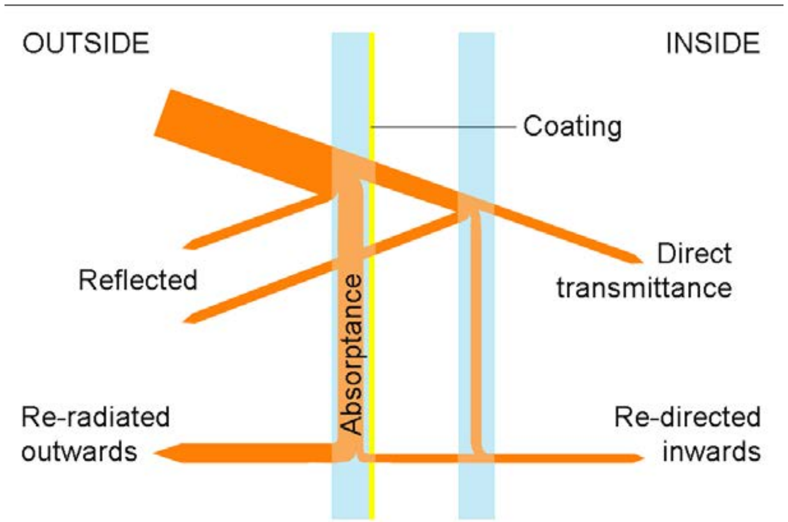


Figure 3. Insulating glazing incorporating coated solar control glass.

Combination possibilities

Nowadays technology makes it possible for a variety of combinations, e.g. high visible light transmittance with solar control and low-emissivity performance all in one product.

GLASS - IMPORTANT SPECIFICATION CRITERIA

U-value

The U-value, also known as the U-factor or coefficient of heat transmission, is the measure of the rate of non-solar heat loss or gain through a material or assembly. U-values gauge how well a material allows heat to pass through. U-value ratings generally fall between 0.20 and 1.20. The lower the U-value, the greater a product's resistance to heat flow and the better its insulating value. U-value is expressed in units of W/m2 K.

G-value

The g-value, or solar factor of an IGU, is the percentage of total solar radiant heat energy transmitted through glazing (the sum of energy transmitted directly and energy absorbed and re-emitted to the interior). G-value is expressed as a number between 0 and 1. The lower a glazing's G-value, the less solar heat it transmits.

LT

Light transmittance, or light transmission value, is defined as the relation between light flux transmitted by the material and the light flux incident on it.

Translucent materials

Translucent Facades have properties in terms of functionality, energy and visual effects that make them supplementary to ordinary, opaque walls and transparent glass. As opaque walls, they define and shade a space, but they also let in light. Unlike transparent glass the translucent facades have, in varying degrees, the ability to spread the incident light, resulting in a smoother and quieter interior illuminated with less contrast.

These materials also have the ability to capture the light as to make them luminous. The light is "materialized" on the surface. New translucent products, with better thermal insulation properties, have made the translucent facades interesting when dealing with energy consumption, as they may reduce the need for electric light whilst giving a satisfactory insulation according to low energy buildings.

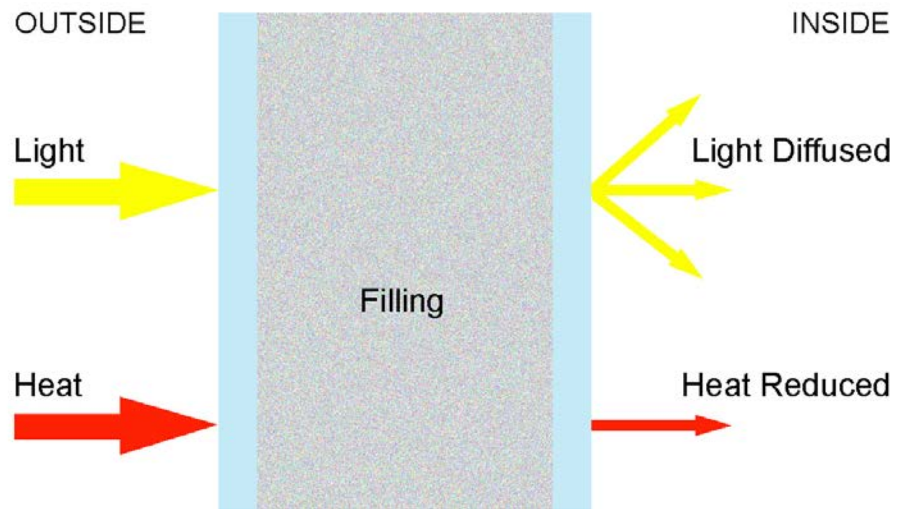


Figure 4. Insulating glazing incorporating translucent filling.

A translucent light effect (refraction of light) can be achieved in different ways and with different products. In essence, you can divide the various translucent products into four main categories:

1. Products containing translucent and insulating filling material between transparent materials, such as aerogel.
2. Products in which the surface itself is translucent. Examples are polycarbonate or frosted glass.
3. Products, where a translucent effect is created with a foil. An example of this is normal 3-layer glass with translucent foil.
4. Products where the material itself can change (phase change materials).

Products with a translucent and insulating filling

There are various translucent insulating materials, but so far the only relevant product for buildings is Nanogel, recently been renamed Aerogel Lumira. Nanogel is one of the world's lightest and most efficient thermal insulating materials. It is a form of crystalline aerogel consisting of 5% silica and 95% air, and it is the pore size and the unique structures of glass threads that captures the flow of air and prevent heat loss and solar heating.

The capability for insulation is determined by the thickness of the panel, and the thickness also reduces the light transmission (LT) and G-value equivalent. It is therefore a direct correlation between the insulation and the light transmission. Nanogel is especially effective as a skylight as the insulation is the same regardless of whether placed horizontally or vertically, as opposed to transparent glazing that has a lower thermal resistance when installed horizontally.

Nanogel diffuses light more effectively than other translucent products and films, but the main challenge is the size of formats. Although bestowed with good insulating properties, it is dependent on producing large enough sizes so that this will not be impaired by too many bridges in the frame details.

Choosing a translucent glazing

Some of the main aspects in the choice of translucent glazings:

1. *Thickness*. The thickness of the product may be important to as if the product can be used in a standard facade system, or if it is necessary to make adjustments or use other system. For many products the thickness are directly related to the insulation value.

2. *Possible dimensions*. The size of the formats available for each product can be crucial to the overall insulation value of the façade.

3. *U-value*. Insulation ability of the product.

4. *G-value*. Solar energy that comes through the material. For transparent products it is dependent on the chosen foil.

5. *Light transmission*. For transparent products it is dependent on the chosen foil.

6. *Weight*. Weight is important for the choice of formats, and for constructability and manageability on the construction site.

7. *Energy consumption*. Energy consumption related to production of the product.

5 The artificial sky used in the project

The Artificial Sky is one of the features at the Daylight Laboratory at the Department of Architectural Design, Form and Colour Studies, NTNU. Through the use of fluorescent light tubes, a horizontal white canvas and eight vertical mirrors placed around a working table it simulates a totally overcast sky, i.e. sufficiently overcast to prevent perception of the sun and its halo. A sky with a thick layer of clouds is an extreme version of the sky. It is characterized by generally low luminance, and an even luminance distribution with the highest luminance at zenith. Based on systematic measurements of real skies in a number of geographic regions, there has been developed a standard model of the perfectly cloudy sky, the CIE Overcast Sky model.[8] The distribution of light in the NTNU Artificial Sky is very similar to the theoretical model in which the horizon luminance is equal 1/3 of the zenith luminance.[9]

The Artificial Sky at NTNU is composed of two steel structures, an external structure which supports the roof and an internal structure which supports the mirrors. The roof, made of corrugated metal sheet, serves as a support for the lighting fixtures. The light in the Artificial Sky is produced by fluorescent light tubes of the Cool Daylight type (PHILIPS MASTER TL5 HE 28W) composed in rows and columns. To even the light from tubes, a translucent white canvas is suspended about 20 cm beneath them. The canvas has a neutral white colour, 45% light transmittance and nearly lambertian reflectance.[10] The mirrors (1,5m x 1,5m) are positioned vertically just beneath the canvas. They make octagon in plan. The mirrors reflect light from the ceiling down to the working table placed at the middle of the Artificial Sky. To avoid undesirable reflections and light leaks, black curtains are suspended beneath the mirrors and a black carpet is used on the floor.

The artificial sky was primarily designed to simulate a specific distribution of light. In order to be useful in observations involving colour it must, however, also perform good colour rendering. To be able to adequately simulate daylight it should also give a colour temperature similar to that of daylight. According to manufacturer, the tubes have the Correlated Colour Temperature (Tc) 6500K and the Colour Rendering Index 85. The Spectral Power Distribution is shown in figure 9.

[8] The CIE overcast sky model is presented in a joint publication from The International Commission on Illumination (CIE) and the International Organization for Standardization (ISO); Spatial distribution of daylight - CIE standard general sky (2004).
[9] For a comprehensive scientific presentation of the artificial sky, see Matusiak & Arnesen 2005.
[10] Lambertian reflectance is the property that defines an ideal diffusely reflecting surface. The apparent brightness of such a surface to an observer is the same regardless of the observer's angle of view. More technically, the surface's luminance is isotropic, and the luminous intensity obeys Lambert's cosine law. Lambertian reflectance is named after Johann Heinrich Lambert.

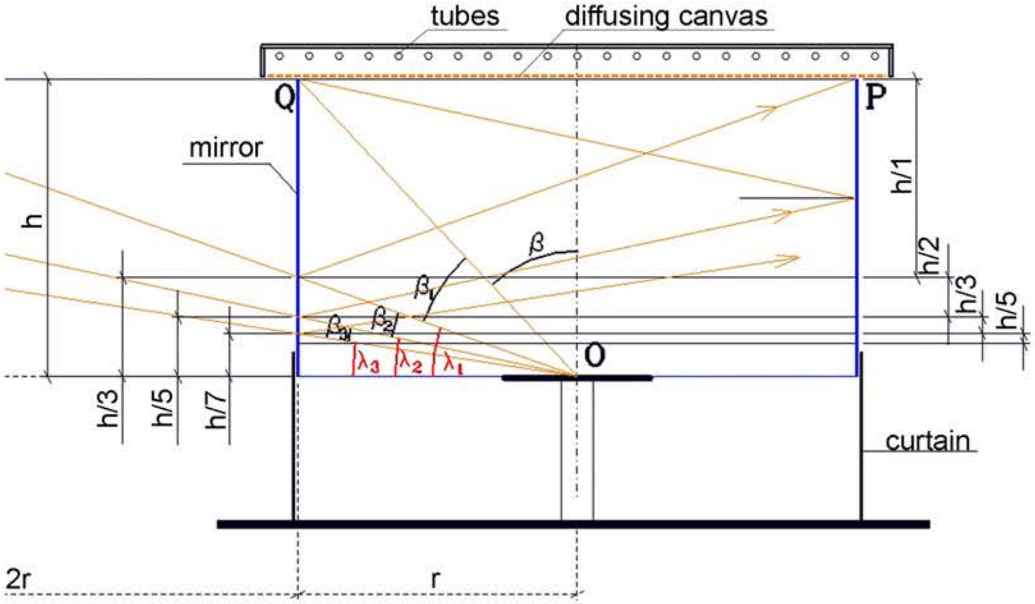


Figure 6. Vertical section. Total height approximately three meters.

Figure 5. The artificial sky seen from the outside.

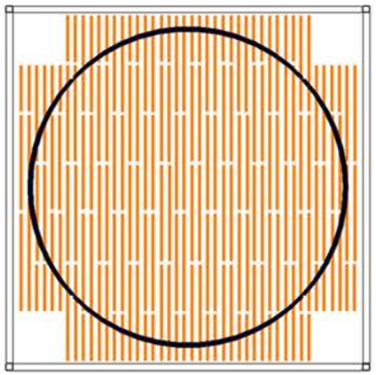


Figure 8. Philips Master TL5 HE 28W Composition of light tubes in the ceiling.

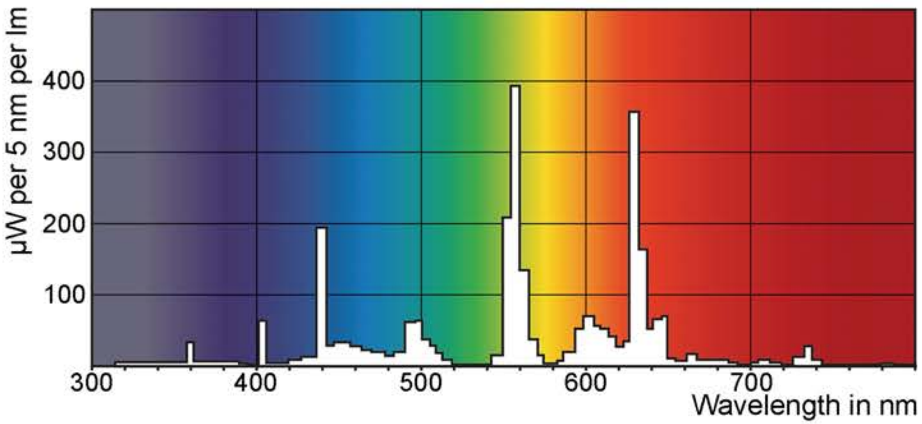


Figure 9. Spectral power distribution of the PHILIPS MASTER TL5 HE 28W.

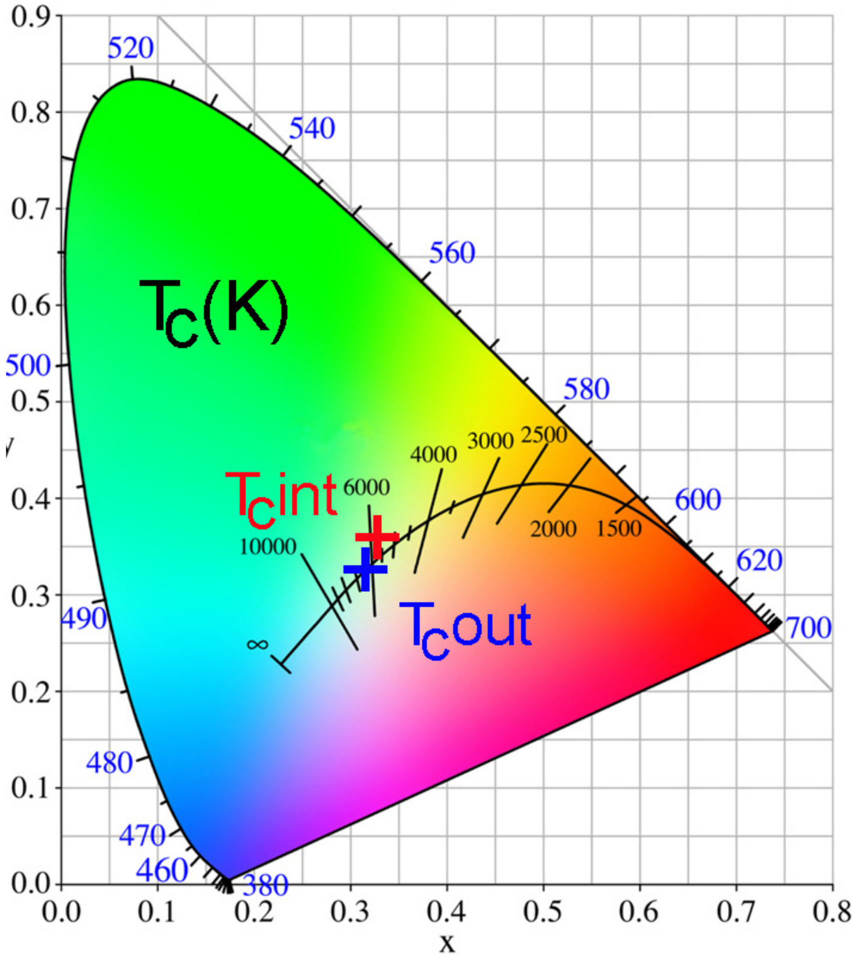


Figure 10. Correlated colour temperature measured in Artificial Sky (TcInt: 5550K – x=0.323/y=0.351) and outside on a totally cloudy day (TcOut: 6000K – x=0.318/y=0.332).

To examine the colour temperature (T) of light in the Artificial Sky, the correlated colour temperature (Tc) was measured on July 20th 2010, using a spectro radiometer and a reflectance standard.[11] The x and y coordinates were measured in the artificial sky (TcInt) and outside (TcOut) under perfectly cloudy sky. The results are presented in figure 10; the correlated colour temperature in the mirror box is 5550K, a slightly lower value than the one measured outside, i.e. 6000K. [12]

There is a discrepancy between the Tc value given by the manufacturer (6500K) and our measured value (5500K). This could be caused by a lack of precision in our measurements and/or the values given by the manufacturer. If we consider the measured and given values as valid there must be other reasons for the discrepancy. One option is that the light tubes have changed by aging. Another, possibly co-operating option is that the translucent canvas alters the spectral distribution and makes the light slightly more yellowish-green.

Whichever reason, we can conclude that the spectral distribution shown in figure 9 and the theoretical rendering index of 85, as a consequence, are not fully valid for the light under the artificial sky. Furthermore, we are aware that since the construction of the artificial sky, light sources with better colour rendering have become available. Still the artificial sky, which was already there, gave the best possible conditions for studying of colour shift behind glazing that we could afford. It is reasonable to claim that any bias due to the small difference between real daylight outdoors and "daylight" in artificial sky is without significance for most purposes where observers are adapted to either light.

