Study of Colour Shifts in Various Daylights: Dominantly Reddish and Greenish Rooms Illuminated by Sunlight and Skylight

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The article presents a study on colour appearance in natural daylight from different compass directions in Sweden. The intention of the study was to forecast how certain colours in the red-green sector would appear in a specific room, to help architects and designers in achieving required results from colour schemes. The problem was to find trends between inherent colour and identity colour in rooms facing different directions and illuminated by different kinds of natural light. An empirical study of dominantly reddish and greenish colours was conducted using full-scale rooms facing towards and away from the sun. Identity colours were described using five comparative methods. Results were compared with a previous study in environmental colour design concerned with yellowish and bluish colours. The study shows a regular pattern in shift of hue and nuance, from inherent colour to identity colour. In general, room identity colours were more chromatic and less whitish than inherent colours. In the room facing towards the sun all identity colours increased in chromaticness, particularly yellowish colours while reddish colours showed the least increase. Colours with a yellowish attribute shifted towards elementary yellow. In the room facing away from the sun a hue shift towards bluish-red was observed, and all colours increased in chromaticness, except yellowish colours.

1 Introduction

Choosing colours for interior design purposes poses the difficulty of trying to foresee how a planned design will appear in a given room. There is a general awareness that differences between a chosen colour sample and the end result can be expected. This is often encountered with the colour on room walls, which can differ quite markedly from that of the chosen colour sample. Colour appearance will also vary in rooms facing in different compass directions, i.e. rooms illuminated with different qualities of daylight. There are many different causes: visual, physical, psychological and emotional. The point of departure is those perceptual differences arising from rooms facing different compass directions, i.e. differences that endure after light adaptation. While much research has been conducted charting changes experienced in the colour of flat surfaces, colour appearance in three-dimensional space is a relatively new field. In recent years, Billger has worked with full-scale studies of rooms in artificial light, showing how lighting causes different patterns of colour appearance [1–4].

The present study was carried out between 0900 hours and 1500 hours during long summer days in Stockholm, Sweden. North- and south-facing rooms were chosen, since light conditions diverge the most between these two directions; the north-facing room was illuminated by skylight and the south-facing by sunlight. The intention was to gain an understanding regarding how such variations might appear for daylight-illuminated rooms with systematically selected inherent colours, since such an understanding is hitherto lacking. The aim was to conduct a systematic charting of any colour shifts from the chosen colour sample to the colour appearance in the room.

Empirical studies were conducted to investigate and map the nature of colour shift patterns.

Comparative methods with colour matching, memory matching and verbal description were used and further developed in full-scale studies in daylight. Twelve hues in two nuances were chosen from the NCS colour circle, with a perceptually equal distance between the chosen hues. The walls in two full-scale rooms were painted one at a time with these inherent colours.

This survey is part of a larger project relevant to colouring of interiors in daylight, and will be applicable to all such circumstances. The project was carried out in two phases with the same nuances but different hues. A similar study concentrating on yellowish and bluish colours has been published previously [5,6]. The current article focuses on reddish and greenish colours, and consequently is referred to as the 'red-green study'. Reddish colours are referred to in terms of 'pinkish', since reddish colours in these nuances generally are called pink. A part study was presented previously [7].

1.1 Terminology

The NCS (natural colour system) was used and its colour terminology was adopted [8]. Thus colour is defined as 'that which human beings see as colour as used to define objects and background on the basis of colour differences'. Hues are defined according to their relation to the six elementary colours red, blue, green, yellow, black and white. Hue relation is shown through its position in the colour circle. Thus orange has two chromatic elementary attributes: yellow and red. The colour triangle shows the colour nuance, described in visual proportions of blackness, whiteness, and chromaticness. Chromaticness is the sum of a colour's chromatic attributes.

Colour appearance is used as a general concept for research concerning how coloured materials appear under different lighting and viewing conditions[1]. The term *inherent colour* is used to denote the colour an object would have if observed in standard observation conditions used where the NCS colour samples accord with their colour notation. A D65 light source is used in the NCS standard situation while natural daylight was used in this study. The term *perceived colour* emphasises the importance of subject and colour changeability. I have, however, chosen to consistently use the term identity colour, which has evolved for colour studies in three-dimensional space [1] (p.11). *Identity colour* is defined as the main colour impression of surfaces or parts of a room that are perceived to be uniformly coloured. Local colour appearances, called colour variations, might depend on light distribution, reflections from other surfaces and contrast effects. The identity colour is a term corresponding to a holistic attitude, using real rooms instead of experimental set-ups. As a specific coloured material can vary in appearance under different specified conditions in a room, that phenomenon is called *colour elasticity*. This elasticity can be shown as an extension in three dimensions in colour space, or as mapped-out areas in the NCS hue circle and the nuance triangle [1] (p.12).

The difference between inherent and identity colours I term *shift*. This shift is described as the difference between inherent and identity colour expressed as steps in the NCS colour circle and colour triangle. I distinguish between a *hue shift*, *nuance shift* and *colour shift*, the latter being a shift in both hue and nuance. The *breaking point*[2] is a specified point in colour space where a general trend in shift stops and is replaced by a trend in another direction [9].

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[1] The ASTM standard defines terms used in description of *appearance* includes, but are not limited to colour, gloss, opacity, scattering, texture, and visibility of materials and light sources.

[2] Fridell Anter has previously used breaking point to denote a specified point in colour space where the general shift tendency discontinues and the inherent colour and perceived colour coincide. I use identity colour where Fridell Anter uses the term perceived colour.

I use the term *light quality* when referring to differences in daylight indoors caused by illumination from different compass directions. Natural daylight contains variations in spectral characteristic, light distribution and luminous intensity. These variations cause differences in spatial and colour perception. Thus colour impressions in a room can change, both in hue and nuance. The perceived colour of light is a quality in daylight as well as in artificial light. Light itself has no intrinsic colour, but in rooms with a corresponding inherent colour it can appear to have its own colour. Sunlight can be said the have a light colour, which amplifies yellow elementary qualities, something that skylight usually does not do [10,11].