These things together tell that the artificial sky provides a substitute for daylight that can be used to find general tendencies in colour distortion caused by glazing. For more specific conclusions there is, however, a need for further comparisons with real daylight situations.

[11] Spectro radiometer (SpectraScan650) and reflectance standard from PhotoResearch, Inc. Web address: www. photoresearch.com.
[12] Further reading on colour temperature and correlated colour temperature, see chapter 3.4, Lyskultur 2009.


SYN-TES project group inside the artificial sky laboratory

6 Research method

The experiment was carried out under the artificial sky presented in section 5. Observers made visual matching between a test sample seen in a reference situation and a number of comparison samples, seen two at a time behind the material to be tested. We used a scale model, in approximately scale 1:5 measured H500 x W1000 x D662 mm. The model was divided into two identical chambers adjacent to each other, with a hole on top allowing the test person to look into both chambers at the same time. Inside the model all surfaces were covered with a non-reflecting black, matte paper.[13]

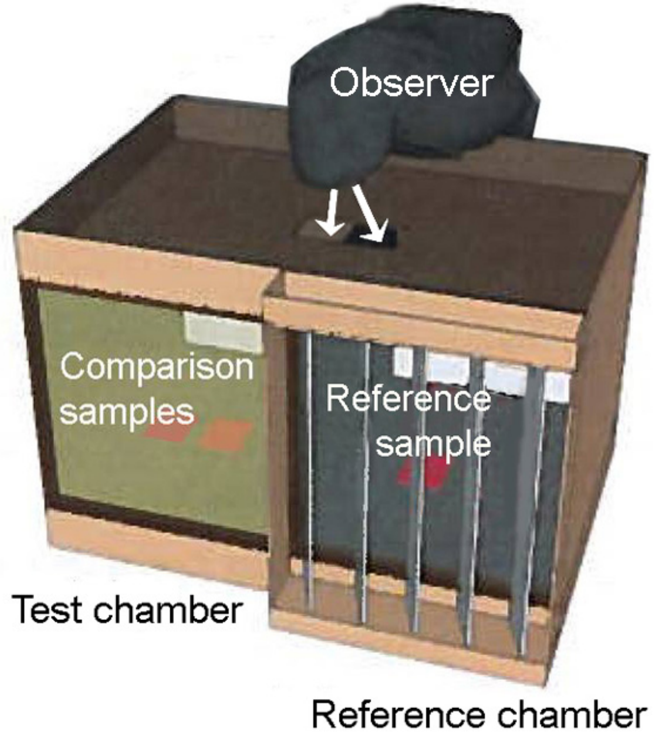


Figure 11. Drawing of the model as used in the testing of the different glazing materials.

[13] The method was partly based on Hussein 2007. Studies of colour shifts in different situations have also been carried out by Billger (1999, rooms lit with different types of artificial light), Fridell Anter (2000, facades in different natural viewing situations) and Hårleman (2007, rooms with daylight from different compass directions).

From the back we could put colour samples into the chambers. The colour samples were chosen from the NCS colour selection and measured 2 x 5 cm. Two trained colour observers served as test persons.[14] Their task was to visually assess which of a large number of comparison samples seen behind the test material that looked the same as the reference sample seen in the reference chamber.

The procedure can be compared to that which is used by an optician when testing eyeglasses. At first we put identical NCS colour samples in both chambers, and then systematically changed the samples in the second chamber until we found a match to the reference sample in the first chamber (reference chamber). Each time the test person had to choose which of two comparison samples was most similar to the reference sample. First we tested adjacent colours in the NCS circle to find a comparison sample with the same perceived hue as the reference sample, and continued until we were satisfied. To find the nuance we did the same procedure with blackness and chromaticness.

Reference samples were chosen to give a wide distribution of hues, each of them in five distinctly different nuances, and three nominally neutral grey colours.[15] The hues were selected at or near the elementary hues of NCS, with the addition of a violet hue. The reason for adding violet was that such colours typically reflect both long and short wave radiation but very little middle wave, which makes them sensitive to even small changes in spectral distribution of light.

In order to understand the rule of adaptation, the whole matching procedure was made twice for every reference sample, glass and observer, with the samples in both chambers seen against first black and then white background. Backgrounds were in both cases matte and identical for both chambers.

Transparent glass reduces the intensity of incoming light and the light transmittance of translucent materials is even less. In order to give the colour samples in both chambers the same illuminance, vertical adjustable blinds were placed in front of the chamber offering the highest light transmittance. The fronts of the two chambers were covered differently in different phases of the project. Technical details for all glasses are given in appendix 1.

YELLOW	RED	VIOLET	BLUE	GREEN	GREY
S0510-Y	S0510-R	S0510-R60B	S0510-R90B	S0510-G	S1000-N
S1020-Y	S1020-R	S1020-R60B	S1020-R90B	S1020-G	S4000-N
S6020-Y	S6020-R	S6020-R60B	S6020-R90B	S6020-G	S7000-N
S3040-Y	S3040-R	S3030-R60B	S3040-R90B	S3040-G	
S1070-Y	S1070-R	S3050-R60B	S2060-R90B	S2060-G	

Figure 12. The NCS notations for the reference samples.

[14] The observers were one architect and one interior designer. Their colour vision was tested for defects by using Farnsworth Munsell 100 Hue test. In some of the tests one more observer participated to help detect any margin of error. Independent results from each of the observers proved very coherent with the others.

[15] The nominal colour of a colour sample is that which is given by its NCS-code, e.g. 1010-R50B for a violet colour with a hue just between red and blue. Fridell Anter 2000 p. 23-26 discusses the concepts *perceived colour* and *inherent colour*. Fridell Anter 2012 suggests that the term *inherent colour* should be replaced by *nominal colour*.

Phase A. The effects of single and multilayer glazing

The aim was here to investigate the colour effects of one or more layers of glass. Here the reference chamber had no glass whereas the test chamber was covered with subsequently one, two and three layers of glass.

As single layer glass we used 6mm clear float glass (Appendix 1, glazing A2), as two layer glazing we used Pilkingtion Insulight Therm S3 (Appendix 1, glazing A3) and as three layer glazing we used the glass from Saint Gobain Bøckmann (Appendix 1, glazing A1).

Phase B. Comparison between a reference glass and different translucent materials

The aim was here to investigate the effect of translucent façade and transparent windows, simultaneously filtering daylight into a room. The question was formulated and the materials where selected according to the requirements given within the Translucent façade project, where a three-layered low-energy glass was selected as a reference glass.[16] The reference glass was placed in front of the reference chamber, and the other tested materials in front of the test chamber.

Phase C. The effects of other transparent glass materials as compared to the reference glass

The same method as for translucent façade materials was used when testing different transparent window glasses. This means that the reference glass was placed in front of the reference chamber, and the other tested materials in front of the test chamber. The totally 12 tested glasses were selected amongst energy efficient glasses available on the Norwegian market.

Phase D. Additional testing of reference glass as compared to unfiltered daylight

In the process of analysing results we found that it would have been better to test all materials with an open reference chamber. To obtain comparable data for all situations we therefore carried out one more observation series with the reference glass in front of the reference chamber and the test chamber open to unfiltered light from the artificial sky.

For all phases, the obtained observation results are presented in appendix 2.[17] The term colour shift is used for the change in perceived colour for a sample seen first in the open chamber and then in the chamber behind the tested glass. Results for colours shifts were obtained through a combination of observation results in phase D with those of phase B or C, as presented above.

The observations in the open fronted chamber give a reasonably good indication of the colours that would be perceived on the samples under normal daylight conditions – a situation similar to the standard situation in which the colour samples have been named. Thus the colour shifts from open to glass covered chambers are approximately the same as the shift from nominal colour to the colour perceived in a specific situation, an analysis method developed and used in previous colour research.[18]

[16] Saint Gobain Bøchman, CLIMATOP 2 ONE "4 ONE-12-4-12-4 ONE". Recommended by "Glass og Fasadeforbundet" as the best, most clear (untinted) energy efficient glazing for facades available. See http://www.bockmann.sggs.com/Bockmann/images/FCK/File/Norske%20produktblade%20dec%202011/Produktoversigt%20Norge.pdf for more product information, or www.glassportal.no to contact "Glass og Fasadeforbundet".

[17] NCS is presented in appendix 3.

[18] Billger 1999, Fridell Anter 2000, Hårleman 2007.

Louisiana Museum of Modern Art, Danmark

Photo: Johanna Enger

7 Results

Observations against white and black background

All glasses were tested twice, with samples seen against white and against black background, similar for both chambers. We found that the colour shifts between different situations were slightly larger when colour samples were seen against black background, as compared to white background. This result was expected for two reasons. One is the important of adaptation luminance, as shown in figure 1, page 10. The other reason is the fact that we use white – or that which can be perceived as white – as an anchor judging all other colours in our visual field. This means that if the whole scene, including white surfaces, is lit by the same light, our visual sense will dismiss the possible colouring caused by the light source.[19]

With both backgrounds, colour shifts had the same direction. As the aim was to detect patterns and tendencies rather than exact measurements of colour shifts, we decided to use only the observations against black ground for further analysis. All these are presented in appendix 2.

Observations behind one, two or three layers of glazing

No colour shifts were detected between one glass layer and a totally open front. For two glass layers, shifts occurred for a few colours, but they were very small and always in the same direction as the more obvious shifts detected behind three layers of glass. For presentation of the tested glasses, see appendix 1, glazing A1-3

Comparison between different tested materials

All the tested materials, both transparent and translucent, showed the same typical patterns for colour shifts, but the shifts appeared weaker for the translucent façade materials than for the transparent glazings. When studied in detail, the observation results indicate some small, but seemingly consistent, differences between materials. For example most tested glazings enhance the perceived greenness whereas the translucent material with Nanogel filling seems to enhance yellowness more than greenness. Another

[19] Klarén & Fridell Anter 2011.

example of a seemingly different material is one of the transparent glazings designed to "stop" the sunlight coming in through the glazing (e.g. transmits approximately 20%, in comparison to 80% for ordinary float glass. See appendix 1, glazing A6) which typically enhances blackness more than other glasses. These differences between glazings are noted in appendix 2 but not further analyzed. Thus, the tendencies presented below are, with small variations valid for all tested materials.

Colour shifts of light and dark colours

The observations show that surfaces with pale colours, which have only little blackness and are not strongly chromatic, are very liable to shifts both in hue and nuance, whereas strongly chromatic, intense colours and dark colours tend to be much more stable. Figure 13 shows the nuance area where one can expect clear colour shifts. In the cases when also the darker and/or stronger nuances were affected by the glass, the shift was typically in the same direction as for the lighter colours, but not as large.

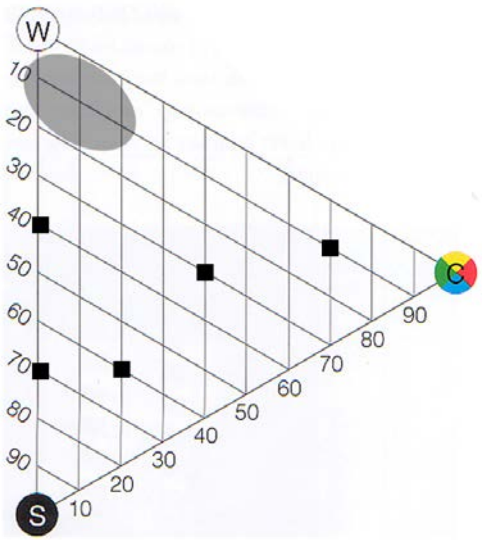


Figure 13. Approximate nuance area where the tested colours proved sensitive to hue shift caused by glazings (shaded area), shown in the NCS triangle.The points show tested nuances that, for most hues, did not prove sensitive to such shifts.

Typical pattern for hue shifts

Figure 14 shows the principle of hue shifts for pale and subdued colour samples seen behind the tested glazings, in comparison with how they look in unfiltered daylight. When the nominal hue has a dominating blueness and/or greenness (hues between approximately R50B and G50Y), there is a tendency for a hue shift clockwise in the NCS model. Colours with nominal hues dominated by a redness and/or yellowness instead tend to be shifted counter clockwise in the model. These tendencies are the same for both transparent and translucent glazings, but they are stronger for the tested transparent glazings.

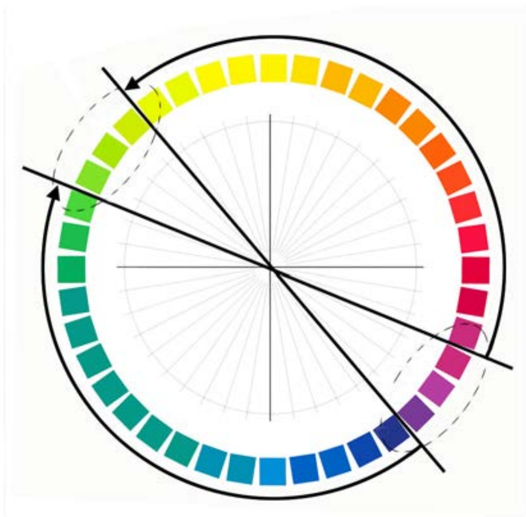


Figure 14. Typical pattern for hue shifts shown in the NCS colour circle.
The arrows show the direction of the colour shift from the colour sample seen in daylight to the same colour sample as seen behind the test glazings. The figure shows only the direction, not the size of the colour shift. The lines through the circle points to the violet and yellow-green "breaking points" for the colour shifts. Breaking points are not exactly the same for all tested materials. Within the oval, stippled areas the colour-shifts are therefore extremely difficult to predict.

Typical patterns for nuance shifts

Nuance shifts varied between different areas of the colour circle. Pale samples with nominally yellowish or greenish hues tended to get increased chromaticness and reduced blackness when seen behind glazing. This was true also for light grey samples that assumed an obvious green-yellow hue when seen behind the glass.

For samples with their nominal hue between red and blue the opposite was found and chromaticness was typically reduced. The very lightest nominally blue sample instead assumed a distinct chromaticness in a hue between yellow and green.
All these shifts seem logical, given the fact that all glazings had an obvious yellowish-green colour and thus functioned as yellow-green filters for daylight.

Figures 15 - 19 show the principles of colour shifts for pale and subdued colours seen behind the tested transparent window glass (arrow tip) compared to unfiltered daylight (the origin of the arrow). Shifts behind translucent glazings show similar tendencies.

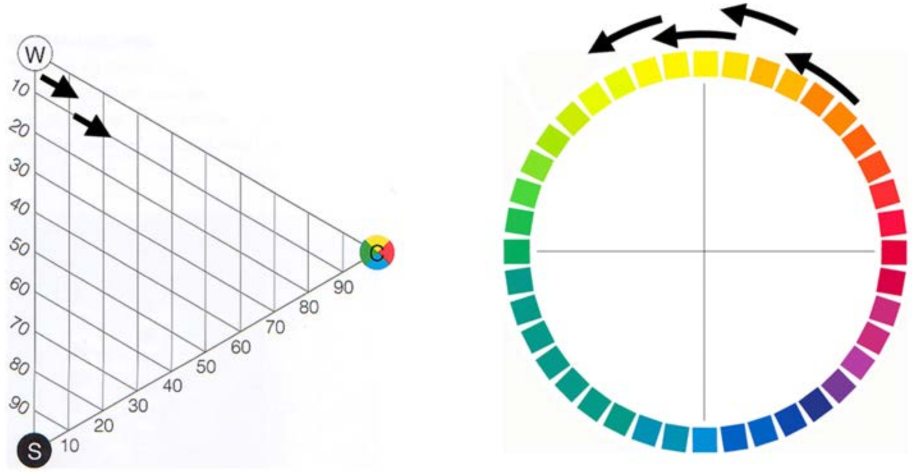
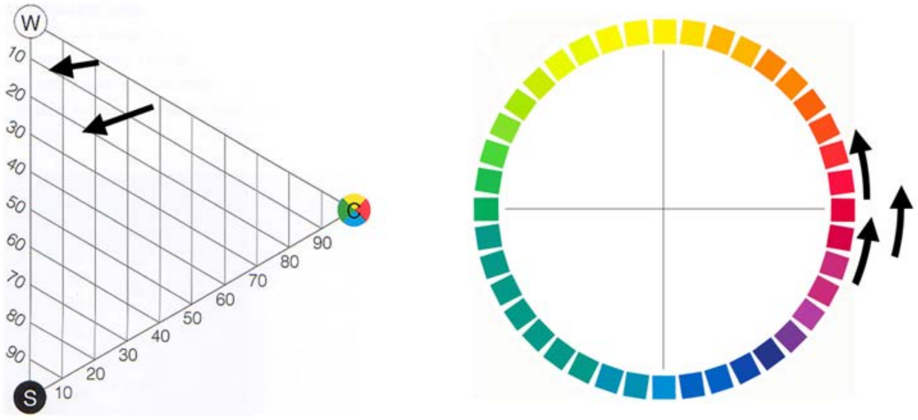
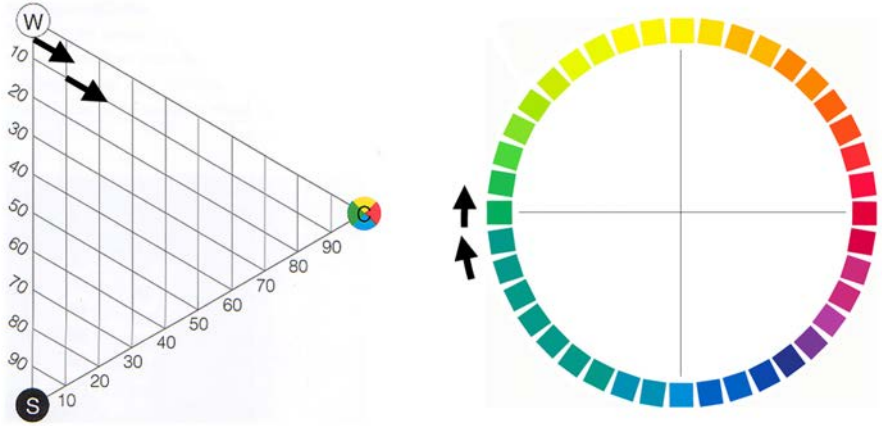
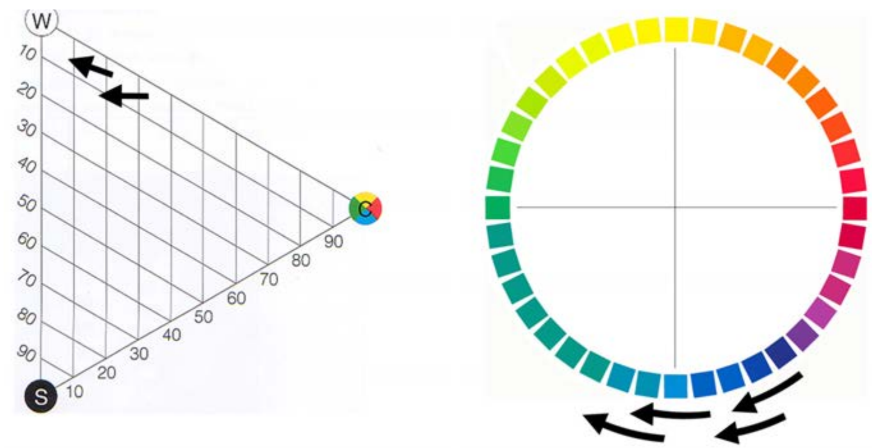


Figure 15. YELLOWISH COLOURS: Nuances become more chromatic (stronger colour). Hues shifts from red – towards green.