1.2 Research on Colour Coordinates in Daylight

Different academic disciplines tend to look at a problem in different ways. One example is the different approaches adopted by practitioners in colour measurement and environmental studies. In the latter discipline there may be an uncertainty about the applicability of laboratory studies in real-life situations. A view can be taken that although a phenomenon is well understood in the laboratory, outside, in a practical application, the situation can be less clear-cut.

It is well known that differences in the intensity of illumination can cause changes in perceived colour [12] (p.79). At low luminance levels, red and green hues predominate over yellow and blue. The reverse is true at high luminance (the Bezold-Brücke effect). Increasing the intensity of coloured lights causes colours with a wavelength greater than 505 nm to shift towards yellow; those with wavelengths shorter than 505 nm shift toward blue. Three particular wavelengths are found to be invariant, purest blue (470 nm), green (505 nm), and yellow (572 nm). Increases in light intensity are also found to produce increases in saturation (the Abney effect). Unsaturated blues and reds shift toward purple.

In 2002, Romero *et al.* published a study concerning colorimetric changes on objects illuminated by natural daylight in Granada, Spain [13]. The horizontal surfaces of objects were measured at different solar elevations, on separate days, in different seasons, and under diverse meteorological conditions. The aim was to measure trends in daylight-correlated colour temperature, but not in relation to luminance. Comparisons were made between different solar elevations during the day, and between different days. Most important was that variations in the chromaticity coordinates followed the tendency shown by daylight itself. They elucidate the results as follows (p.27):

> If we express this in terms of appearance, the trends would be to diminish or to augment the red content respectively. Another way to express this would be that the variations are given in the red-green direction, depending on the relative yellow-blue content in the object's color.

1.3 Research on Environmental Colour

In 1983 Hård *et al.* conducted a study comparing colour samples in different types of lighting [14]. This was based on the fact that the sides of objects, when illuminated by different light sources, such as fluorescent or incandescent lighting, will have different colours. The study showed that within individual parts of the colour realm, varied illumination resulted in varying degrees of shift both in nuance and hue. Nuance shifts were small for slightly chromatic colours, but the more chromatic had a clear tendency towards greater chromaticness, except for blue where chosen samples were markedly blacker. From standard light (daylight fluorescent 5400 K) to incandescent light, yellow-green inherent colour gave a colour shift towards green; green to blue-green, blue-green to blue, and certain of the bluish inherent colours gave a colour shift to greater blueness. Yellow inherent colours gave a colour shift towards yellow-red, yellow-red to red, blue-red to blue; while red inherent colours displayed only minor hue shifts, most often towards yellow-red.

Billger conducted experiments with model and full-scale rooms, comparing colours in two- and three-dimensional studies [1,2]. I used Billger's methods and the term *identity colour* for colour studies in rooms. Billger developed a colour reference box for use in colour magnitude estimation [3,4]. The colour reference box enables comparison between identity colours in a room and colour samples placed in the box. The latter are illuminated with one form of artificial light source, artificial daylight (5400 K) and incandescent light (2800 K), while the room is illuminated with a different type. With these experiments, Billger could show evidence of patterns in colour variation. Test sequences concerning the colour reference box showed different scales, and could be constructed depending on different combinations of artificial lighting in both room and box. Identity colour was experienced as moving around the colour circle in different directions, depending on source of illumination. Yet all colour samples in the box were perceived as more yellowish in the room with simulated daylight compared with the room lit by incandescent illumination, regardless of the light source in the box. Hue shift tendencies valid for incandescent light and simulated daylight seemed to be comparable with results from my own daylight study of yellowish and bluish colours in rooms in sunlight and skylight respectively. Hue shift tendencies for colours in incandescent light are similar to tendencies in sunlight, and hue shift tendencies for simulated daylight are similar to tendencies in skylight.

Fridell Anter conducted colour studies in daylight to examine differences between inherent and perceived colours of facades [9]. Various types of lighting such as skylight and sunlight made up the variables, along with angle of observation, distance of observation and adjoining colours. She established that the difference between inherent and perceived colour was always greater than change caused by the different variables. Perceived colour always differed from inherent colour in nuance and sometimes in hue, the main difference being that perceived colour was always less blackish than inherent colour. Reduced blackness was compensated by greater whiteness and/or chromaticness. Whitish inherent colours resulted mostly in perceived colours in greater whiteness and unchanged chromaticness. Inherent colours with only a small proportion of whiteness increased in chromaticness, with unchanged whiteness. For hue changes she established a pattern similar to Billger's directions for colour samples in the colour reference box. Fridell Anter found that perceived hue tended in two directions from a stable position at Y50R where inherent colour and perceived colour coincide. She located a breaking point at Y45R from where hues tended anticlockwise towards another breaking point near R80B. From Y50R, colours tended in a clockwise direction towards R80B. This was most clear for more whitish nuances. Within the blue area, a zone exists between R70B and B with overlapping breaking points. Blue inherent colours with a small proportion of redness tended towards greater redness, while bluish-red inherent colours tended towards greater blueness. Light blue inherent colours tended towards blue-green, and Fridell Anter concluded that different nuances might have their own breaking points.

My previous yellow-blue study showed that daylight variations caused two different patterns for colour appearance in rooms [5,6]. Colour shifts resulting from light from different compass directions demonstrate a pattern *between* rooms. Beside this, a pattern was found for rapid variations *within* rooms. Reflections and changes in light quality caused shifts in identity colour in two ways: by shifts in hue and nuance. Sunlight caused yellowish rooms to show increased yellowness through hue shifts towards elementary yellow. All identity colours increased in chromaticness in rooms illuminated by sunlight, but mostly the yellowish colours. In sunlight, no or only very small hue shifts were observed in rooms painted elementary yellow and elementary blue inherent colours. On the other hand, colours with two chromatic elementary attributes showed a considerable hue shift towards yellow or blue respectively. Rooms illuminated by skylight showed increased blueness (increased chromaticness with bluish colours and decreased chromaticness with yellowish colours), and hue shifts towards elementary blue (Figure 1).