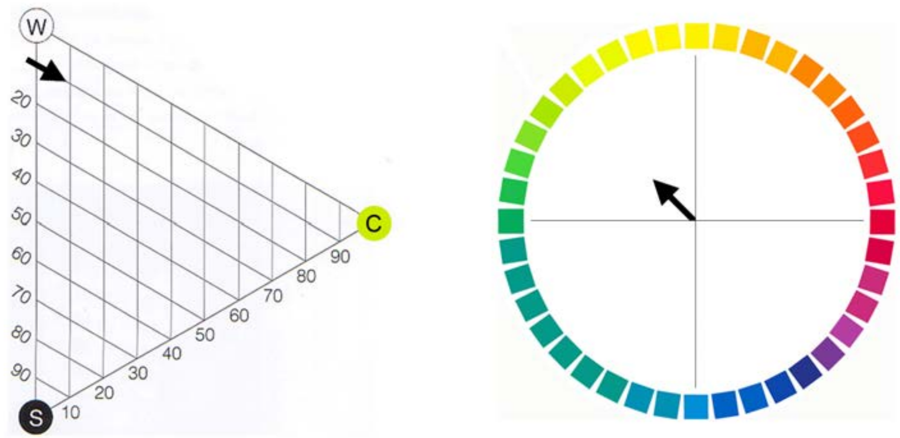


Figure 16. REDDISH COLOURS: Nuances become more dark and less chromatic (more muted colour). Hues shift from blue – towards yellow.

Figure 17. BLUEISH COLOURS: Nuances become less chromatic (more pale and subdued colour). Hues shifts from red – towards green.

Figure 18. GREENISH COLOURS: Nuances become more chromatic (stronger colour). Hues shift from blue – towards yellow.

Figure 19. GREY COLOURS: Nominal greys acquire a yellowish greenish hue.

8 Conclusions – colour shifts behind glazing

Results shows that the tested transparent glazings tends to give quite obvious strong colour distortions compared to the open chamber (open window), which let in unfiltered daylight. Results for the translucent material show a similar pattern, although not as strong as for the transparent glass.

However, these results were reached in a specific laboratory situation and are fully valid only in similar circumstances as in the test. There, tested colour surfaces lit with different filtered daylight where observed instantly after each other without any mixing of light from the two windows. The situation could be compared to a real life situation with a transarent window in a translucent façade or with one window in a row opened to let in unfiltered daylight. In such situations there are zones dominated by light from one or the other saylight opening, but contrary to the experiment situation the borders between these zones will be more or less diffuse.

Another important question is to what extent these shifts would occur also in real buildings using these materials. The most important difference between the test situation and a complex real life situation is the adaptation. In the test, the observer was adapted to artificial daylight of a certain intensity, and was given the task to match samples seen in chambers where the spectral distribution of light was altered by the tested glass materials. Also the intensity of light was altered, both by the glass materials and by the blinds which were used also outside the open chamber front.

In a normal situation you are adapted to the existing light, and the colour constancy will make you perceive the colour of a surface more or less the same as in another light situation.[20] This means that you would not perceive these strong colour shifts in a room totally lit through the tested glass material. The existence of white, or near white, surfaces in the room would contribute to adaptation and colour constancy, as opposed to the totally black surroundings used in the test. On the other hand the colour constancy is considerably weaker in light very different from the natural light and its continuous spectral distribution. Thus, the rule of adaptation and colour constancy in situations other than the tested ones cannot easily be presupposed.

[20] Adaption and colour constancy are discussed above in section 2

Still the tests give ground for conclusions that are essential for the perception of colours and colour combinations in real rooms. The range of colours that can be perceived in the interior will be slightly decreased, which will make the totality look a bit more dull than when lit though an open window.[21] Also, the balance and contrasts between different colours will be affected.

In some colour areas the contrasts between different coloured surfaces will change drastically when seen behind the glass as compared to what can be observed in unfiltered daylight. Pale coloured surfaces in the greenish-yellowish area are likely to become more similar behind the glass, as all colours, including the nominally neutral grey, will here be strongly tinted by the yellowish green of the glass. For pale reddish-bluish colours the contrary will occur. Violet colours nominally closer to red will visually be pushed towards red, whereas violet colours nominally closer to blue will be pushed towards blue. At the same time, all pale colours within the reddish-bluish area will lose much of their intensity.

If we have in mind that the darker and more intense colours are much less affected by the glass, these things can mean that a colour scheme based on hue similarities or on subtle colour differences will become changed and even ruined if the glass is not considered throughout the process of colour design. Here we must, however, bear in mind that the contrasts in these examples tend to be further enhanced by simultaneous contrast effects between the samples placed together on a flat surface and would not be as obvious if the coloured surfaces were combined in three dimensions.[22]

Notes on colour contrast

To understand not only the shifts of separate colours, but also the glazings' effects on perceived colour contrasts and relationships, we arranged combinations of colour samples with nominal similarity in hue or in nuance, and viewed them in the open reference chamber and behind the three layered, reference glazing (see appendix 1, glass A3). This was compared and commented and also photographed.

The pictures were taken from the top of the model and down into the chambers. The pictures on the left are of the reference samples in the reference chamber without any glazing in front, and the pictures on the right are of the reference samples in the test chamber with the reference glazing in front. The colour samples are in the size A6. The pictures were taken with an ordinary digital camera, and do not give an exact colour rendering, and the digital reproduction on a screen or in a print is not perfect. Still the pictures illustrate how differently the same coloured surfaces can look when seen in an interior with or without a specific glazing.
The notes are describing the difference in the contrast in colours when seen behind the reference glazing as compared to when seen without any glazing. They were noted by the observers when comparing the samples in the same conditions as when tested.

YELLOW	RED	VIOLET	BLUE	GREEN	GREY
S0510-Y	S0510-R	S0510-R60B	S0510-R90B	S0510-G	S1000-N
S1020-Y	S1020-R	S1020-R60B	S1020-R90B	S1020-G	S4000-N
S6020-Y	S6020-R	S6020-R60B	S6020-R90B	S6020-G	S7000-N
S3040-Y	S3040-R	S3030-R60B	S3040-R90B	S3040-G	
S1070-Y	S1070-R	S3050-R60B	S2060-R90B	S2060-G	

Figure 20. The reference samples in the experiment. The NCS notations in the red frame show the colour samples compared and commented in figure 21. The colour samples in figure 22-26 are for all nuances in one hue, for example all five nunaces of yellow (Y).

[21] The importance of the contrast range is discussed in Fridell Anter 2011 p 38-40
[22] See Billger 1999 for studies on the interreflections between coloured surfaces in enclosed spaces.

The nuance 1020- in all hues + 2000-N, which is the nominally neutral grey with its lightness most similar to the others
When seen behind the reference glazing, the samples are not similar in nuance.
The blue and violet samples are more blackish and less chromatic than the others.
The red sample has got a slightly increased blackness.
The yellow and green samples are less blackish and more chromatic than the rest.
The nominally neutral grey has a clearly perceived greenish-yellow hue.
When you compare the two samples that are perceived the least chromatic, we see that the nominally violet (in the middle) is perceived as greyish blue and the nominally grey sample is perceived as a greenish yellow and more chromatic than the nominally violet.

Without glazing With glazing A3

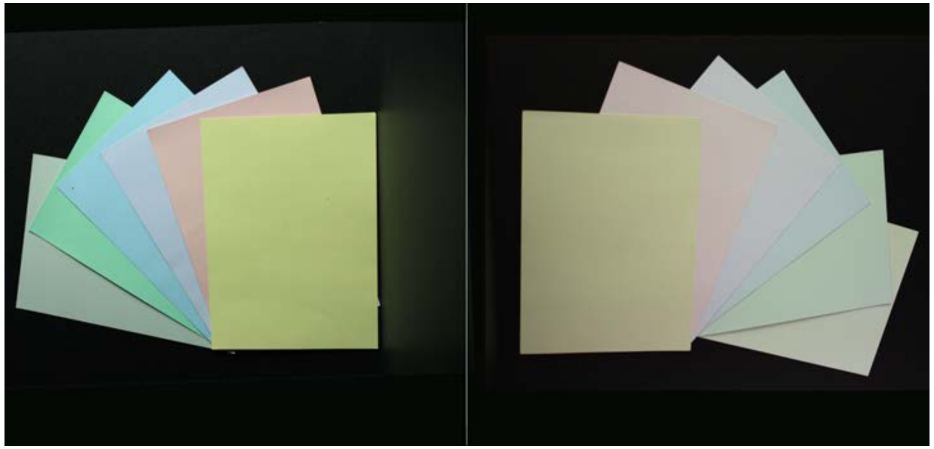


Figure 21. Order from the middle: -Y, -R, -R60B, -R90B, -G and -N.

The colours in the scale are not similar in perceived hue when seen behind glazing.
The palest nuance is almost white, with a slightly perceivable yellowish hue.
The three middle nuances are greenish yellow.
The darkest nuance has no noticeable greenness.
This means that the three middle samples are greenish, but not the lightest and darkest one.

Yellow (Y) – in all nuances
Without glazing With glazing A3

Figure 22. Order from the middle: 1070-Y, 6020-Y, 3040-Y, 1020-Y and 0510-Y.

The colours in the scale are not similar in perceived hue when seen behind glazing.
The palest nuance could be called "peach", with a hue more yellow than red.
The darker of the two pale colours are much redder in its hue.
The most chromatic nuance is even less red than the palest, and may even have a certain blueness in the hue.

Red (R) – in all nuances

Without glazing | With glazing A3

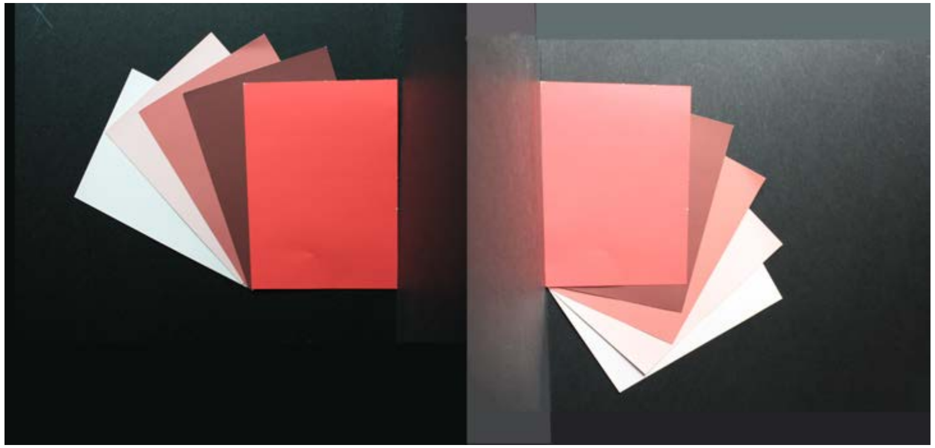


Figure 23. Order from the middle: 1070-R, 6020-R, 3040-R, 1020-R and 0510-R.

The colours in the scale are not similar in perceived hue when seen behind glazing.
The palest nuance is greenish-yellow, and does not seem to belong to this colour scale at all.
The darker of the two pale colours looks almost neutral or perhaps with just a very little hint of a violet hue.
The darkest nuance does not seem to belong to this colour scale either, but unlike the palest colour it has shifted in the direction from red towards blue.
All but the palest sample show relationship in hue, but no complete hue similarity.

Violet (R60B) – in all nuances

Without glazing | With glazing A3

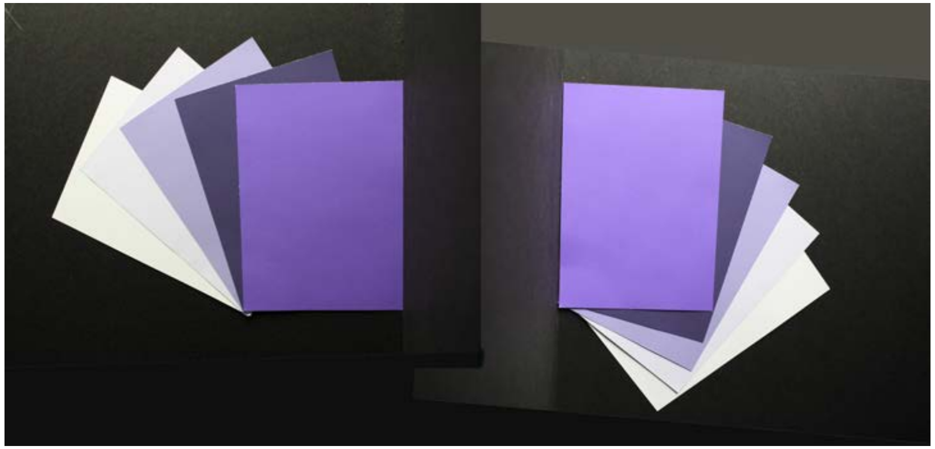


Figure 24. Order from the middle: 3050-R60B, 6020-R60B, 3030-R60B, 1020-R60B and 0510-R60B.

The colours in the scale are not similar in perceived hue when seen behind glazing. The palest nuance is yellowish, like "eggshell".
The darker of the two pale colours is greenish-blue, and also the next in lightness has got a hint of perceived green.
The most chromatic of the nuances is perceived as a pure blue, i.e. without the hint of redness that is nominally there.

Blue (R90B) – in all nuances

Without glazing | With glazing A3

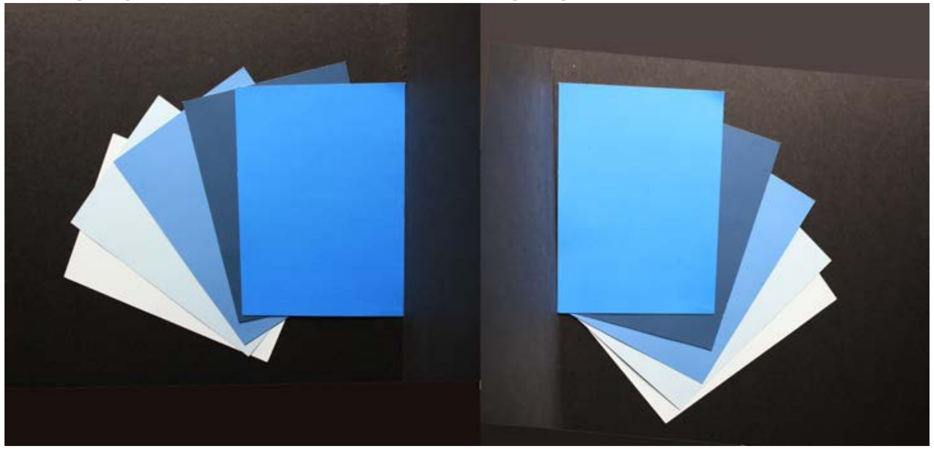


Figure 25. Order from the middle: 2060-R90B, 6020-R90B, 3040-R90B, 1020-R90B and 0510-R90B.

The colours in the scale are similar in perceived hue when seen behind glazing, contrary to all the other tested samples. All of them are clearly green and have a perceived "freshness".
Although there are small shifts in both nuance and hue, green is the only hue that does not look duller when seen behind the glazing.