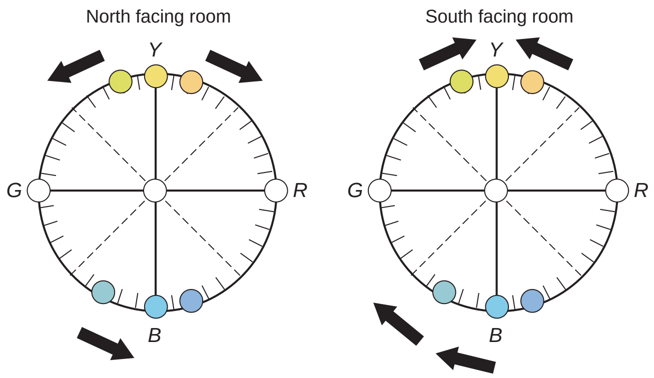

Figure 1 Hue shift in the yellow-blue study; the hues shift from elementary yellow in the north-facing room and towards the same in the south-facing room

1.4 Problems and Objectives

One problem is to identify how the colour appearance of a given room with walls of a specific colour will be affected in terms of hue and nuance; relevant factors include room size and distance apart of coloured (vertical) walls, reflectance and uneven light distribution from a window as well as a personal interpretation of the situation. A verbal description of the room and its colour completes the illustration. Another problem is to locate how the specific light qualities will affect hue and nuance in making comparisons between the rooms. The identity colour of the room can be described with a colour matching method and a colour reference box [4]. It is important to be able to identify tendencies for any shift in hue or nuance and locate breaking points where such tendencies turn in one or another direction. The overall objective has been to acquire knowledge to facilitate a preliminary forecast, in NCS steps, of how a planned colour will appear in a given room. A normal daylight situation is taken as the norm, as colour appearance in north- and south-facing rooms usually differs over the time span 0900 to 1500 hours. Ordinary paint and colours were used, with relatively small differences in hue and nuance between inherent colours. Treatment in the present article will be confined to colour shifts and breaking points between rooms and not within them.

Will light quality cause a nuance shift also with rooms in reddish and greenish colours? Can breaking points be identified through collating study results between this study and the previous yellow-blue study? Based on previous studies, the hypothesis is that rooms in reddish and greenish inherent colours will exhibit similar hue shifts as yellowish and bluish rooms did, as follows:

1. Room walls will reflect colours towards a shift in hue and nuance
2. A room in reddish and greenish inherent colours illuminated by sunlight will increase in yellowish attributes compared with the inherent colour
3. A room lit by skylight will increase in blueness, compared with the inherent colour, implying tendencies for hue shift exist also for reddish and greenish identity colours
4. Yellow and blue attributes will increase more in chromaticness than the reddish and greenish inherent colours.

2 Study Design

2.1 Observers and Experimental Rooms

The experimental period was June to September in Stockholm, where the sun rises between 0334 and 0634 hours and sets between 2205 and 1845. In total, 72 observers made 118 observations. Observers were architects and interior designers, plus students reading these subjects. This choice of professional category, with people interested in both colour and space, was made so as to obtain, as far as possible, informed and detailed descriptions. Each observer gave two complete descriptions of colour appearance in natural daylight, one in each room. These together took over one hour.

Two similar full-scale rooms were set up in a construction cabin positioned facing north–south[3]. Most of the time differences in colour temperature between the rooms were higher. The cabin was placed on a slope, with vegetation in front of the room in sunlight and other houses with yellow plaster outside the room in skylight. Room measurements were 4.2 × 2.9 m. The inner surface of the walls consisted of plywood roller-painted with a new inherent colour for each test sequence. Floors were covered with beige-speckled lino, and ceilings consisted of white-painted roof boarding. Both rooms had similar short-end windows with white-painted frames and inner reveals. The outside door and frame were painted brown (Figure 2).

2.2 Colour Selection

The colours chosen were three reddish and three greenish hues in two nuances commonly used in interior colour plans. They were chosen to have equal perceptual difference in hue between each colour sequence[4]. The nuances were whitish 1010 and the more chromatic 1030. The hues were yellowish-red (Y80R), red (R), bluish-red (R20B), bluish-green (B70G), green (G) and yellowish-green (G20Y). Due to unsuitable weather conditions over a lengthy period, one of

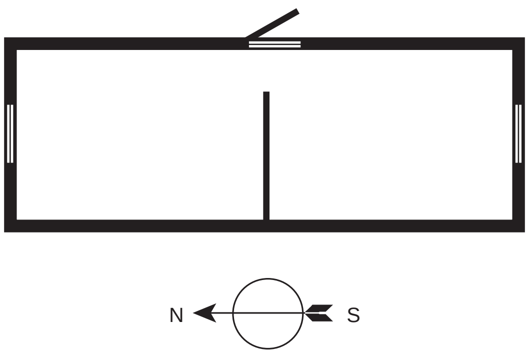

Figure 2 Experimental rooms; two experimental rooms were situated in a building shed, placed in a north–south direction; the rooms measured 4.20 x 2.90 m; observers were sitting so as to observe one room at a time

[3] Colour temperature on a fairly cloudy day was approximately 8000 K in the north-facing and to 7000 K in the south facing room. Most of the time differences in colour temperature between the rooms were higher.

[4] In the NCS colour system colours are arranged according to similarity with the elementary colours: white, black, yellow, red, blue and green. As a consequence, the NCS system does not define equal distance between elementary colours, and the colour circle has in fact less perceptual difference between colours in the blue-green quadrant than in the others. Consequently, I have chosen to adjust that situation by selecting one green inherent colour at a larger distance from the elementary green.

the 12 inherent colours was omitted: the pale yellowish-green colour (1010-G20Y) was left out in favour of the more chromatic yellowish-green colour (1030-G20Y). One yellowish and one bluish inherent colour that were used previously and might represent possible points for hue shift were included. These hues, reddish-yellow (1030-Y20R) and reddish-blue (1030-R80B), showed interesting patterns of hue shift, and were therefore subjected to further study. The identity colours of inherent colours displayed different tendencies in the experimental rooms, suggesting the presence of breaking points. They can furthermore function as colour references between the two studies (Figure 3).

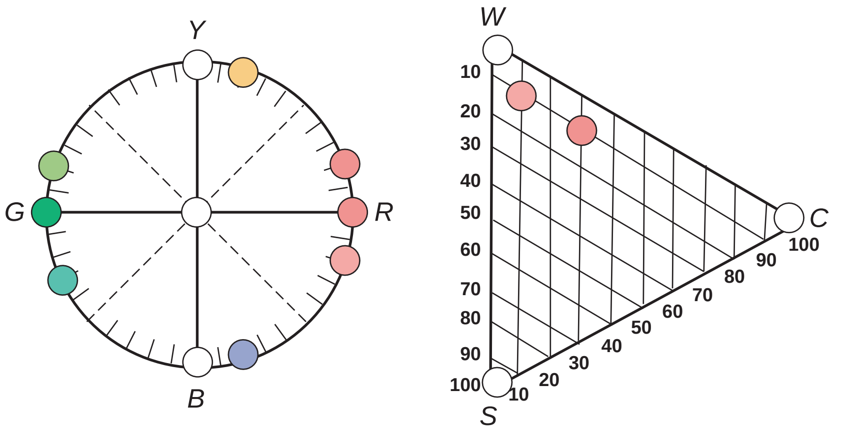

Figure 3 Selected colours in the red-green study; the NCS colour circle show the hues chosen and the nuance triangle show the nuances (whiteness, blackness and chromaticness)

2.3 Empirical Methods

The operative terms of the study are inherent colour and identity colour. Five methods of comparison were used

1. Colour matching method aided by *colour reference box*
2. Verbal description in standardised colour terms
3. Verbal description using *own vocabulary*
4. Memory matching in comparison between rooms
5. Colour matching with *given colour samples*.

Observers remained in each experimental room throughout the individual case. After adaptation to room light conditions, perceived colour in the room was to be described verbally. A spontaneous impression of entire room would be described using the observer's own words to capture the moment, with a description relating to hue and nuance ensuing. Identifications of colour on three of the room walls were then evaluated. On the instructions of the observer, the experiment supervisor picked out colour samples to be placed in a colour reference box. The observer compared the identity colour of the room walls with colour samples in the colour reference box until a good matching was found. After that, a verbal comparison was made using the observer's own words to compare the identity colour of the wall in the current room with the colour recollected from the previous room. After completion of this series, the box was moved to the second room and the process was repeated. Finally, colour matching of both rooms with given colour samples was undertaken.

Colour Reference Box

This was the basic method for colour matching. The observers described the wall colours by comparison with colour samples placed in the box and displayed through a small opening so that the box illumination would not leak out. The samples were illuminated with a D55 light source (Osram Dulux 5500 K, R_a 96), the same in both rooms, and thus functioning as standard lighting.

Verbal Description in Standardised Colour Terms

Observers were asked to describe the identity colour's hue and nuance in terms such as reddish, yellowish, greenish, bluish, blackish, greyish and whitish. This method was used as a supplement to colour matching and has previously been used as a method of analysis.

Verbal Description with Own Vocabulary

The idea was to find means to describe colour appearance using the observers' own vocabulary of colour response in each room. A method for free mode of expression was used here in order to capture spontaneous descriptions of colour response. Colours make an instant impression that takes some time for a subject to transform into colour terms and colour codes. This first impression may persist in situations where no further description is asked for; such is the case in daily life. Therefore comparing such spontaneous descriptions with colour shift data is useful.

Memory Matching Method

This method was used for direct comparison between the rooms. Observers were asked to provide a verbal description of how the present room looked in comparison with the previous one. Comparison between the rooms was made in the second room, 20–25 min after leaving the first one. This method is concerned with the observer's instant colour impression.

Method with Given Colour Samples

This study was conducted between the two rooms. Selected colour samples were compared side by side in front of the dividing wall between rooms to achieve similar illumination on the colour samples. These samples were chosen in advance once a tendency had become clear after the initial observations, and were presented to observers as the concluding element following studies in the two rooms. A new set of colour samples was selected prior to each new inherent colour. One colour sample was chosen to represent identity colour in each room. Each set of colour samples had the same nuance, i.e. 10 steps more chromatic than the inherent colour. Hues were chosen so that the inherent colour would flank a colour sample on each side of the hue circle, along with an additional colour sample with a probable shift tendency.[5] This method was introduced to give the study greater comparative qualities. Colour matching using given colour samples is relative and comparative.

2.4 Methods of Analysis

Data from colour matching with the colour reference box were tabulated. Inherent colours represented points of reference, while shift was calculated as the difference between inherent

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[5] When the inherent colour was 1030-R, I selected 1040-Y90R, 1040-R, 1040-R10B and 1040-R20B as given colour samples.

and identity colours. Blackness, whiteness, chromaticness and hue of inherent and identity colours were added to the statistics, together with compass direction, weather and time data. Data were statistically analysed by simple frequency analysis as mean values. Data from the other methods described above were used for supplementary and comparative analysis, especially in cases when colour matching with the colour reference box failed to concur with the general tendency.

The box was used principally as a standard method to gain instant and comparative data, in individual cases and between cases.

3 Study Results

Results of the study show that daylight in both rooms caused clear patterns of shift in hue and nuance, from inherent colour to identity colour; the pattern differed between compass directions, and between hue and nuance series.

Differences in nuance were recorded within the room in itself. Room identity colours had a lesser proportion of whiteness than inherent colours, in general by 10 NCS steps. There was also a clear perceptual difference in chromaticness between inherent and identity colours. Reduced whiteness was compensated for by greater chromaticness and sometimes also in blackness. The average increase in chromaticness was five to 10 steps, and increase in blackness was up to five steps.

Both series of *nuances* had their own variations. The whitish nuance 1010 shifted more in hue than the 1030 nuance did. The more chromatic nuance in turn, 1030, became more chromatic. The various *hues* had individual patterns for chromaticness. This was most evident in the 1030 nuance since this series contained three more experimental colours. Chromatic patterns were heavily influenced by room compass direction. Chromatic differences were greatest with the bluish and yellowish identity colours. In most cases when the room was given the inherent colour bluish pink (1010-R20B and 1030-R20B) the study was conducted in rainy weather as can be seen from the results where these identity colours include a great deal of blackness.