Green (G) – in all nuances

Without glazing | With glazing A3

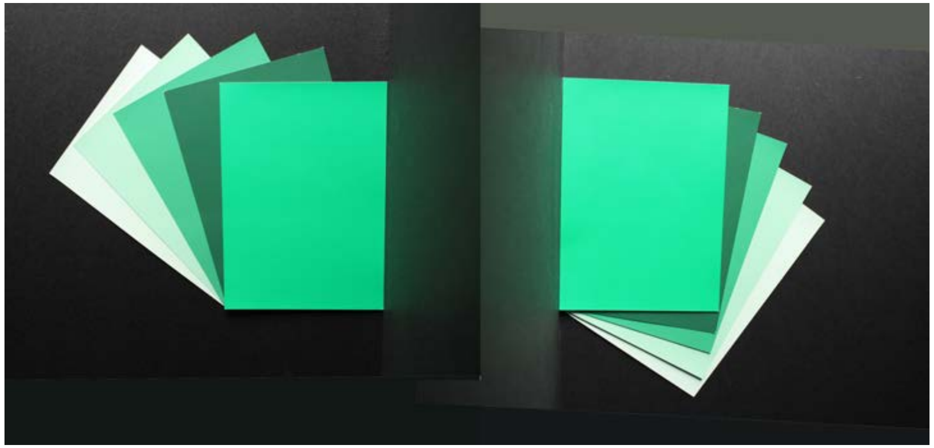


Figure 26. Order from the middle: 2060-G, 6020-G, 3040-G, 1020-G and 0510-G.

The perceived colour scale has a good similarity of hue, but the hue is no longer neutral but yellowish green.

Grey (N) – in all nuances
Without glazing With glazing A3

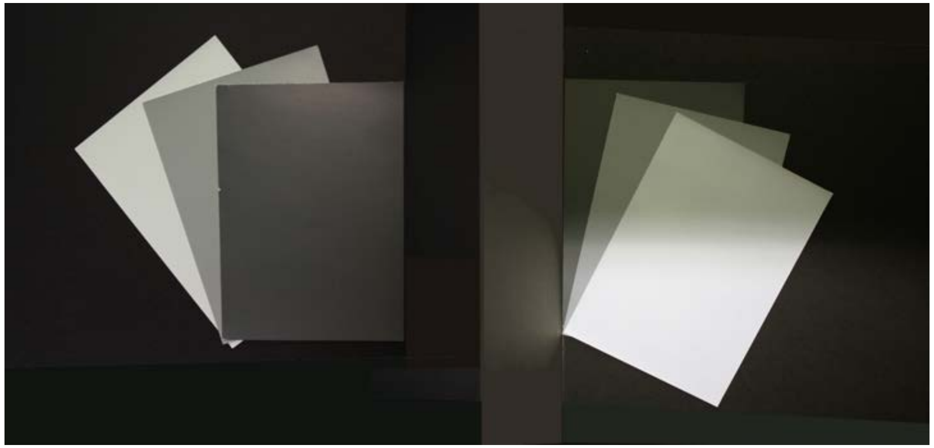


Figure 26. Order from the middle: 2060-G, 6020-G, 3040-G, 1020-G and 0510-G.

Rooms with different light situations

When different light situations are combined in the same room, this will disrupt the adaptation and coloured surfaces might look very different in different parts of the room. Some examples:

If one window - in a row of windows using energy glass - is to be opened and lets in unfiltered daylight, the colours will be perceived dramatically differently in the two situations. If we are adapted to the greenish light, the unfiltered daylight will be seen as reddish blue and also more intense and bright. The daylight will reveal colour contrasts that can hardly be seen when the windows are closed, and certain colours in the room will change character dramatically.

If transparent windows are placed in a translucent facade, the light coming in through the windows will be perceived more intense and slightly greener than the dim, diffuse light let in through the translucent material. How this will affect our colour perception depends on how we are adapted to the whole, and this will in turn depend on the location and the relative size of the two materials.

In real buildings there are, in addition, a variety of different artificial light sources with different light colours and different colour rendering capacities. Their interaction with the translucent or transparent façade materials has not been examined or discussed within this project. We can, however, see a great need for further studies of the interaction between different light transmitting materials and light sources, including external light sources that lights up the interior when it is dark outside.

"…a colour scheme based on likeness in hue or subtle colour differences will change, and might even be destroyed, if one does not take into account the glass used in windows or the façade throughout the design process."

9 Method evaluation

The project is a pilot study with one main objective to develop methods for the analysis of colour shifts in rooms behind different kinds of glazings. In our evaluation of the tested method we can conclude that it can be used to give reliable results, but that it needs to be improved in a number of ways.

The artificial sky

The artificial sky used in the project provides a substitute for daylight that can be used to find general tendencies in colour distortion caused by glazing. For more specific conclusions there is, however, a need for further comparisons with real daylight situations. One way to do this could be to place the test model outside in number of daylight situations and test a number of samples and glasses in the same way as under the artificial sky.

The use of reference glass and reference samples

In an early stage of the project it was decided to use one glass as a reference for all the others. We can conclude that it would have been better to do all tests with an "open window" as a reference. To give test results that can be comprehensively analyzed and presented, and compared with results from other colour research, the question should have been posed: This sample, which in daylight is perceived in a way that nearly coincides with its NCS code, how is it perceived behind the glass? In our study, we had to use several subsequent steps to be able to answer that question. The pre-decided test sample should instead have been placed behind the test glass and the search for a matching sample should have been done in the chamber without front glass.

The observers and observation procedure

The observations were made by observers who are well trained to judge colours and who know the NCS system well. Some of the tests were in addition made with a less experienced observer. The correlation between independent matchings' made by different observers was very high, see figure 28, and also repeated independent matchings' with the same observer gave very coherent results. In some colour areas, especially with low chromaticness, it was, however, a difficult and tiering procedure to decide which of a number of very similar samples that was the best match.

We found that it was most efficient and reliable to work two well-trained persons together and change the roles of selecting and observing samples. Initially the observer was given the choice between pairs of samples with where the one considered the worst match was exchanged before the next observation. When we had found a number of samples that gave a rather good match regarding hue and nuance the two persons changed roles. In the last step we often used NCS categories to describe the observed differences and agree on the best match.

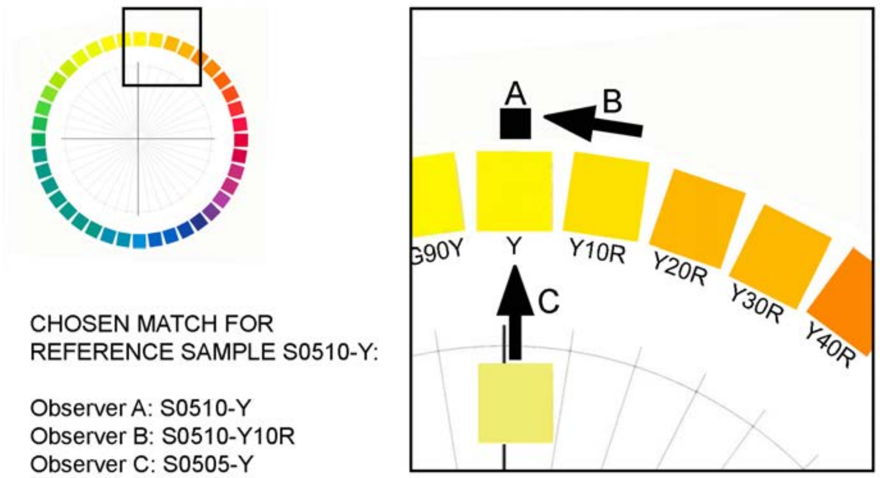


Figure 28. Example of deviation in the correlation between independent matchings' by the observers. The results were very coherent for all hues and nuances, but small differences could be detected for some of the pale colours.

The selection of NCS samples

The NCS selection is not equally distributed throughout the colour space. Also in colour areas with dense representation of samples it was sometimes impossible to find a really good match. We solved this problem by choosing one of a few very similar samples. When analyzing the results we find that it would have been better to use interpolations between NCS samples, in order to detect also small colour shifts.

The size of test samples

For economic reasons we used test samples from NCS index, sized 2cm x 5cm, and comparison samples from NCS box (A9), covered with a black frame to give the same size as the test sample. It is, however, much easier to match larger colour samples, and in future studies A9 samples should be used throughout.

The background colours

The effect of white and black backgrounds on adaptation should be further analyzed.

Interpolation between NCS samples - some examples:

Hue: You choose between 3010-B70G and 3010-B90G. After interpolation you can note for example 3010-B80G, or maybe 3010-B78G (if B70G is considered a slightly better choice)

Nuance: You choose between 3020-Y80R, 3030-Y80R and 2030-Y80R, and none of them is perfect. After interpolation you can note for example 2828-Y80R

Totality: You select 2020-Y20R as the nearest sample, but want it a bit more chromatic, a bit more whiteish and a bit more reddish. This can be noted as for example 1522-Y22R.

Note that the interpolations are not exact. For example you cannot judge it you shall choose 1522-Y22R or 1623-Y23R. Still they tell both which is the nearest sample (in both cases 2020-Y20R) and the direction of deviation from this sample.

10 Suggestions for further research

Daylight transmitted through windows is seldom the only light source in a room. Therefore it would be valuable to study how daylight interacts with different artificial light sources regarding perception of colours. Initially, this would include further methodological work.
Full scale studies in existing buildings could add very much to the understanding of glazing´s colour effects. It could be expected that some of the colour distortions that we have found would be less obvious or even eliminated in situations where the observer is exposed to more complex scenes which offer additional visual references. On the other hand, real life situations most often offer a mixture of light sources, including artificial light sources, daylight through different glazings and through open windows. This calls for studies in functioning real life spaces, possibly involving people who work in or otherwise use the space.

In interiors with minimum two qualitatively different light sources situated at a large distance, minimum two zones will be created, one illuminated by the first light source, another by the second light source. In addition an interim zone will be created with the light from both sources. It would be valuable to examine the impact of transition between the two zones (abrupt versus smooth) on the colour perception in the room.

Colour shifts caused by glazing that change the spectral distribution of daylight could possibly be investigated with spectrophotometric and/or colorimetric methods. One way could be to measure the tristimulus values of light behind the glazing: the light directly transmitted through glazing and the light reflected from the colour samples. An even simpler way could be to use the manufacturer's data for the glass material as a base for calculating colour distortions. To investigate the potential of such methods, the results of measurements and calculations could be compared to visual assessments of the same combinations of light, glass and coloured materials. On this basis a more useful measure of glazing dependent colour shift than the Colour Rendering Index (Ra) could be developed.

There is a need for a simple method for showing the essential colour distorting properties of transparent and translucent glazing materials. Such a system, numerical and/or graphical, could be developed with use of the findings from this and forthcoming studies. Its usefulness could be tested with the help of professionals within glazing industry, architects and others involved in the development and choice of glazing products.

11 References

Arsenault, H., Hébert, M. & Dubois, M.-C. (2012). Effects of glazing colour type on perception of daylight quality, arousal, and switch-on patterns of electric light in office rooms. *Building and Environment 56, pp 223-231*

Billger, M. (1999) *Colour in Enclosed Space. Observation of Colour Phenomena and Development of Methods for Identification of Colour Appearance in Rooms.* Göteborg: Chalmers University of Technology, Architecture (diss.)

Chain, C., Dumortier, M. & Fontoynont, M. (2001). Consideration of daylight's colour. *Energy and Buildings 33, pp 193-198*

Fridell Anter, K. (2000) *What colour is the red house? Perceived colour of painted facades.* Stockholm: KTH Architecture (diss.)

Fridell Anter, K. (2011) *OPTIMA*. 'Metodstudie om färg, ljus och rumsupplevelse.' *SYN-TES rapport 1*, www.konstfack.se/SYN-TES.

Fridell Anter, K (2012)'Light and Colour: Concepts and their use'. In H. Arnkil (ed.): *Colour and Light - Concepts and Confusions*. Helsinki: Aalto University School of Arts, Architecture and Design. Swedish version in SYN-TES rapport 3, www.konstfack.se/SYN-TES.

Hussein, I. (2007) *Hur olika glas och ljus samverkar ur färgåtergivningssynpunkt.* Stockholm: KTH Teknik och hälsa Report 2005:178.

Hård, A. (1995). 'Det naturliga färgsystemet.' I Hård A. & Å. Svedmyr. *Färgsystemet NCS. Tanke, tillkomst, tillämpning. Färgantologi bok 1 sid 53-125.* Stockholm: Byggforskingsrådet.

Hårleman, M. (2007) *Daylight Influence On Colour Design. Empirical Study On Perceived Colour.* Stockholm: Axl Books (diss.)

Häggström, C. & Fridell Anter, K. *Ljusförstärkande färgsättning av rum.* SYN-TES rapport 4, www.konstfack.se/SYN-TES.

ISO/CIE Standard (2004). *Spatial distribution of daylight - CIE standard general sky.* ISO 15469/CIE S 011/E, http://www.cie.co.at/index.php?i_ca_id=476.

Klarén U. & Fridell Anter K. (2009) *Så vitt vi vet. Nominellt kulörta färger som vithetsankare.* http://www.konstfack.se/sv/Forskning/Konstnarligt-utvecklingsarbete-KU/KU-projekt/Avslutade-KU-projekt-2009/.

Klarén U. & Fridell Anter K. (2011). 'Colour and light in space: Dynamic adaptation and spatial understanding.' In V. M. Schindler & S. Cuber (eds). , 2011. *AIC 2011, Interaction of Colour & Light in the Arts and Sciences, Midterm Meeting of the International Color Association, Zurich, Switzerland, 7–10 June 2011: Conference Proceedings*, pp 485-488. Eds: Zürich: pro/colore

Lyskultur (2009). *Lysboken*, Lyskulturs publikasjon 1A, http://www.lyskultur.no/index.php?site=lyskultur/522&cmd=readmore&id=10491.

Matusiak, B & Arnesen, H (2005). *The limits of the mirror box concept as an overcast sky simulator.* The Lighting Research & Technology. December 2005 vol. 37 no. 4 313-327 http://lrt.sagepub.com/content/37/4/313

Norges Forskningsråd (2012). *Veileder for bruk av translusente fasader.* Translusente fasader, prosjektnummer 200557 (in press), http://www.forskningsradet.no.

Valberg, A. (2005) *Light Vision Color*, Chichester: John Wiley & Sons, Ltd.

Saint Gobain Bøchman. CLIMATOP 2 ONE "4 ONE-12-4-12-4 ONE". http://www.bockmann.sggs.com/Bockmann/images/FCK/File/Norske%20produktblade%20dec%202011/Produktoversigt%20Norge.pdf

Glass og Fasadeforeningen www.glassportal.no

1. Specifications of tested glazings

Specifications are given from outside (exterior) to inside (interior). Thicknesses of (float) glass are given in millimeters (mm). Light transmitted/Heat transmitted in percentage (marked *).

A. Transparent glazings

A1. Clear, transparent float glass from Tore Ligaard (single glass without frame) Clear, transparent float glass, 6mm

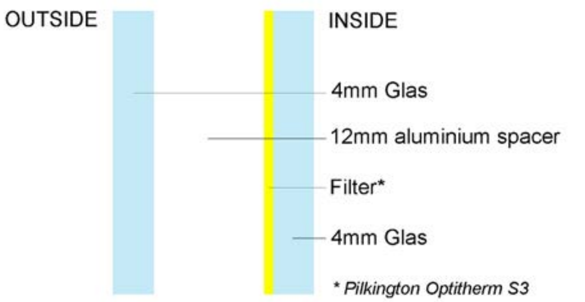
A2. Pilkington Insuligt Therm S3(two layer glazing) Insulight Therm: Optifloat Clear 4mm (glass) - 12mm spacer - Optitherm S3 4mm (energy glass with coating)

A3. Reference glazing – Saint-Gobain Bøckmann (three layer glazing). CLIMATOP 2 ONE "4 ONE-12-4-12-4 ONE". 4mm glass with 1.coating – 12mm spacer – 4mm glass – 12mm spacer – 4mm glass with 2.coating.

A4. Pilkington Insulight Therm S1 (two layer glazing) Insulight Therm: Optifloat Clear 4mm (glass) - 12mm spacer - Optitherm S1 4mm (energy glass with coating)

A5. Pilkington Insulight Therm Activ (two layer glazing)
Insulight Activ: Activ Clear 4mm (glass with 1.coating) - 12mm spacer - Optitherm S1 4mm (glass with 2. coating)

A6. Glassfabrikken, Solstopp (two layer glazing).Solstopp 4: 6mm Brilliant 30/17 (glass with 1. coating) – 12mm spacer – 4mm Float (energy glass with 2. coating).