3.1 Influence of Compass Direction

Hue shift tendencies were strongly influenced by the different light quality originating from different compass directions. The greatest chromatic increase in the reddish-blue colour (1030-R80B) was observed in the room in skylight, by 15 steps. Pinkish (1030-R), and bluish-pink (1030-R20B), greenish (1030-G), and bluish-green (1030-B70G), increased by approx. 10 steps each in chromaticness. Yellowish colours and attributes increased least in chromaticness; yellowish-green (1030-G20Y) and reddish-yellow (1030-Y20R) by only 5–6 steps, while increasing in blackness (Figure 4).

The same north-facing room caused a hue shift towards a bluish hue. The greatest hue shift was caused in the whitish nuance, 1010; light bluish-green (1010-B70G) and light green (1010-G), 35 steps, the light pink (1010-R) and light bluish-pink (1010-R20B), 15–18 steps. Colours with a yellowish attribute tended towards red or green, indicating a breaking point at yellow (Y). The reddish-yellow colour (1030-Y20R) appeared as pink, and the yellowish-green (1030-G20Y) room tended towards increased greenness. Another breaking point zone was located between reddish-blue and bluish-red (1030-R80B and 1030-R20B). In the 1010 nuance the yellowish breaking point seems to be much closer to elementary red, between yellowish-pink and pink (Y80R–R).

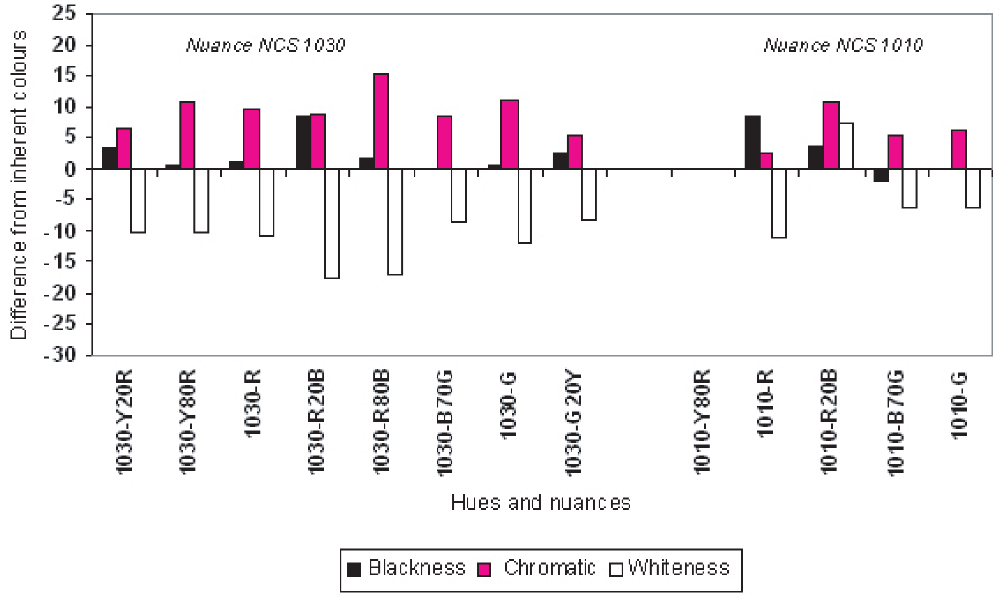

Figure 4 Nuance shift in the north-facing room; the inherent colours are represented by level zero; nuance 1030 has greater nuance shift than 1010 (bluish, reddish and greenish colours increase most in chromaticness)

The greatest chromatic increase in colours with a yellowish attribute was observed in the room in *sunlight*; the reddish-yellow colour (1030-Y20R) used for reference purpose increased 20 steps in chromaticness, yellowish-green (1030-G20Y) and yellowish-pink (1030-Y80R), 13 steps. The smallest increase in chromaticness, 6–7 steps, was observed with the inherent colours pink (1030-R) and bluish-pink (1030-R20B). In the same room less blackish increase in identity colours were observed in comparison with the north-facing room (Figure 5). In the south-facing room, yellowish attributes tended between a stable position and a more yellowish hue. The yellowish-green room (1030-G20Y) appeared stable in hue, 0 steps, while the yellowish-pink room (1030-Y80R) tended towards elementary red, 5 steps. The reddish-yellow colour (1030-Y20R) tended towards elementary yellow, 5 steps. Remaining pinkish and greenish inherent colours shifted towards increased bluishness in both rooms, yet with fewer steps in the room facing towards the sun (Figure 6). The relative difference between the north- and south-facing rooms is clear (Figure 7).

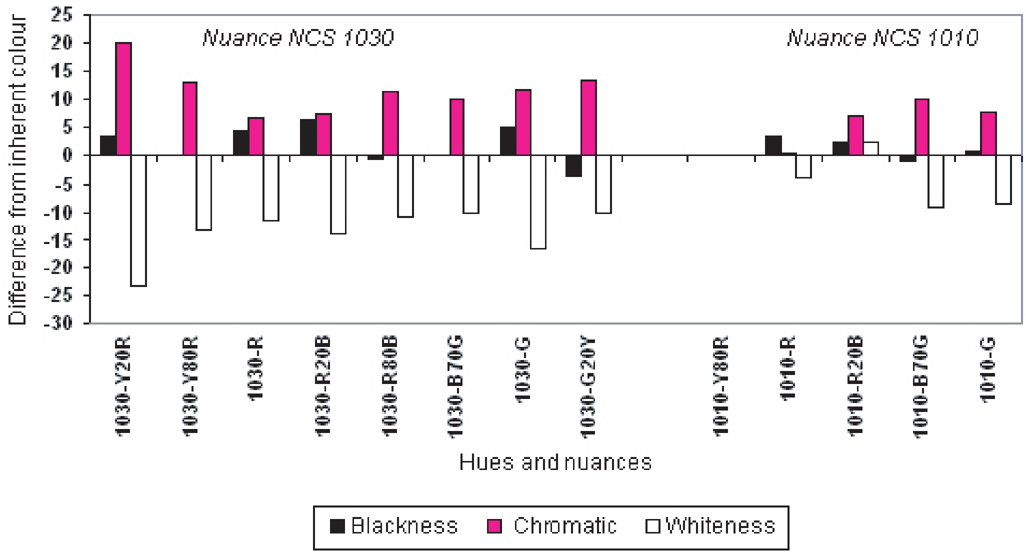

Figure 5 Nuance shift in the south-facing room; the inherent colours are represented by level zero; nuance 1030 has greater nuance shift than nuance 1010 (yellowish colours increase the most and reddish the least in chromaticness)

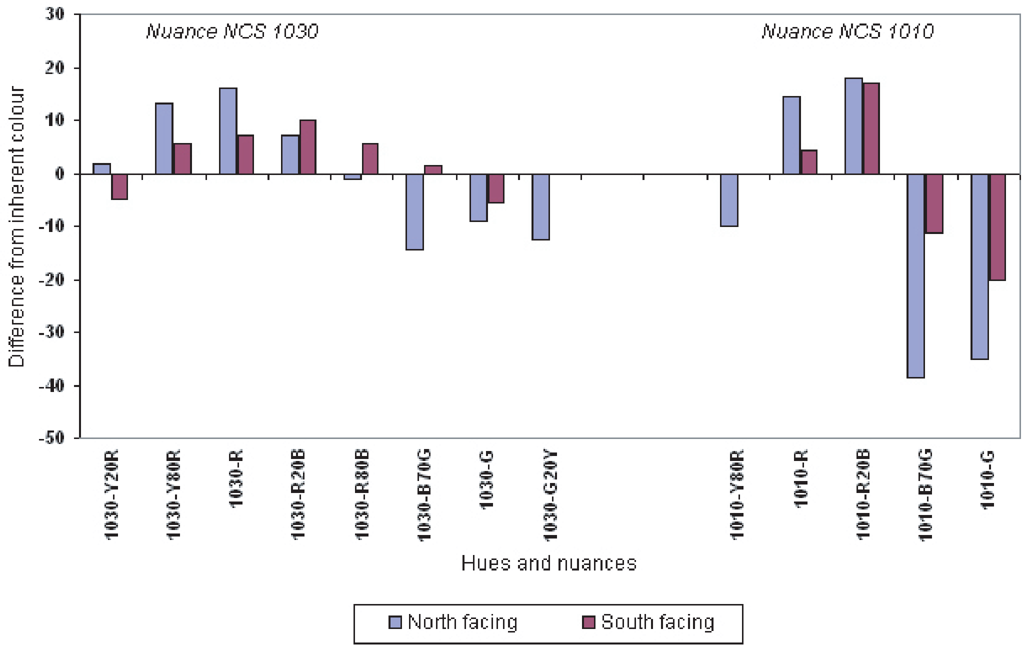

Figure 6 Hue shift tendencies in comparison between the rooms; nuance 1010 has greater hue shift than 1030;

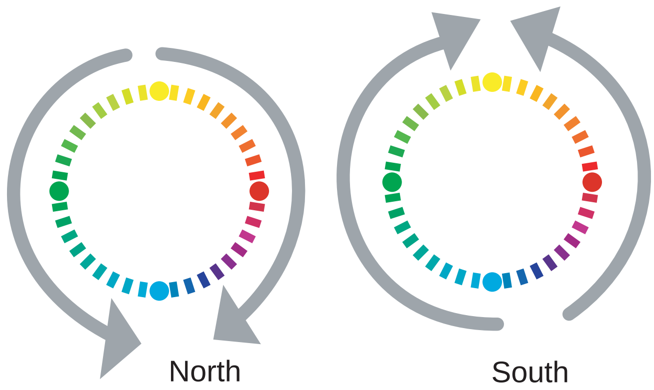

Figure 7 Hue shift tendencies in both rooms; results compiled from the yellow-blue and the red-green studies; the two compass orientations involved caused opposing hue shift tendencies; the colours tended to be more bluish in the north-facing and more yellowish in the south-facing room

3.2 Colour Response with Own Words

Observers applied different verbal descriptions using their own words, mostly expressions of sense data. The expressions are easy to understand but more difficult to comprehend in relation to the colour shifts. The identity colour of inherent colour 1030-Y80R in the room in skylight was described as 'sharper', and in sunlight as 'softer'. No specific data difference explaining choice of words could be found, yet the choice is so apt; there are no other differences than absence or presence of yellowness. Words such as 'soft' and 'rich' were often particularly used to describe identity colours in rooms in sunlight. In skylight, identity colours could be described as thin. Rooms in sunlight showed increased yellowness, especially pinkish colours but also greenish ones, giving a soft and rich appearance. The same inherent colours in the room illuminated by skylight seemed to lack an intermediate colour, and gave an empty, thin or sharp impression. Bluish-pink in the room facing towards the sun appeared as 'soft' when described as greyish-pink or greyish-purple, while the same inherent colour in the room facing away from the sun was described as 'horrible red' as it appeared as reddish-violet (Figures 8 and 9).

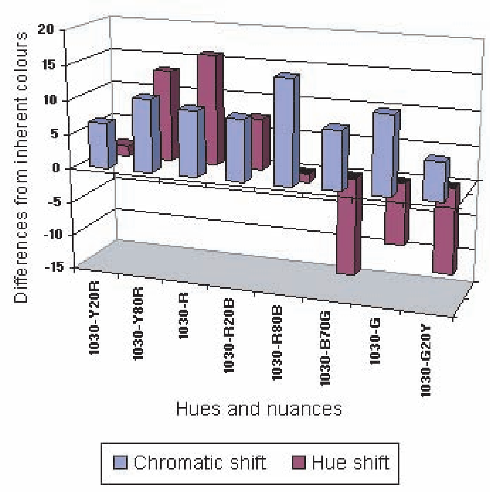

Figure 8 Colour shifts in the north-facing room; the greatest chromatic increase was found in the bluish, reddish and greenish colours; the hue shift tendency went from yellowish towards elementary blue