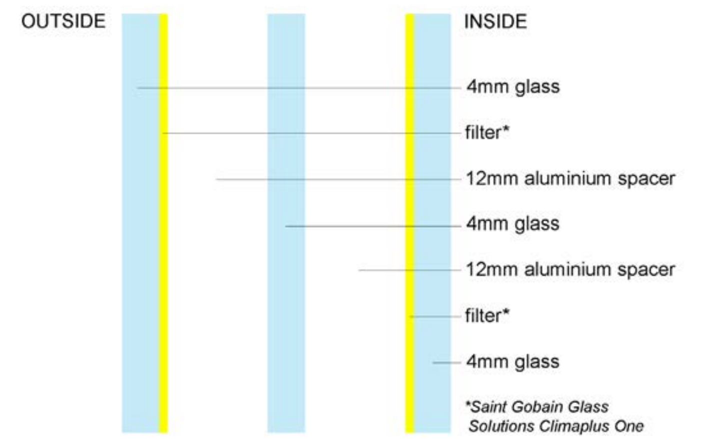
A7. CG Glass Energy Super (three layer glazing) 4mm Energy Super (glass with 1. coating) – 12mm spacer – 4mm Float Clear (glass) – 12mm spacer - 4mm Energy Super (energy glass with 2. coating)

A8. CG Glass Stopray Energy (three layer glazing) 6mm Stopray Energy 71/39 (glass with 1. Coating) – 12mm spacer – 4mm Float Clear (glass) – 12mm spacer – 4mm Energy Super (energy glass with 2. coating).

A9. CG Glass Stopray Safir (three layer glazing) 6mm Stopray Safir 61/32 (glass with 1. Coating) – 12mm spacer – 4mm Float Clear (glass) – 12mm spacer – 4mm Energy Super (energy glass with 2. coating).

A10. CG Glass Stopray Vision (three layer glazing)6mm Stopray Vision 50/12 (glass with 1. Coating) – 12mm spacer – 4mm Float Clear (glass) – 12mm spacer – 4mm Energy Super (energy glass with 2. coating).

A11. Saint Gobain Emmaboda Glas Cool Lite SKN 174 (three layer glazing) 6mm Cool-Lite SKN 174 (glass with 1. coating) – 12mm spacer – 4mm Float (glass) – 12mm spacer – 4mm Planitherm Ultra (energy glass with 2. coating).



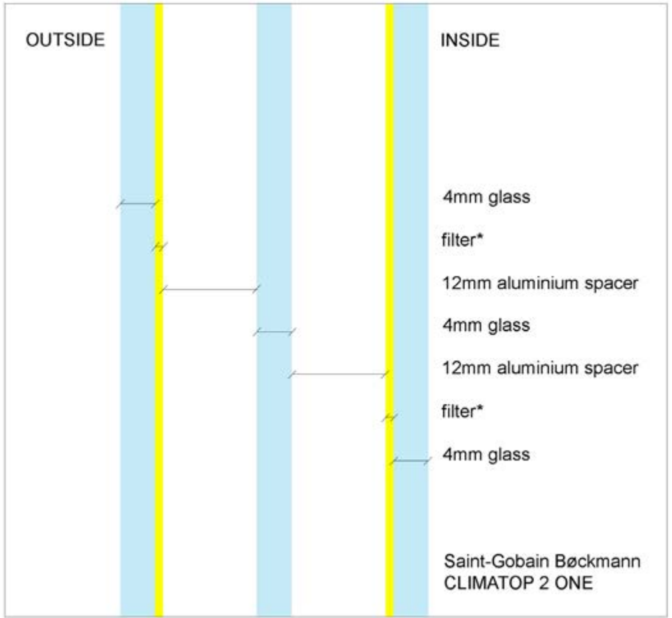
A12. Saint Gobain Emmaboda Glas Cool Lite Xtreme (three layer glazing) 6mm Cool-Lite Xtreme 60/28 (glass with 1. coating) – 12mm spacer – 4mm Float (glass) – 12mm spacer – 4mm Planitherm Ultra (energy glass with 2. coating).

A13. Saint Gobain Emmaboda Glas Cool Lite SKN 165 (three layer glazing) 6mm Cool-Lite 165 (glass with 1. coating) – 12mm spacer – 4mm Float (glass) – 12mm spacer – 4mm Planitherm Ultra (energy glass with 2. coating).

A14. Saint Gobain Emmaboda Glas Cool Lite SKN 154 (three layer glazing) 6mm Cool-Lite 154 (glass with 1. coating) – 12mm spacer – 4mm Float (glass) – 12mm spacer – 4mm Planitherm Ultra (energy glass with 2. coating).

B. Translucent glazings

B1. "Nanogel" from Okalux (double glazing with Nanogel filling)
B2. "HeatMirror" (double glazing with HeatMirror film)



2. Commented test results for tested glazings

The procedure of the testing is explained in chapter 6. Research Method, and further discussed in chapter 7. Results.

Symbols

RC Reference chamber
TC Test chamber
0 No glazing in front of reference chamber/open window.
R Reference glass in front of the reference chamber (A3).

RC	TC*	TC – name of tested glazing	Page
0	A1	Clear, transparent float glass. Single glass without frame	45
0	A2	Pilkington Insulight Therm S3	46
0	A3	Saint-Gobain Bøckmann CLIMATOP 2 ONE - Reference glass	47
0	B1	Nanogel	49
R	A2	Pilkington Insulight Therm S3	50
R	A4	Pilkington Insulight Therm S1	51
R	A5	Pilkington Insulight Therm Activ	52
R	A6	Glassfabrikken Solstoppglass 30/17	53
R	A7	CG Glass Energy Super	54
R	A8	CG Glass Stopray Energy 71/39	55
R	A9	CG Glass Stopray Safir 61/32	56
R	A10	CG Glass Stopray Vision 50/12	57
R	A11	Saint-Gobain Emmaboda Glas Cool Lite SKN 174	58
R	A12	Saint-Gobain Emmaboda Glas Cool Lite Xtreme	59
R	A13	Saint-Gobain Emmaboda Glas Cool Lite SKN 165	60
R	A14	Saint-Gobain Emmaboda Glas Cool Lite SKN 154	61
R	B1	Nanogel	62
R	B2	HeatMirror	63

* A1-A14 and B1-2: reference to Appenix 1.

Tables pages 44 – 63

The observers task was to visually assess which comparison samples matched the test sample, finding first the hue, then blackness and chromaticness. Example of testing procedure:

Reference sample	Hue	Blackness	Chrom.	Matching sample	Notes**
S 0510-Y	S 0510-Y	S 0510-Y	S 0510-Y	S 0510-Y10R	Less redness
S 1020-Y	S 1020-Y	S 1020-Y	S 1020-Y	S 1020-Y10R	Less redness
S 6020-Y	S 6020-Y	S 6020-Y	S 6020-Y	S 6020-Y	-
S 3040-Y	S 3040-Y	S 3040-Y	S 3040-Y	S 3040-Y	-
S 1070-Y	S 1070-Y	S 1070-Y	S 1070-Y	S 1070-Y	-

** If the observer couldn't find a matching sample that completely matched, the nearest matching sample was selected, and the difference was commented in "Notes". In this example, the nearest matching sample would need a little less redness to make a complete match with the reference sample.

In the appendix we have only included the NCS notation for the reference sample and the matching sample. If the matching sample differs from the reference sample, the difference is marked and the changes in hue and nuance are commented. Example:

Reference sample	Matching sample
S 0510-Y	**S 0510-Y10R**
S 1020-Y	**S 1020-Y10R**
S 6020-Y	S 6020-Y
S 3040-Y	S 3040-Y
S 1070-Y	S 1070-Y

No glazing versus three layer glass/reference glazing and no glazing versus nanogel is commented more thoroughly as these offer the most significant changes, see page 44 -63.

Example of light level with or without the adjustable blinds

0-1: No glazing versus one glass.
Lux – black background: Without glass 510/with blinds 378. Test glass 368.
Lux – white background: Without glass 513/with blinds. 379. Test glass 380.
0-2: No glazing versus two layers of glass.
Lux – black background: Without glass 510/with blinds 379. Test glass 373.
Lux – white background: Without glass 514/with blinds 454. Test glass 445.
0-3: No glazing versus three layers of glass/reference glass.
Lux – black background: Without glass 511/with blinds 245. Test glass 249.
Lux – white background: Without glass 515/with blinds 261. Test glass 262.
0-Nanogel: No glazing versus Nanogel.
Lux – black background: Without glass 510/with blinds 104. Test glass 94.

The same procedure of adjusting blinds was carried out for all glazings, so that the light level was approximately the same in both chambers when matching colour samples.

0-A1: No glazing versus Clear, transparent float glass. Single glass without frame.

Black background
YELLOW:

Reference sample	Matching sample
S 0510-Y	S 0510-Y
S 1020-Y	S 1020-Y
S 6020-Y	S 6020-Y
S 3040-Y	S 3040-Y
S 1070-Y	S 1070-Y

White background
YELLOW:

Reference sample	Matching sample
S 0510-Y	S 0510-Y
S 1020-Y	S 1020-Y
S 6020-Y	S 6020-Y
S 3040-Y	S 3040-Y
S 1070-Y	S 1070-Y

Black background
RED:

Reference sample	Matching sample
S 0510-R	S 0510-R
S 1020-R	S 1020-R
S 6020-R	S 6020-R
S 3040-R	S 3040-R
S 1070-R	S 1070-R

White background
RED:

Reference sample	Matching sample
S 0510-R	S 0510-R
S 1020-R	S 1020-R
S 6020-R	S 6020-R
S 3040-R	S 3040-R
S 1070-R	S 1070-R

Black background
VIOLET:

Reference sample	Matching sample
S 0510-R60B	S 0510-R60B
S 1020-R60B	S 1020-R60B
S 6020-R60B	S 6020-R60B
S 3030-R60B	S 3030-R60B
S 3050-R60B	S 3050-R60B

White background
VIOLET:

Reference sample	Matching sample
S 0510-R60B	S 0510-R60B
S 1020-R60B	S 1020-R60B
S 6020-R60B	S 6020-R60B
S 3030-R60B	S 3030-R60B
S 3050-R60B	S 3050-R60B

Black background
BLUE:

Reference sample	Matching sample
S 0510-R90B	S 0510-R90B
S 1020-R90B	S 1020-R90B
S 6020-R90B	S 6020-R90B
S 3040-R90B	S 3040-R90B
S 2060-R90B	S 2060-R90B

White background
BLUE:

Reference sample	Matching sample
S 0510-R90B	S 0510-R90B
S 1020-R90B	S 1020-R90B
S 6020-R90B	S 6020-R90B
S 3040-R90B	S 3040-R90B
S 2060-R90B	S 2060-R90B

Black background
GREEN:

Reference sample	Matching sample
S 0510-G	S 0510-G
S 1020-G	S 1020-G
S 6020-G	S 6020-G
S 3040-G	S 3040-G
S 2060-G	S 2060-G

White background
GREEN:

Reference sample	Matching sample
S 0510-G	S 0510-G
S 1020-G	S 1020-G
S 6020-G	S 6020-G
S 3040-G	S 3040-G
S 2060-G	S 2060-G

Black background
GREY:

Reference sample	Matching sample
S 1000-N	S 1000-N
S 4000-N	S 4000-N
S 7000-N	S 7000-N

White background
GREY:

Reference sample	Matching sample
S 1000-N	S 1000-N
S 4000-N	S 4000-N
S 7000-N	S 7000-N

Comments: No changes in hue or nuance between reference sample and matching sample, though the matching sample were noted to be a little more dull in comparison to reference sample.

0-A2: No glazing versus Pilkington Insuligt Therm S3

Black background
YELLOW:

Reference sample	Matching sample
S 0510-Y	**S 0510-Y10R**
S 1020-Y	**S 1020-Y10R**
S 6020-Y	S 6020-Y
S 3040-Y	S 3040-Y
S 1070-Y	S 1070-Y

White background
YELLOW:

Reference sample	Matching sample
S 0510-Y	S 0510-Y
S 1020-Y	**S 1020-Y10R**
S 6020-Y	S 6020-Y
S 3040-Y	S 3040-Y
S 1070-Y	S 1070-Y

Black background
RED:

Reference sample	Matching sample
S 0510-R	S 0510-R
S 1020-R	S 1020-R
S 6020-R	S 6020-R
S 3040-R	S 3040-R
S 1070-R	S 1070-R

White background
RED:

Reference sample	Matching sample
S 0510-R	S 0510-R
S 1020-R	S 1020-R
S 6020-R	S 6020-R
S 3040-R	S 3040-R
S 1070-R	S 1070-R

Black background
VIOLET:

Reference sample	Matching sample
S 0510-R60B	**S 0510-R50B**
S 1020-R60B	**S 1020-R50B**
S 6020-R60B	S 6020-R60B
S 3030-R60B	S 3030-R60B
S 3050-R60B	S 3050-R60B

White background
VIOLET:

Reference sample	Matching sample
S 0510-R60B	S 0510-R60B
S 1020-R60B	S 1020-R60B
S 6020-R60B	S 6020-R60B
S 3030-R60B	S 3030-R60B
S 3050-R60B	S 3050-R60B

Black background
BLUE:

Reference sample	Matching sample
S 0510-R90B	**S 0510-R80B**
S 1020-R90B	**S 1020-R80B**
S 6020-R90B	S 6020-R90B
S 3040-R90B	S 3040-R90B
S 2060-R90B	S 2060-R90B

White background
BLUE:

Reference sample	Matching sample
S 0510-R90B	S 0510-R90B
S 1020-R90B	S 1020-R90B
S 6020-R90B	S 6020-R70B
S 3040-R90B	S 3040-R90B
S 2060-R90B	S 2060-R90B

Black background
GREEN:

Reference sample	Matching sample
S 0510-G	**S 0510-B90G**
S 1020-G	**S 1020-B90G**
S 6020-G	S 6020-G
S 3040-G	S 3040-G
S 2060-G	S 2060-G

White background
GREEN:

Reference sample	Matching sample
S 0510-G	**S 0510-B80G**
S 1020-G	S 1020-G
S 6020-G	S 6020-G
S 3040-G	S 3040-G
S 2060-G	S 2060-G

Black background
GREY:

Reference sample	Matching sample
S 1000-N	**S 1002-R**
S 4000-N	**S 4502-R**
S 7000-N	S 7000-N

White background
GREY:

Reference sample	Matching sample
S 1000-N	S 1000-N
S 4000-N	S 4000-N
S 7000-N	S 7000-N

Comments: No significant changes. The hue changes a very little in the pale colours and the nuance stays the same for all but let the light, neutral greys that changes towards a little more redness.

0-A3: No glazing versus Saint Gobain Bøckmann/Reference glazing

Black background
YELLOW:

Reference sample	Matching sample
S 0510-Y	**S 0510-Y50R**
S 1020-Y	**S 1015-Y20R**
S 6020-Y	**S 6020-Y10R**
S 3040-Y	**S 3040-Y10R**
S 1070-Y	**S 1070-Y10R**

Comments: The glazing adds greenness to hues of all nuances, and most dramatically in the pale nuances.
The nuance is enhanced a very little in the pale nuances.

Black background
RED:

Reference sample	Matching sample
S 0510-R	**S 0520-R30B**
S 1020-R	**S 0540-R20B**
S 6020-R	S 6020-R
S 3040-R	**S 3040-R10B**
S 1070-R	**S 1070-R10B**

Comments: The glazing adds redness to hues of most nuances, and most noticeable in the pale nuances.
The nuance is weakened, especially in the pale nuances.

Black background
VIOLET:

Reference sample	Matching sample
S 0510-R60B	**S 0520-R50B**
S 1020-R60B	**S 2020-R50B**
S 6020-R60B	S 6020-R60B
S 3030-R60B	S 3030-R60B
S 3050-R60B	S 3050-R60B

Comments: The glazing reduces the redness of the violet hues, but is significant only for the pale nuances.
The nuance is weakened in the pale nuances.

Black background
BLUE:

Reference sample	Matching sample
S 0510-R90B	**S 0520-R60B**
S 1020-R90B	**S 1030-R70B**
S 6020-R90B	S 6020-R90B
S 3040-R90B	S 3040-R90B
S 2060-R90B	S 2060-R90B

Comments: The glazing reduces the redness of the blue hues, but only significally for the pale nuances.
The nuance is weakened in the pale nuances.

Black background
GREEN:

Reference sample	Matching sample
S 0510-G	**S 0502-G**
S 1020-G	**S 1010-G**
S 6020-G	S 6020-G
S 3040-G	S 3040-G
S 2060-G	S 2060-G

Comments: The glazing does not add significant changes to the hue, but enhances the chromaticness a little in the pale hues.

Black background
GREY:

Reference sample	Matching sample
S 1000-N	**S 0515-R20B**
S 4000-N	**S 4505-R20B**
S 7000-N	S 7000-N

Comments: The glazing adds greenness to the neutral greys in most nuances but the dark.

Comments: All the matching samples were noted to be a little duller in comparison to reference sample.

0-A3: No glazing versus Saint Gobain Bøckmann/Reference glazing

White background
YELLOW:

Reference sample	Matching sample
S 0510-Y	**S 0515-Y50R**
S 1020-Y	**S 1020-Y10R**
S 6020-Y	**S 6020-Y10R**
S 3040-Y	S 3040-Y
S 1070-Y	S 1070-Y

White background
RED:

Reference sample	Matching sample
S 0510-R	**S 0515-R10B**
S 1020-R	**S 1030-R20B**
S 6020-R	**S 6020-R10B**
S 3040-R	**S 3040-R10B**
S 1070-R	**S 1070-R10B**

White background
VIOLET:

Reference sample	Matching sample
S 0510-R60B	**S 0510-R50B**
S 1020-R60B	**S 1030-R60B**
S 6020-R60B	S 6020-R60B
S 3030-R60B	S 3040-R60B
S 3050-R60B	S 3050-R60B

White background
BLUE:

Reference sample	Matching sample
S 0510-R90B	S 0510-R70B
S 1020-R90B	**S 1030-R80B**
S 6020-R90B	S 6020-R90B
S 3040-R90B	S 3040-R90B
S 2060-R90B	S 2060-R90B

White background
GREEN:

Reference sample	Matching sample
S 0510-G	**S 0510-B90G**
S 1020-G	**S 1020-B90G**
S 6020-G	**S 6020-B90G**
S 3040-G	**S 3050-B90G**
S 2060-G	S 2060-G

White background
GREY:

Reference sample	Matching sample
S 1000-N	**S 1005-R40B**
S 4000-N	S 4000-N
S 7000-N	S 7000-N

Comments: All the matching samples were noted to be a little duller in comparison to reference sample. The changes in hue and nuance are more or less as when tested with a black background, though a little less significant.