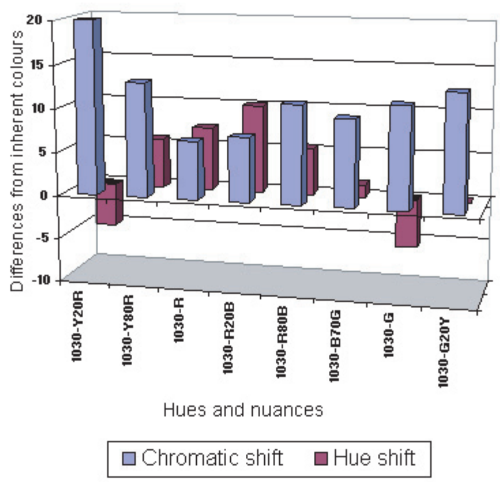

Figure 9 Colour shifts in the south-facing room; yellowish and greenish colours had greatest chromatic increase, the hue shift tendency went towards increased yellowness

4 Discussion

4.1 Study Comparisons

Tendencies for hue shift from inherent colour to identity colour were the same in both interior studies. Skylight increased bluishness, likewise sunlight enhanced yellowness in both hue and nuance. Hue shift in the north-facing room tended in two directions: from yellowish towards a bluish and reddish hue. In the south-facing room the opposite tendency was observed: from bluish and reddish inherent hue towards elementary yellow. In both cases yellowish chromaticness and a zone in the reddish-blue and bluish-red area are crucial. In the previous yellow-blue study the reddish-blue reference colour (1030-R80B) was unstable, but in the current study a tendency towards elementary blue in the room facing towards the sun was unequivocal. The identity colour tended towards reduced redness (R90B), while the skylight caused an increased redness (R75B). This correlates well with Fridell Anter's 'overlapping breaking points' [9] (p.107) in the blue area, between R70B and B. Blue inherent colours with a small proportion of redness tended towards greater redness, while bluish-red inherent colours tended towards greater blueness. This may depend on the so-called 'purple gap'; as the inherent colours are bluish-red and reddish-blue, very small changes in the light situation may cause abrupt colour shifts in this area.

Fridell Anter agrees on the observation that the different nuances appear to possess different breaking points. Nuance 1030 increased in chromaticness both on facades [9] (p.226) and in rooms.

4.2 Hue Shift as Perception and Response

In both rooms green inherent colours in nuance 1010 entailed the greatest hue shift, calculated in terms of number of steps in the NCS systems. Despite this, pink colours, which typically made deep emotional impacts, appeared as varying most in hue. This was noticeable in both verbal descriptions and spontaneous judgements. Might the green hue shift have been exaggerated in order to make visible the relatively small differences between hues in the green-blue sector? The distance between elementary colours in the NCS colour circle grants a perceptually greater space in the quadrant between blue and green elementary colours, i.e. small differences between hues. With the other quadrants, perceptual space is less and the difference between the various hues greater. This is particularly the case for the quadrant between red and blue. Five steps in the red-blue quadrant result in a large perceptual difference between hues, whereas five steps in the blue-green quadrant convey only a small difference. This means that the many steps in the green quadrant do not necessarily result in a major difference between hues.

Shifts in hue and nuance, even small ones, can cause major differences in colour appearance. For example, a yellowish colour, when it shifts five steps more blackish, appears as a brownish nuance; a pinkish colour, when it shows a 10 step increase in chromaticness along with a 15 step hue shift towards blue, differs clearly from the same inherent colour that undergoes a 5 step increase in chromaticness and a 5 step hue shift. Figures 10 and 11 show approximately how certain colour shifts might appear, in the relationship between rooms and between inherent colour and identity colour, despite the significant risk of erroneous colour rendition.

4.3 Discussion of Methods

The broad methodology selected for the project is very important: as the appearance of these rooms was changed by shifts in both hue and nuance, the responses recorded were complex and interdependent.

Colour matching using the colour reference box is an effective method; through careful observation it allows observers to see the results of their matching. When an observer had difficulty in verbalise differences between hue and chromaticness, the method served to clarify,

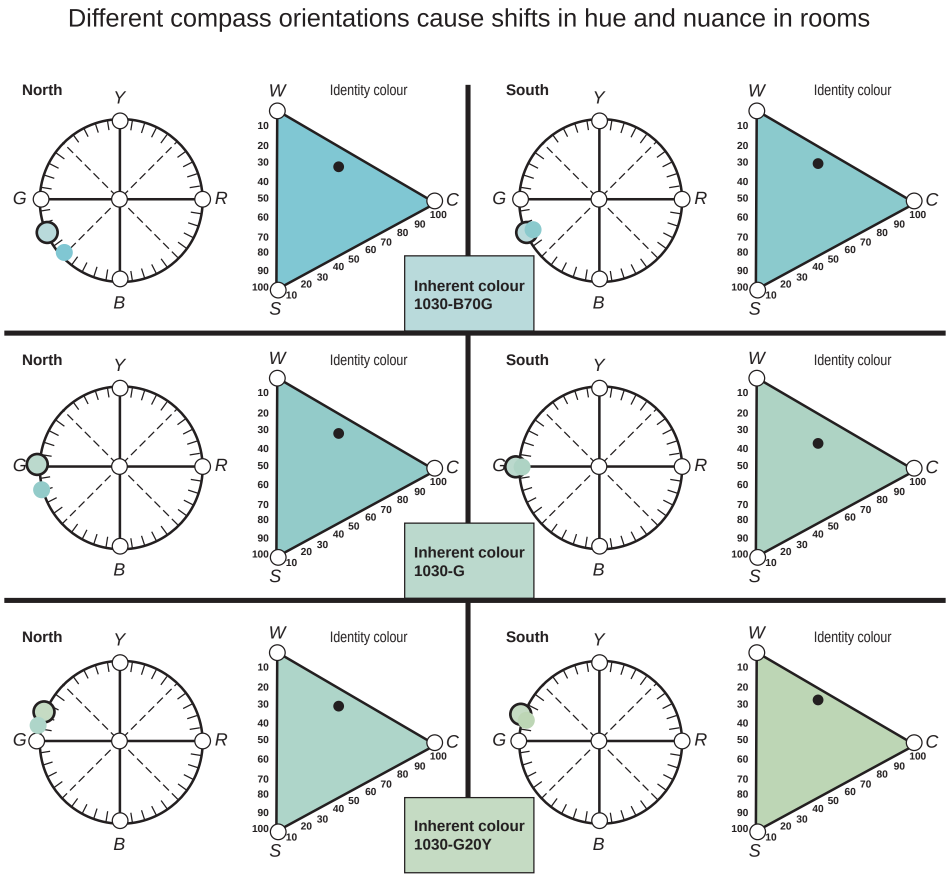

Figure 10 Greenish colours in both rooms; colour appearances from the north-facing room are displayed to the left and the south-facing to the right; top 1030-B70G, middle 1030-G, bottom 1030-G20Y; inherent colour with black contours can be seen in colour circle, with adjacent identity colour in the nuance triangle