0-B1: No glazing versus Nanogel

Black background
YELLOW:

Reference sample	Matching sample
S 0510-Y	**S 0604-Y30R**
S 1020-Y	**S 0510-Y15R**
S 6020-Y	S 6020-Y
S 3040-Y	S 3040-Y
S 1070-Y	S 1070-Y

Comments: The glazing adds greenness to the yellow hues, most visible in the pale nuances.
It enhances the nuance, especially the pale and the more chromatic.

Black background
RED:

Reference sample	Matching sample
S 0510-R	**S 0515-R20B**
S 1020-R	**S 0530-R20B**
S 6020-R	S 6020-R
S 3040-R	S 3040-R
S 1070-R	S 1070-R

Comments: The glazing adds yellowness the red hues, most visible in the pale hues.
It weakens the nuance in the pale red hues.

Black background
VIOLET:

Reference sample	Matching sample
S 0510-R60B	**S 0520-R60B**
S 1020-R60B	**S 0530-R60B**
S 6020-R60B	S 6020-R60B
S 3030-R60B	S 3030-R60B
S 3050-R60B	S 3050-R60B

Comments: The glazing adds no significant changes to the violet hues.
It weakens the nuance in the pale violet hues.

Black background
BLUE:

Reference sample	Matching sample
S 0510-R90B	S 0520-R70B
S 1020-R90B	S 0530-R80B
S 6020-R90B	S 6020-R90B
S 3040-R90B	S 3040-R90B
S 2060-R90B	S 2060-R90B

Comments: The glazing takes out some of the redness in the blue hues.
It weakens the nuance in the pale blue hues

Black background
GREEN:

Reference sample	Matching sample
S 0510-G	S 0510-B50G
S 1020-G	S 1020-B80G
S 6020-G	S 5040-G
S 3040-G	S 3040-G
S 2060-G	S 2060-G

Comments: The glazing adds yellowness the green hues, most visible in the pale hues.
It enhances the nuance in the pale green hues.

Black background
GREY:

Reference sample	Matching sample
S 1000-N	S0510-R55B
S 4000-N	S 4000-N
S 7000-N	S 7000-N

Comments: The glazing adds more yellow-greenness to pale hues. It adds significant changes to grey nuances.

R-A2: Reference glazing versus Pilkington Insulight Therm S3

Black background
YELLOW:

Reference sample	Matching sample
S 0510-Y	S 0510-Y
S 1020-Y	S 1020-Y
S 6020-Y	S 6020-Y
S 3040-Y	S 3040-Y
S 1070-Y	S 1070-Y

White background
YELLOW:

Reference sample	Matching sample
S 0510-Y	S 0510-Y
S 1020-Y	S 1020-Y
S 6020-Y	S 6020-Y
S 3040-Y	S 3040-Y
S 1070-Y	S 1070-Y

Black background
RED:

Reference sample	Matching sample
S 0510-R	S 0510-R
S 1020-R	S 1020-R
S 6020-R	S 6020-R
S 3040-R	S 3040-R
S 1070-R	S 1070-R

White background
RED:

Reference sample	Matching sample
S 0510-R	S 0510-R
S 1020-R	S 1020-R
S 6020-R	S 6020-R
S 3040-R	S 3040-R
S 1070-R	S 1070-R

Black background
VIOLET:

Reference sample	Matching sample
S 0510-R60B	**S 1015-R60B**
S 1020-R60B	S 1020-R60B
S 6020-R60B	S 6020-R60B
S 3030-R60B	S 3030-R60B
S 3050-R60B	S 3050-R60B

White background
VIOLET:

Reference sample	Matching sample
S 0510-R60B	**S 1015-R60B**
S 1020-R60B	S 1020-R60B
S 6020-R60B	S 6020-R60B
S 3030-R60B	S 3030-R60B
S 3050-R60B	S 3050-R60B

Black background
BLUE:

Reference sample	Matching sample
S 0510-R90B	S 0510-R90B
S 1020-R90B	S 1020-R90B
S 6020-R90B	S 6020-R90B
S 3040-R90B	S 3040-R90B
S 2060-R90B	S 2060-R90B

White background
BLUE:

Reference sample	Matching sample
S 0510-R90B	**S 0510-B**
S 1020-R90B	**S 1020-B**
S 6020-R90B	S 6020-R90B
S 3040-R90B	S 3040-R90B
S 2060-R90B	S 2060-R90B

Black background
GREEN:

Reference sample	Matching sample
S 0510-G	S 0510-G
S 1020-G	S 1020-G
S 6020-G	S 6020-G
S 3040-G	S 3040-G
S 2060-G	S 2060-G

White background
GREEN:

Reference sample	Matching sample
S 0510-G	S 0510-G
S 1020-G	S 1020-G
S 6020-G	S 6020-G
S 3040-G	S 3040-G
S 2060-G	S 2060-G

Black background
GREY:

Reference sample	Matching sample
S 1000-N	S 1000-N
S 4000-N	S 4000-N
S 7000-N	S 7000-N

White background
GREY:

Reference sample	Matching sample
S 1000-N	S 1000-N
S 4000-N	S 4000-N
S 7000-N	S 7000-N

Comments: No significant changes.

R-A4: Reference glazing versus Pilkington Insulight Therm S1

Black background
YELLOW:

Reference sample	Matching sample
S 0510-Y	**S 0515-Y**
S 1020-Y	S 1020-Y
S 6020-Y	S 6020-Y
S 3040-Y	S 3040-Y
S 1070-Y	S 1070-Y

White background
YELLOW:

Reference sample	Matching sample
S 0510-Y	S 0510-Y
S 1020-Y	S 1020-Y
S 6020-Y	S 6020-Y
S 3040-Y	S 3040-Y
S 1070-Y	S 1070-Y

Black background
BLUE:

Reference sample	Matching sample
S 0510-R90B	**S 0510-B**
S 1020-R90B	**S 1020-B**
S 6020-R90B	S 6020-R90B
S 3040-R90B	S 3040-R90B
S 2060-R90B	S 2060-R90B

White background
BLUE:

Reference sample	Matching sample
S 0510-R90B	S 0510-R90B
S 1020-R90B	S 1020-R90B
S 6020-R90B	S 6020-R90B
S 3040-R90B	S 3040-R90B
S 2060-R90B	S 2060-R90B

Black background
RED:

Reference sample	Matching sample
S 0510-R	**S 1015-Y80R**
S 1020-R	**S 1020-Y80R**
S 6020-R	S 6020-R
S 3040-R	**S 3040-Y90R**
S 1070-R	**S 1070-Y90R**

White background
RED:

Reference sample	Matching sample
S 0510-R	S 0510-R
S 1020-R	S 1020-R
S 6020-R	S 6020-R
S 3040-R	S 3040-R
S 1070-R	S 1070-R

Black background
GREEN:

Reference sample	Matching sample
S 0510-G	**S 0510-G30Y**
S 1020-G	S 1020-G
S 6020-G	S 6020-G
S 3040-G	S 3040-G
S 2060-G	S 2060-G

White background
GREEN:

Reference sample	Matching sample
S 0510-G	S 0510-G
S 1020-G	S 1020-G
S 6020-G	S 6020-G
S 3040-G	S 3040-G
S 2060-G	S 2060-G

Black background
VIOLET:

Reference sample	Matching sample
S 0510-R60B	**S 0505-R60B**
S 1020-R60B	**S 1015-R60B**
S 6020-R60B	S 6020-R60B
S 3030-R60B	S 3030-R60B
S 3050-R60B	S 3050-R60B

White background
VIOLET:

Reference sample	Matching sample
S 0510-R60B	**S 1015-R60B**
S 1020-R60B	S 1020-R60B
S 6020-R60B	S 6020-R60B
S 3030-R60B	S 3030-R60B
S 3050-R60B	S 3050-R60B

Black background
GREY:

Reference sample	Matching sample
S 1000-N	**S 1002-Y50R**
S 4000-N	S 4000-N
S 7000-N	**S 7500-N**

White background
GREY:

Reference sample	Matching sample
S 1000-N	**S 1500-N**
S 4000-N	**S 4500-N**
S 7000-N	S 7000-N

Comments: Red hues and pale nuances changes a little. The pale nuances changes a little in chromaticness and the red hues changes towards yellow

R-A5: Reference glazing versus Pilkington Insulight Therm Activ

Black background
YELLOW:

Reference sample	Matching sample
S 0510-Y	S 0510-Y
S 1020-Y	S 1020-Y
S 6020-Y	S 6020-Y
S 3040-Y	S 3040-Y
S 1070-Y	S 1070-Y

White background
YELLOW:

Reference sample	Matching sample
S 0510-Y	S 0510-Y
S 1020-Y	S 1020-Y
S 6020-Y	S 6020-Y
S 3040-Y	S 3040-Y
S 1070-Y	S 1070-Y

Black background
RED:

Reference sample	Matching sample
S 0510-R	S 0510-R
S 1020-R	S 1020-R
S 6020-R	S 6020-R
S 3040-R	S 3040-R
S 1070-R	S 1070-R

White background
RED:

Reference sample	Matching sample
S 0510-R	S 0510-R
S 1020-R	S 1020-R
S 6020-R	S 6020-R
S 3040-R	S 3040-R
S 1070-R	S 1070-R

Black background
VIOLET:

Reference sample	Matching sample
S 0510-R60B	S 1015-R60B
S 1020-R60B	S 1020-R60B
S 6020-R60B	S 6020-R60B
S 3030-R60B	S 3030-R60B
S 3050-R60B	S 3050-R60B

White background
VIOLET:

Reference sample	Matching sample
S 0510-R60B	**S 1015-R60B**
S 1020-R60B	S 1020-R60B
S 6020-R60B	S 6020-R60B
S 3030-R60B	S 3030-R60B
S 3050-R60B	S 3050-R60B

Black background
BLUE:

Reference sample	Matching sample
S 0510-R90B	S 0510-R90B
S 1020-R90B	S 1020-R90B
S 6020-R90B	S 6020-R90B
S 3040-R90B	S 3040-R90B
S 2060-R90B	S 2060-R90B

White background
BLUE:

Reference sample	Matching sample
S 0510-R90B	S 0510-R90B
S 1020-R90B	S 1020-R90B
S 6020-R90B	S 6020-R90B
S 3040-R90B	S 3040-R90B
S 2060-R90B	S 2060-R90B

Black background
GREEN:

Reference sample	Matching sample
S 0510-G	S 0510-G
S 1020-G	S 1020-G
S 6020-G	S 6020-G
S 3040-G	S 3040-G
S 2060-G	S 2060-G

White background
GREEN:

Reference sample	Matching sample
S 0510-G	S 0510-G
S 1020-G	S 1020-G
S 6020-G	S 6020-G
S 3040-G	S 3040-G
S 2060-G	S 2060-G

Black background
GREY:

Reference sample	Matching sample
S 1000-N	**S 1500-N**
S 4000-N	**S 4500-N**
S 7000-N	**S 7500-N**

White background
GREY:

Reference sample	Matching sample
S 1000-N	S 1000-N
S 4000-N	S 4000-N
S 7000-N	S 7000-N

Comments: No significant changes. The hue hues stay the same, and the blackness in the nuance changes a very little in neutral greys.

R-A6: Reference glazing versus Glassfabrikken Solstoppglass 30/17 Activ

Black background
YELLOW:

Reference sample	Matching sample
S 0510-Y	**S 0520-Y10R**
S 1020-Y	S 1020-Y
S 6020-Y	S 6020-Y
S 3040-Y	S 3040-Y
S 1070-Y	S 1070-Y

White background
YELLOW:

Reference sample	Matching sample
S 0510-Y	S 0520-Y
S 1020-Y	S 1020-Y
S 6020-Y	S 6020-Y
S 3040-Y	S 3040-Y
S 1070-Y	S 1070-Y

Black background
RED:

Reference sample	Matching sample
S 0510-R	**S 0510-Y70R**
S 1020-R	**S 1020-Y80R**
S 6020-R	S 6020-R
S 3040-R	S 3040-R
S 1070-R	S 1070-R

White background
RED:

Reference sample	Matching sample
S 0510-R	**S 1010-Y90R**
S 1020-R	**S 1020-Y90R**
S 6020-R	**S 6020-Y90R**
S 3040-R	**S 3040-R90**
S 1070-R	**S 1070-R90**

Black background
VIOLET:

Reference sample	Matching sample
S 0510-R60B	**S 0502-R50B**
S 1020-R60B	**S 0505-R50B**
S 6020-R60B	S 6020-R60B
S 3030-R60B	**S2030-R60B**
S 3050-R60B	S 3050-R60B

White background
VIOLET:

Reference sample	Matching sample
S 0510-R60B	**S 0505-R60B**
S 1020-R60B	**S 1015-R60B**
S 6020-R60B	S 6020-R60B
S 3030-R60B	S 3030-R60B
S 3050-R60B	S 3050-R60B

Black background
BLUE:

Reference sample	Matching sample
S 0510-R90B	**S 0502-G50Y**
S 1020-R90B	**S 0515-B20G**
S 6020-R90B	**S 6020-B10G**
S 3040-R90B	**S 2040-B**
S 2060-R90B	S 2060-B

White background
BLUE:

Reference sample	Matching sample
S 0510-R90B	**S 0510-B**
S 1020-R90B	S 1020-R90B
S 6020-R90B	**S 6020-B**
S 3040-R90B	S 3040-R90B
S 2060-R90B	**S 2065-R90B**

Black background
GREEN:

Reference sample	Matching sample
S 0510-G	**S 0510-G40Y**
S 1020-G	**S 1020-G20Y**
S 6020-G	S 6020-G
S 3040-G	**S 3040-G10Y**
S 2060-G	S 2060-G

White background
GREEN:

Reference sample	Matching sample
S 0510-G	**S 0510-G10Y**
S 1020-G	S 1020-G
S 6020-G	**S 6030-G**
S 3040-G	**S 3050-G**
S 2060-G	**S 2565-G**

Black background
GREY:

Reference sample	Matching sample
S 1000-N	**S 0505-Y40R**
S 4000-N	**S 3502-Y**
S 7000-N	**S 6502-Y**

White background
GREY:

Reference sample	Matching sample
S 1000-N	**S 1002-Y50R**
S 4000-N	**S 4002-Y**
S 7000-N	S 7000-N

Comments: Significant changes in all hues and nuance, with exception of the yellow hues. The blue hues changes both towards green and red, and the chromaticness are enhanced in pale yellows, but weakened in pale violets and pale blues.

R-A7: Reference glazing versus CG Glass Energy Super

Black background
YELLOW:

Reference sample	Matching sample
S 0510-Y	**S 0510-G70Y**
S 1020-Y	**S 2020-G90Y**
S 6020-Y	S 6020-Y
S 3040-Y	S 3040-Y
S 1070-Y	S 1070-Y

White background
YELLOW:

Reference sample	Matching sample
S 0510-Y	**S 0510-G90Y**
S 1020-Y	**S 1015-G90Y**
S 6020-Y	S 6020-Y
S 3040-Y	**S 3040-G90Y**
S 1070-Y	S 1070-Y

Black background
RED:

Reference sample	Matching sample
S 0510-R	**S 1010-R**
S 1020-R	**S 1515-R**
S 6020-R	S 6020-R
S 3040-R	S 3040-R
S 1070-R	S 1070-R

White background
RED:

Reference sample	Matching sample
S 0510-R	**S 0507-R**
S 1020-R	S 1020-R
S 6020-R	S 6020-R
S 3040-R	S 3040-R
S 1070-R	S 1070-R

Black background
VIOLET:

Reference sample	Matching sample
S 0510-R60B	S 0510-R60B
S 1020-R60B	S 1020-R70B
S 6020-R60B	S 6020-R60B
S 3030-R60B	S 3030-R60B
S 3050-R60B	S 3050-R60B

White background
VIOLET:

Reference sample	Matching sample
S 0510-R60B	S 0510-R70B
S 1020-R60B	S 1020-R60B
S 6020-R60B	S 6020-R60B
S 3030-R60B	S 3030-R60B
S 3050-R60B	S 3050-R60B

Black background
BLUE:

Reference sample	Matching sample
S 0510-R90B	S 0510-R90B
S 1020-R90B	**S 1020-B**
S 6020-R90B	S 6020-R90B
S 3040-R90B	S 3040-R90B
S 2060-R90B	S 2060-R90B

White background
BLUE:

Reference sample	Matching sample
S 0510-R90B	S 0510-R90B
S 1020-R90B	S 1020-R90B
S 6020-R90B	S 6020-R90B
S 3040-R90B	S 3040-R90B
S 2060-R90B	S 2060-R90B

Black background
GREEN:

Reference sample	Matching sample
S 0510-G	S 0510-G
S 1020-G	S 1020-G
S 6020-G	S 6020-G
S 3040-G	S 3040-G
S 2060-G	S 2060-G

White background
GREEN:

Reference sample	Matching sample
S 0510-G	S 0510-G
S 1020-G	S 1020-G
S 6020-G	S 6020-G
S 3040-G	S 3040-G
S 2060-G	S 2060-G

Black background
GREY:

Reference sample	Matching sample
S 1000-N	S 1000-N
S 4000-N	**S 3502-B**
S 7000-N	**S 6502-G**

White background
GREY:

Reference sample	Matching sample
S 1000-N	S 1000-N
S 4000-N	**S 4502-G**
S 7000-N	S 7000-N

Comments: No significant changes. The hue changes in some pale colours and neutral greys. The nuance changes a very little in chromaticness.

R-A8: Reference glazing versus CG Glass Stopray Energy 71/39

Black background
YELLOW:

Reference sample	Matching sample
S 0510-Y	**S 0510-G80Y**
S 1020-Y	S 1020-Y
S 6020-Y	S 6020-Y
S 3040-Y	S 3040-Y
S 1070-Y	S 1070-Y

White background
YELLOW:

Reference sample	Matching sample
S 0510-Y	**S 0510-G90Y**
S 1020-Y	**S 1015-G90Y**
S 6020-Y	S 6020-Y
S 3040-Y	**S 3040-G90Y**
S 1070-Y	S 1070-Y

Black background
RED:

Reference sample	Matching sample
S 0510-R	S 0510-R
S 1020-R	S 1020-R
S 6020-R	S 6020-R
S 3040-R	S 3040-R
S 1070-R	S 1070-R

White background
RED:

Reference sample	Matching sample
S 0510-R	**S 0507-R**
S 1020-R	S 1020-R
S 6020-R	S 6020-R
S 3040-R	S 3040-R
S 1070-R	S 1070-R

Black background
VIOLET:

Reference sample	Matching sample
S 0510-R60B	S 0510-R60B
S 1020-R60B	S 1020-R60B
S 6020-R60B	S 6020-R60B
S 3030-R60B	S 3030-R60B
S 3050-R60B	S 3050-R60B

White background
VIOLET:

Reference sample	Matching sample
S 0510-R60B	**S 0510-R70B**
S 1020-R60B	S 1020-R60B
S 6020-R60B	S 6020-R60B
S 3030-R60B	S 3030-R60B
S 3050-R60B	S 3050-R60B

Black background
BLUE:

Reference sample	Matching sample
S 0510-R90B	S 0510-R90B
S 1020-R90B	S 1020-R90B
S 6020-R90B	S 6020-R90B
S 3040-R90B	S 3040-R90B
S 2060-R90B	S 2060-R90B

White background
BLUE:

Reference sample	Matching sample
S 0510-R90B	S 0510-R90B
S 1020-R90B	S 1020-R90B
S 6020-R90B	S 6020-R90B
S 3040-R90B	S 3040-R90B
S 2060-R90B	S 2060-R90B

Black background
GREEN:

Reference sample	Matching sample
S 0510-G	**S 0510-G10Y**
S 1020-G	S 1020-G
S 6020-G	S 6020-G
S 3040-G	S 3040-G
S 2060-G	S 2060-G

White background
GREEN:

Reference sample	Matching sample
S 0510-G	S 0510-G
S 1020-G	S 1020-G
S 6020-G	S 6020-G
S 3040-G	S 3040-G
S 2060-G	S 2060-G

Black background
GREY:

Reference sample	Matching sample
S 1000-N	S 1000-N
S 4000-N	S 4000-N
S 7000-N	S 7000-N

White background
GREY:

Reference sample	Matching sample
S 1000-N	S 1000-N
S 4000-N	**S 4502-G**
S 7000-N	S 7000-N

Comments: No significant changes. The hue changes in some pale colours, and the nuance changes a very little in chromaticness.

R-A9: Reference glazing versus Glass Stopray Safir 61/32

Black background
YELLOW:

Reference sample	Matching sample
S 0510-Y	**S 0510-G90Y**
S 1020-Y	**S 1020-G90Y**
S 6020-Y	S 6020-Y
S 3040-Y	S 3040-Y
S 1070-Y	**S 1070-G90Y**

White background
YELLOW:

Reference sample	Matching sample
S 0510-Y	S 0510-Y
S 1020-Y	S 1020-Y
S 6020-Y	S 6020-Y
S 3040-Y	S 3040-Y
S 1070-Y	S 1070-Y

Black background
RED:

Reference sample	Matching sample
S 0510-R	**S 1010-R**
S 1020-R	**S 2020-R**
S 6020-R	S 6020-R
S 3040-R	S 3040-R
S 1070-R	S 1070-R

White background
RED:

Reference sample	Matching sample
S 0510-R	**S 1010-R**
S 1020-R	**S 2020-R**
S 6020-R	S 6020-R
S 3040-R	S 3040-R
S 1070-R	S 1070-R

Black background
VIOLET:

Reference sample	Matching sample
S 0510-R60B	**S 0510-R70B**
S 1020-R60B	S 1020-R60B
S 6020-R60B	S 6020-R60B
S 3030-R60B	S 3030-R60B
S 3050-R60B	S 3050-R60B

White background
VIOLET:

Reference sample	Matching sample
S 0510-R60B	**S 0510-R70B**
S 1020-R60B	S 1020-R60B
S 6020-R60B	S 6020-R60B
S 3030-R60B	S 3030-R60B
S 3050-R60B	S 3050-R60B

Black background
BLUE:

Reference sample	Matching sample
S 0510-R90B	S 0510-R90B
S 1020-R90B	S 1020-R90B
S 6020-R90B	S 6020-R90B
S 3040-R90B	S 3040-R90B
S 2060-R90B	S 2060-R90B

White background
BLUE:

Reference sample	Matching sample
S 0510-R90B	S 0510-R90B
S 1020-R90B	S 1020-R90B
S 6020-R90B	S 6020-R90B
S 3040-R90B	S 3040-R90B
S 2060-R90B	S 2060-R90B

Black background
GREEN:

Reference sample	Matching sample
S 0510-G	S 0510-G
S 1020-G	S 1020-G
S 6020-G	S 6020-G
S 3040-G	S 3040-G
S 2060-G	S 2060-G

White background
GREEN:

Reference sample	Matching sample
S 0510-G	S 0510-G
S 1020-G	S 1020-G
S 6020-G	S 6020-G
S 3040-G	S 3040-G
S 2060-G	S 2060-G

Black background
GREY:

Reference sample	Matching sample
S 1000-N	S 1000-N
S 4000-N	**S 4500-N**
S 7000-N	S 7000-N

White background
GREY:

Reference sample	Matching sample
S 1000-N	S 1000-N
S 4000-N	**S 4500-N**
S 7000-N	**S 7500-N**

Comments: No significant changes. The hue changes in some pale colours and neutral greys. The nuance changes a little in chromaticness.

R-A10: Reference glazing versus CG Glass Stopray Vision 50/12

Black background
YELLOW:

Reference sample	Matching sample
S 0510-Y	**S 0510-G90Y**
S 1020-Y	**S 1015-G90Y**
S 6020-Y	**S 6020-G90Y**
S 3040-Y	**S 3040-G90Y**
S 1070-Y	S 1070-Y

White background
YELLOW:

Reference sample	Matching sample
S 0510-Y	S 0510-Y
S 1020-Y	S 1020-Y
S 6020-Y	S 6020-Y
S 3040-Y	S 3040-Y
S 1070-Y	S 1070-Y

Black background
RED:

Reference sample	Matching sample
S 0510-R	**S 0507-R**
S 1020-R	S 1020-R
S 6020-R	S 6020-R
S 3040-R	S 3040-R
S 1070-R	S 1070-R

White background
RED:

Reference sample	Matching sample
S 0510-R	S 0510-R
S 1020-R	S 1020-R
S 6020-R	S 6020-R
S 3040-R	S 3040-R
S 1070-R	S 1070-R

Black background
VIOLET:

Reference sample	Matching sample
S 0510-R60B	S 0510-R70B
S 1020-R60B	S 1020-R60B
S 6020-R60B	S 6020-R60B
S 3030-R60B	S 3030-R60B
S 3050-R60B	S 3050-R60B

White background
VIOLET:

Reference sample	Matching sample
S 0510-R60B	S 0510-R70B
S 1020-R60B	S 1020-R60B
S 6020-R60B	S 6020-R60B
S 3030-R60B	S 3030-R60B
S 3050-R60B	S 3050-R60B

Black background
BLUE:

Reference sample	Matching sample
S 0510-R90B	S 0510-R90B
S 1020-R90B	S 1020-R90B
S 6020-R90B	S 6020-R90B
S 3040-R90B	S 3040-R90B
S 2060-R90B	S 2060-R90B

White background
BLUE:

Reference sample	Matching sample
S 0510-R90B	S 0510-R90B
S 1020-R90B	S 1020-R90B
S 6020-R90B	S 6020-R90B
S 3040-R90B	S 3040-R90B
S 2060-R90B	S 2060-R90B

Black background
GREEN:

Reference sample	Matching sample
S 0510-G	S 0510-G
S 1020-G	S 1020-G
S 6020-G	S 6020-G
S 3040-G	S 3040-G
S 2060-G	S 2060-G

White background
GREEN:

Reference sample	Matching sample
S 0510-G	S 0510-G
S 1020-G	S 1020-G
S 6020-G	S 6020-G
S 3040-G	S 3040-G
S 2060-G	S 2060-G

Black background
GREY:

Reference sample	Matching sample
S 1000-N	S 1000-N
S 4000-N	S 4000-N
S 7000-N	S 7000-N

White background
GREY:

Reference sample	Matching sample
S 1000-N	S 1000-N
S 4000-N	S 4000-N
S 7000-N	S 7000-N

Comments: No significant changes, but for the yellow hues of most nuances. The yellow hues change towards a little green.

R-A11: Reference glazing versus Saint-Gobain Emmaboda Glas Cool Lite SKN 174.

Black background
YELLOW:

Reference sample	Matching sample
S 0510-Y	S 0510-Y
S 1020-Y	S 1020-Y
S 6020-Y	S 6020-Y
S 3040-Y	S 3040-Y
S 1070-Y	S 1070-Y

White background
YELLOW:

Reference sample	Matching sample
S 0510-Y	S 0510-Y
S 1020-Y	S 1020-Y
S 6020-Y	S 6020-Y
S 3040-Y	S 3040-Y
S 1070-Y	S 1070-Y

Black background
BLUE:

Reference sample	Matching sample
S 0510-R90B	**S 0510-B**
S 1020-R90B	**S 1020-B**
S 6020-R90B	S 6020-R90B
S 3040-R90B	S 3040-R90B
S 2060-R90B	S 2060-R90B

White background
BLUE:

Reference sample	Matching sample
S 0510-R90B	S 0510-R90B
S 1020-R90B	S 1020-R90B
S 6020-R90B	S 6020-R90B
S 3040-R90B	S 3040-R90B
S 2060-R90B	S 2060-R90B

Black background
RED:

Reference sample	Matching sample
S 0510-R	**S 0510-Y90R**
S 1020-R	**S 1020-Y90R**
S 6020-R	**S 5030-Y90R**
S 3040-R	S 3040-R
S 1070-R	S 1070-R

White background
RED:

Reference sample	Matching sample
S 0510-R	S 0510-Y90R
S 1020-R	S 1020-Y90R
S 6020-R	S 6020-Y90R
S 3040-R	S 3040-Y90R
S 1070-R	S 1070-Y90R

Black background
GREEN:

Reference sample	Matching sample
S 0510-G	**S 0515-G20Y**
S 1020-G	S 1020-G
S 6020-G	S 6020-G
S 3040-G	S 3040-G
S 2060-G	S 2060-G

White background
GREEN:

Reference sample	Matching sample
S 0510-G	**S 0510-Y90R**
S 1020-G	S 1020-G
S 6020-G	S 6020-G
S 3040-G	S 3040-G
S 2060-G	S 2060-G

Black background
VIOLET:

Reference sample	Matching sample
S 0510-R60B	**S 1015-R60B**
S 1020-R60B	S 1020-R60B
S 6020-R60B	S 6020-R60B
S 3030-R60B	S 3030-R60B
S 3050-R60B	S 3050-R60B

White background
VIOLET:

Reference sample	Matching sample
S 0510-R60B	**S 1015-R60B**
S 1020-R60B	S 1020-R60B
S 6020-R60B	S 6020-R60B
S 3030-R60B	S 3030-R60B
S 3050-R60B	S 3050-R60B

Black background
GREY:

Reference sample	Matching sample
S 1000-N	S 1000-N
S 4000-N	S 4000-N
S 7000-N	S 7000-N

White background
GREY:

Reference sample	Matching sample
S 1000-N	**S 1002-Y50R**
S 4000-N	**S 4500-N**
S 7000-N	**S 7500-N**

Comments: No significant changes. The hue changes a very little in some pale colours and the nuance changes a little in chromaticness.

R-A12: Reference glazing versus Saint-Gobain Emmaboda Glas Cool Lite Xtreme

Black background
YELLOW:

Reference sample	Matching sample
S 0510-Y	**S 0510-Y10R**
S 1020-Y	**S 1020-Y10R**
S 6020-Y	S 6020-Y
S 3040-Y	S 3040-Y
S 1070-Y	S 0580-Y

White background
YELLOW:

Reference sample	Matching sample
S 0510-Y	**S 0515-Y**
S 1020-Y	**S 1020-Y10R**
S 6020-Y	S 6020-Y
S 3040-Y	S 3040-Y
S 1070-Y	S 1070-Y

Black background
RED:

Reference sample	Matching sample
S 0510-R	**S 0510-Y90R**
S 1020-R	**S 0530-Y90R**
S 6020-R	S 6020-R
S 3040-R	S 3040-R
S 1070-R	S 1070-R

White background
RED:

Reference sample	Matching sample
S 0510-R	S 0510-R
S 1020-R	S 1020-R
S 6020-R	S 6020-R
S 3040-R	S 3040-R
S 1070-R	S 1070-R

Black background
VIOLET:

Reference sample	Matching sample
S 0510-R60B	**S 0502-R50B**
S 1020-R60B	**S 0520-B50G**
S 6020-R60B	S 6020-R60B
S 3030-R60B	S 2030-R60B
S 3050-R60B	S 3050-R60B

White background
VIOLET:

Reference sample	Matching sample
S 0510-R60B	S 0510-R60B
S 1020-R60B	S 1020-B60G
S 6020-R60B	S 6020-R60B
S 3030-R60B	S 2030-R60B
S 3050-R60B	S 3050-R60B

Black background
BLUE:

Reference sample	Matching sample
S 0510-R90B	**S 0502-B**
S 1020-R90B	S 0520-R90B
S 6020-R90B	S 6020-R90B
S 3040-R90B	S 3040-R90B
S 2060-R90B	S 2060-R90B

White background
BLUE:

Reference sample	Matching sample
S 0510-R90B	**S 0510-B**
S 1020-R90B	S 0520-R90B
S 6020-R90B	S 6020-R90B
S 3040-R90B	S 3040-R90B
S 2060-R90B	S 2060-R90B

Black background
GREEN:

Reference sample	Matching sample
S 0510-G	**S 0505-G40Y**
S 1020-G	**S 1020-G10Y**
S 6020-G	S 6020-G
S 3040-G	S 3040-G
S 2060-G	S 2060-G

White background
GREEN:

Reference sample	Matching sample
S 0510-G	**S 0510-G10Y**
S 1020-G	S 1020-G
S 6020-G	S 6020-G
S 3040-G	S 3040-G
S 2060-G	S 2060-G

Black background
GREY:

Reference sample	Matching sample
S 1000-N	**S 0505-Y60R**
S 4000-N	**S 3000-N**
S 7000-N	S 7000-N

White background
GREY:

Reference sample	Matching sample
S 1000-N	S 1000-N
S 4000-N	S 4000-N
S 7000-N	**S 7502-G**

Comments: No significant changes. The hue changes in some pale colours and the nuance changes a little in chromaticness.

R- A13: Reference glazing versus Saint-Gobain Emmaboda Glas Cool Lite SKN 165.