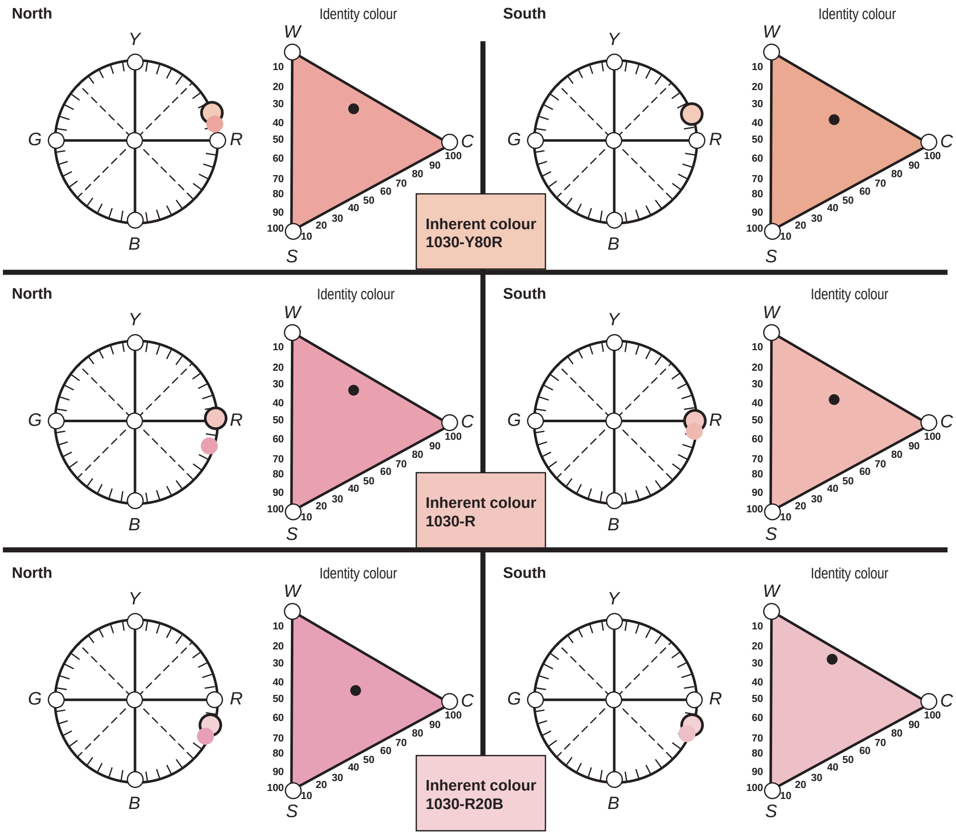

Figure 11 Pinkish colours in both rooms; top 1030-Y80R, middle 1030-R, bottom 1030-R20B; inherent colour with black contours can be seen in the colour circle, with adjacent identity colour in the nuance triangle

providing visible results to adjustments made. This in turn had a positive effect on verbal description. Earlier tests have shown that adaptation effects caused by the colour reference box can be calculated and corrected, although adaptation was negligible for the rooms in daylight [3,4]. The risk of adaptation effects for reddish and greenish inherent colours was not considered to arise, as inherent colour and light quality together do not cause maximum colour effect. Neither the supplementary analysis nor the observer's spontaneous reactions indicated any adaptation effects, though such effects cannot be completely excluded.

The new method involving given colour samples was a successful supplementary method. It lacked precision but made comparison between rooms clearer. Data from the memory matching method were used only in a supplementary analysis in cases were the observers had trouble using the colour vocabulary and that it affected the colour matching. Concerning the method involving verbal description with the observer's own vocabulary, i.e. without preconceived colour terms, it is clear that important possibilities exist here which cannot be encapsulated by official colour terminology. This was particularly clear in comparative descriptions of identity colours. Details covered by these descriptions could not be explained by any other method and they deserve to be further studied.

The hue shift tendency with natural daylight quality in the south-facing room was surprising and worth another study. It was directed towards elementary yellow in two directions from areas where the yellowish attribute was weak, in the yellowish-red and the yellowish-green quadrants respectively. The yellowish-red area corresponds with other research concerning artificial light [1,2] and natural daylight [9] (p.107), and the yellowish-green inherent colour and identity colour coincided. This may be explained by Romero's observation that an object's relative yellow-blue content also shows as variations in the red-green direction [13].

5 Conclusions

Collating data from both interior studies a regular and considerable pattern was demonstrated for shifts in hue and nuance depending on the light quality. Sunlight, yellowish and greenish colours were concurrent as were skylight, bluish and reddish colours. Even changes as small as 3–5 NCS steps are clearly noticeable colour shifts.

Two breaking points in hue shift directions have been identified in the north-facing room. A more complex pattern for breaking points was observed in the south-facing room.

In terms of observed nuance shifts, the room identity colours became less whitish and more chromatic compared with the inherent colour. Comparing nuances, the less chromatic nuance (1010) was associated with greater hue shifts, while the more chromatic nuance (1030) was linked to greater increases in chromaticness.

The strategy of adopting multiple methods to describe colour appearance showed considerable scope as it enables more than one aspect of colour to be registered. The technique of encouraging users to describe colours verbal using their own vocabulary seems to be a promising method for further explorations of colour appearance.

Using the colour reference box in a colour matching method, subjects were able to describe identity colour and compare colour appearance between rooms. This enabled a fine gradation between different identity colours to be made. This gradation also helps to consider colour elasticity in various cases.

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