Black background
YELLOW:

Reference sample	Matching sample
S 0510-Y	**S 1510-Y**
S 1020-Y	S 1020-Y
S 6020-Y	S 6020-Y
S 3040-Y	S 3040-Y
S 1070-Y	S 1070-Y

White background
YELLOW:

Reference sample	Matching sample
S 0510-Y	S 0510-Y
S 1020-Y	S 1020-Y
S 6020-Y	S 6020-Y
S 3040-Y	S 3040-Y
S 1070-Y	S 1070-Y

Black background
RED:

Reference sample	Matching sample
S 0510-R	S 0510-R
S 1020-R	S 1020-R
S 6020-R	S 6020-R
S 3040-R	S 3040-R
S 1070-R	S 1070-R

White background
RED:

Reference sample	Matching sample
S 0510-R	S 0510-R
S 1020-R	S 1020-R
S 6020-R	S 6020-R
S 3040-R	S 3040-R
S 1070-R	S 1070-R

Black background
VIOLET:

Reference sample	Matching sample
S 0510-R60B	**S 1015-R60B**
S 1020-R60B	**S 2020-R60B**
S 6020-R60B	S 6020-R60B
S 3030-R60B	S 3030-R60B
S 3050-R60B	S 3050-R60B

White background
VIOLET:

Reference sample	Matching sample
S 0510-R60B	S 0510-R60B
S 1020-R60B	S 1020-R60B
S 6020-R60B	S 6020-R60B
S 3030-R60B	S 3030-R60B
S 3050-R60B	S 3050-R60B

Black background
BLUE:

Reference sample	Matching sample
S 0510-R90B	**S 1010-R90B**
S 1020-R90B	**S 2020-R90B**
S 6020-R90B	S 6020-R90B
S 3040-R90B	S 3040-R90B
S 2060-R90B	S 2060-R90B

White background
BLUE:

Reference sample	Matching sample
S 0510-R90B	S 0510-R90B
S 1020-R90B	S 1020-R90B
S 6020-R90B	S 6020-R90B
S 3040-R90B	S 3040-R90B
S 2060-R90B	S 2060-R90B

Black background
GREEN:

Reference sample	Matching sample
S 0510-G	S 0510-G
S 1020-G	**S 1020-R90B**
S 6020-G	S 6020-G
S 3040-G	S 3040-G
S 2060-G	S 2060-G

White background
GREEN:

Reference sample	Matching sample
S 0510-G	**S 0510-G10Y**
S 1020-G	S 1020-G
S 6020-G	S 6020-G
S 3040-G	S 3040-G
S 2060-G	S 2060-G

Black background
GREY:

Reference sample	Matching sample
S 1000-N	**S 1500-N**
S 4000-N	**S 4500-N**
S 7000-N	S 7000-N

White background
GREY:

Reference sample	Matching sample
S 1000-N	**S 1002-Y**
S 4000-N	S 4000-N
S 7000-N	S 7000-N

Comments: No significant changes. The hue changes a very little in some pale colours and the nuance changes a little in chromaticness.

R-A14: Reference glazing versus Saint-Gobain Emmaboda Glas Cool Lite SKN 154.

Black background
YELLOW:

Reference sample	Matching sample
S 0510-Y	S 0510-Y
S 1020-Y	S 1020-Y
S 6020-Y	S 6020-Y
S 3040-Y	S 3040-Y
S 1070-Y	S 1070-Y

White background
YELLOW:

Reference sample	Matching sample
S 0510-Y	**S 0515-Y**
S 1020-Y	S 1020-Y
S 6020-Y	S 6020-Y
S 3040-Y	S 3040-Y
S 1070-Y	S 1070-Y

Black background
RED:

Reference sample	Matching sample
S 0510-R	S 0510-R
S 1020-R	S 1020-R
S 6020-R	S 6020-R
S 3040-R	S 3040-R
S 1070-R	S 1070-R

White background
RED:

Reference sample	Matching sample
S 0510-R	S 0510-R
S 1020-R	S 1020-R
S 6020-R	S 6020-R
S 3040-R	S 3040-R
S 1070-R	S 1070-R

Black background
VIOLET:

Reference sample	Matching sample
S 0510-R60B	**S 0507-R60B**
S 1020-R60B	S 1020-B60G
S 6020-R60B	S 6020-R60B
S 3030-R60B	S 3030-R60B
S 3050-R60B	S 3050-R60B

White background
VIOLET:

Reference sample	Matching sample
S 0510-R60B	S 0510-R60B
S 1020-R60B	S 1020-B60G
S 6020-R60B	S 6020-R60B
S 3030-R60B	S 3030-R60B
S 3050-R60B	S 3050-R60B

Black background
BLUE:

Reference sample	Matching sample
S 0510-R90B	S 0510-R90B
S 1020-R90B	S 1020-R90B
S 6020-R90B	S 6020-R90B
S 3040-R90B	S 3040-R90B
S 2060-R90B	S 2060-R90B

White background
BLUE:

Reference sample	Matching sample
S 0510-R90B	S 0510-R90B
S 1020-R90B	S 1020-R90B
S 6020-R90B	S 6020-R90B
S 3040-R90B	S 3040-R90B
S 2060-R90B	S 2060-R90B

Black background
GREEN:

Reference sample	Matching sample
S 0510-G	S 0510-G
S 1020-G	S 1020-G
S 6020-G	S 6020-G
S 3040-G	S 3040-G
S 2060-G	S 2060-G

White background
GREEN:

Reference sample	Matching sample
S 0510-G	S 0510-G
S 1020-G	S 1020-G
S 6020-G	**S 6020-B90G**
S 3040-G	S 3040-G
S 2060-G	S 2060-G

Black background
GREY:

Reference sample	Matching sample
S 1000-N	S 1000-N
S 4000-N	**S 4502-R**
S 7000-N	**S 6502-R**

White background
GREY:

Reference sample	Matching sample
S 1000-N	S 1000-N
S 4000-N	**S 4502-R**
S 7000-N	**S 6502-R**

Comments: No significant changes. The hue and nuance stays more or less the same, with few, very small exceptions.

R-B1: Reference glazing versus Nanogel.

Black background
YELLOW:

Reference sample	Matching sample
S 0510-Y	**S0507-G40Y**
S 1020-Y	**S1015-G90Y**
S 6020-Y	**S6020-G90Y**
S 3040-Y	**S2040-G90Y**
S 1070-Y	**S0575-G90Y**

White background
YELLOW:

Reference sample	Matching sample
S 0510-Y	**S0507-G40Y**
S 1020-Y	**S1015-G90Y**
S 6020-Y	**S6020-G90Y**
S 3040-Y	**S2040-G90Y**
S 1070-Y	**S0575-G90Y**

Black background
RED:

Reference sample	Matching sample
S 0510-R	**S0510-R40B**
S 1020-R	**S0530-R20B**
S 6020-R	**S5030-R**
S 3040-R	**S3040-R10B**
S 1070-R	S1070-R

White background
RED:

Reference sample	Matching sample
S 0510-R	**S0510-R40B**
S 1020-R	**S0530-R20B**
S 6020-R	**S5030-R**
S 3040-R	**S3040-R10B**
S 1070-R	S1070-R

Black background
VIOLET:

Reference sample	Matching sample
S 0510-R60B	**S0502-R50B**
S 1020-R60B	**S0525-R70B**
S 6020-R60B	S6020-R70B
S 3030-R60B	S3030-R60B
S 3050-R60B	S3050-R60B

White background
VIOLET:

Reference sample	Matching sample
S 0510-R60B	**S0502-R50B**
S 1020-R60B	**S0525-R70B**
S 6020-R60B	**S6020-R70B**
S 3030-R60B	S3030-R60B
S 3050-R60B	S3050-R60B

Black background
BLUE:

Reference sample	Matching sample
S 0510-R90B	**S0510-R90B**
S 1020-R90B	**S0530-R80B**
S 6020-R90B	**S5030-R90B**
S 3040-R90B	**S1555-R80B**
S 2060-R90B	S2060-R90B

White background
BLUE:

Reference sample	Matching sample
S 0510-R90B	S0510-R90B
S 1020-R90B	**S0530-R80B**
S 6020-R90B	**S5030-R90B**
S 3040-R90B	**S1555-R80B**
S 2060-R90B	S2060-R90B

Black background
GREEN:

Reference sample	Matching sample
S 0510-G	**S0510-B50G**
S 1020-G	**S0520-B70G**
S 6020-G	S6020-G
S 3040-G	S3040-G
S 2060-G	S2060-G

White background
GREEN:

Reference sample	Matching sample
S 0510-G	**S0510-B50G**
S 1020-G	**S0520-B70G**
S 6020-G	S6020-G
S 3040-G	S3040-G
S 2060-G	S2060-G

Black background
GREY:

Reference sample	Matching sample
S 1000-N	**S0502-B**
S 4000-N	**S2502-B**
S 7000-N	S7000-N

White background
GREY:

Reference sample	Matching sample
S 1000-N	**S0502-B**
S 4000-N	**S2502-B**
S 7000-N	S7000-N

Comments: Changes in most hues and nuances, but for the very chromatic and dark colours. All the matching samples were noted to be a little duller in comparison to reference sample.

R-B2: Reference glazing versus HeatMirror.

Black background
YELLOW:

Reference sample	Matching sample
S 0510-Y	S 0510-Y
S 1020-Y	**S 0510-Y10R**
S 6020-Y	S 6020-Y
S 3040-Y	S 3040-Y
S 1070-Y	S 1080-Y

White background
YELLOW:

Reference sample	Matching sample
S 0510-Y	S 0510-Y10R
S 1020-Y	S 0510-Y
S 6020-Y	S 6020-G90Y
S 3040-Y	S 3040-Y
S 1070-Y	S 1080-Y

Black background
BLUE:

Reference sample	Matching sample
S 0510-R90B	S 0510-R90B
S 1020-R90B	**S 0520-R90B**
S 6020-R90B	S 6020-R90B
S 3040-R90B	S 3040-R90B
S 2060-R90B	S 2060-R90B

White background
BLUE:

Reference sample	Matching sample
S 0510-R90B	S 0510-R90B
S 1020-R90B	**S 0520-R90B**
S 6020-R90B	**S 6020-B**
S 3040-R90B	S 3040-R90B
S 2060-R90B	S 2060-R90B

Black background
RED:

Reference sample	Matching sample
S 0510-R	**S 0515-R**
S 1020-R	S 1020-R
S 6020-R	S 6020-R
S 3040-R	S 3040-R
S 1070-R	S 1070-R

White background
RED:

Reference sample	Matching sample
S 0510-R	S 0510-R
S 1020-R	S 1020-R
S 6020-R	S 6020-R
S 3040-R	S 3040-R
S 1070-R	S 1070-R

Black background
GREEN:

Reference sample	Matching sample
S 0510-G	**S 0505-G10Y**
S 1020-G	**S 1020-G20Y**
S 6020-G	S 6020-G
S 3040-G	**S 3040-G10Y**
S 2060-G	S 2060-G

White background
GREEN:

Reference sample	Matching sample
S 0510-G	S 0510-G
S 1020-G	S 1020-G
S 6020-G	**S 6030-G**
S 3040-G	S 3040-G
S 2060-G	S 2060-G

Black background
VIOLET:

Reference sample	Matching sample
S 0510-R60B	S 0510-R40B
S 1020-R60B	S 1020-R50B
S 6020-R60B	S 6020-R60B
S 3030-R60B	S 3030-R60B
S 3050-R60B	S 3050-R60B

White background
VIOLET:

Reference sample	Matching sample
S 0510-R60B	S 0510-R60B
S 1020-R60B	S 1020-R60B
S 6020-R60B	S 6020-R60B
S 3030-R60B	S 3030-R60B
S 3050-R60B	S 3050-R60B

Black background
GREY:

Reference sample	Matching sample
S 1000-N	**S 0500-N**
S 4000-N	**S 3500-N**
S 7000-N	**S 6502-Y**

White background
GREY:

Reference sample	Matching sample
S 1000-N	**S 0500-N**
S 4000-N	**S 3500-N**
S 7000-N	S 7000-N

Comments: Changes in most hues and nuances of low chromaticness. All the matching samples were noted to be a little duller in comparison to reference sample

3. Short guide to the NCS system

People can differentiate between approximately 10 million colours under the assumption that they do not have any defects in their colour vision and that colours may be seen next to another under appropriate lighting conditions. It is impossible to give all colours a name with a related meaning. It is true that in many situations it will be sufficient to use our most common words for colour (red, green, blue, yellow black white, grey, brown, purple, etc.), but quite often, and especially when one is working with colour in a profession, one needs to define a colour much more exactly. Thus, we need a notation system by which we may unambiguously describe any imaginable colour.

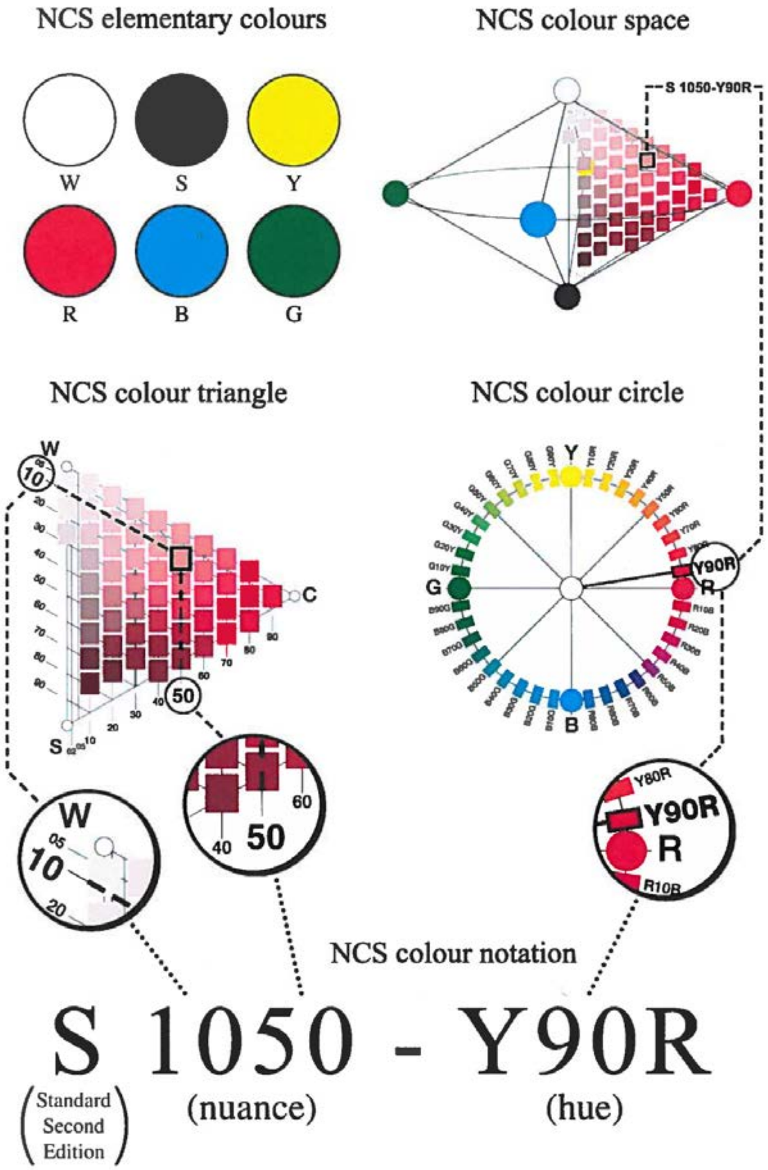
NCS (Natural Color System) is such a system. By the use of this system one can describe any imaginable colour according to how they appear to man. Such a description is therefore totally
Independent of what sort of pigment or dye a coloured surface is made of and further it is independent of the composition of reflected radiation that reaches our eyes from the surface.
NCS is based on two important facts:
a) All people with normal colour vision "see colours alike". It is quite another thing that we may like or dislike different colours. The latter is dependent on other factors as experience, associations, culture, traditions, fashion etc.
b) There exist six different colours that are unique by the fact that they are perceived as pure colours and that they cannot be described in other ways than by themselves. The colours are pure yellow (Y), pure red (R), pure blue (B), pure green (G), pure white (W) and pure black (S). These elementary colours are "built into" the human colour vision. All other colours may be described by the varying resemblance to two, three or four of the elementary colours.

NSC Elementary Colours

The NCS system has six elementary colours. White and black (and grey) are achromatic elementary colours. Yellow, red, blue and green are chromatic elementary colours.

NCS Colour Space

Four of the elementary colours are placed horizontally at four equal steps of a circle which itself is given a third dimension by a line running from white to black through the origin of the circle. This three-dimensional model is called the NCS colour space.
It is between these points that any colour we see (all 10 million) can be visually measured, plotted, studied and given an exact NCS notation.



* For technical reasons the colours may differ from the original NCS samples.

NCS Colour Circle

The NCS Colour Circle is a horizontal section through the middle of the colour space where the four chromatic elementary colours are placed like the points of a compass. Each quadrant between two elementary colours has been divided into 100 equal steps. In the figure, the hue Y90R, yellow with 90% redness, has been marked.

NCS Colour Triangle

The NCS Colour Triangle is a vertical section through the colour space. The base of the triangle is the grey scale from white (W) to black (S) and the apex of the triangle is the maximum chromaticness (C) in the current hue, here Y90R. Colours of the same hue can have different blackness or chromaticness value, i.e. different nuances. This can be illustrated in colour triangles, where the scales are divided into 100 steps. In the figure, the nuance 1090 has been marked, a colour with 10% blackness and 90% chromaticness.

NCS Notation

The NCS Notation is the key to speaking the language of colour. Using the NCS Notation it is easy to define the appearance of a colour. In the notation above 1050 indicates the nuance of the colour.

The nuance describes the relationship of the colour to black (S) and to maximum colour intensity or chromaticness (C). The whiteness (W) is determined as 40%, as the sum of the values of three attributes (chromaticness, whiteness and blackness) must always be 100%.

The hue, Y90R, describes the relationship of the colour to the chromatic elementary colours, in this case Y and R. Y90R means yellow with 90% redness.

The letter S preceding the NCS notation means that the colour is from NCS Edition 2.

Achromatic colours (black, white and grey) lack hue and are only given nuance notations, followed by –N for neutral; S 0500-N or S9000-N.

The text and illustrations in appendix 3 are taken from the NCS Teacher's Guide from Skandinaviska Färginstitutet AB.