

Colorfulness and Reflectivity in Daylit Spaces

Esther Hagenlocher

Department of Architecture, University of Oregon, Eugene, OR 97403, U.S.A. e-mail: ehg@uoregon.edu

***Abstract:** Color reflectivity is valuable not only architecturally and aesthetically but also in terms of performance. The higher the reflectivity of a space the more evenly light is distributed in the space. Reflectivity can improve the performance of a building's system and also increase the occupants' sense of well-being. Given the benefits of color reflectivity, why are rooms not typically designed with high reflective surfaces? The proposed research focuses on the connection between daylight and color reflectivity in understanding how to optimize reflectivity in interior spaces to improve lighting efficiency and visual comfort.*

***Keywords:** color, pattern, harmony*

1 Introduction

Buildings consume 70% of all U.S. electrical energy production, most of it for electrical light. Therefore day lighting is an important strategy both to save energy and reduce greenhouse gases that cause global warming. The amount and distribution of daylight is a function of window size and location, room geometry and surface reflectivity. In a room with a single window, the wall opposite the window contributes to the daylight in the room in proportion to its reflectivity. As the reflectivity of all room surface goes from 90% to 10% the daylight factor at the back of the room drops by 13-1.75%. (Fig.1)

Reflectivity is not only valuable architecturally and aesthetically but also in terms of performance.

Daylit spaces with high reflectivity distribute the light better, are brighter, and therefore more efficient. As the distance from the window increases, the available daylight in the room is provided decreasingly by the sky and increasingly by the reflectivity of the interior surfaces.

Spaces that have high reflectivity have a lower contrast between the brightness of the light at the window and that of the interior room surfaces. Increasing

reflectivity not only increases the daylight in a space but also distributes it more evenly, improving visual comfort.

Given the benefits of reflectivity, why are rooms not typically designed with more reflective surfaces? There are several anecdotal reasons that designers tend to use interior surfaces of low reflectivity.

- Dark colors and heavy materials, such as red velvet, still seem to be more elegant and valuable than lighter ones, such as light-colored linen. Likewise, dark wood finishes like mahogany seem richer than light-colored ones like maple. This is a result of our aesthetic values.
- Floor coverings that have lower reflectivity are seen as easier to keep clean.

Our aesthetic valuing of deep colors thus conflicts with the high reflectivity that is more effective for daylighting.

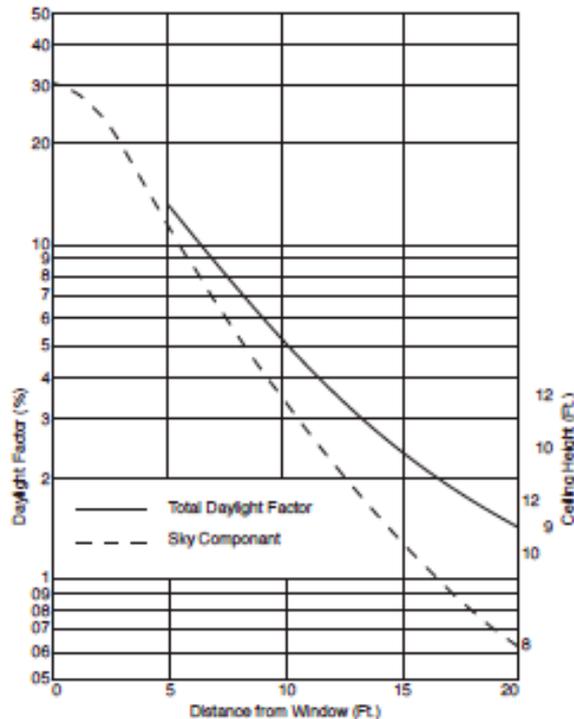


Fig. 1: After a graph by Hopkinson, R.G.: Daylighting. The variation of Sky Component and DaylightFactor with distance from window. P. 43. (2).

Hypothesis:

The average reflectivity of an interior space can be increased without changing people's perceptions of the color in the space.

2 Significance of the project

In my project I conducted experiments using color games and models of rooms to compare subjects' perceptions of colors and reflectivity to actual measured reflectivity. Although these are preliminary experiments and results, the implications were of sufficient interest to continue the work. Observations have been collected, and since the set-up and models can be reconstructed anytime, the experiments provide a source of data. Multiple personal tests are now being conducted, and I will increase the number of human subjects in a larger experiment.

My hypothesis is that low reflective interior surface effects like rich color can be achieved with little change to the space's overall reflectivity. In the case of rich colors, some surfaces (for example, walls) play a less important role in delivering average room reflectivity than others. These walls for example, are candidates for locating color if those same surfaces are primary to the perception of the overall color of the space.

The higher the reflectivity of a space the more evenly light is distributed within the space, diminishing the contrast in brightness between the window and the walls, which results in greater visual comfort.

Metric units are preferred for use in IEEE publications in light of their international readership and the inherent convenience of these units in many fields. In particular, the use of the International System of Units (SI Units) is advocated. This system includes a subsystem the MKSA units, which are based on the meter, kilogram, second, and ampere. British units may be used as secondary units (in parentheses). An exception is when British units are used as identifiers in trade, such as, 3.5 inch disk drive.

There are two ways that reflectivity apertures can improve the performance of a building's systems.

First, by saving energy: daylight is more efficient at providing light than most electric light sources, so less heat is produced for the same amount of light. Therefore, high reflectivity in a building can reduce not only the building's use of electric light but also its use of cooling energy. As a result, it can reduce peak energy use, as well as total energy consumption.

Secod, visual comfort increases with the use of daylight because daylight is the light source that most closely matches the human visual response (psychological and physiological benefits). It often takes a lower level of daylight to perform a task than it would to perform the same task in electrical light. A good visual environment created by windows and reflective surfaces affects a person's ability to see objects in a room properly and to perform visual tasks.

3 Guiding research questions and experiments

A series of experiments were done to test the hypothesis. These experiments were designed to answer these questions:

- Can we achieve the perception of (deep/rich) colors while also providing reflectivity?
- How can the reflectivity of an interior be increased while maintaining the richness and depth of color to provide variation?

Since everything we see results from emitted or reflected light, the reflectivity of surfaces in a room (walls, floor, furnishing etc.) is a large factor in how we perceive and experience the space. Diffuse surfaces determine the distribution of light in a space and their reflectivity determines the amount of light in the space. Beyond its aesthetic value, surface reflectivity determines how efficient daylighting is. For example, classrooms with a window on only one side average a daylight factor that varies from 0.7% when the average surface reflectivity is low, to 1.5% when it is high—a change of 50%. Previous work in this area done by R.G. Hopkinson is described by him as follows: “The chief objective of these experiments was to trace the changes in quality of a color seen in shadow or bright light in terms of Hue, Value and Chroma”.

It is clear that high reflectivity is important, but most commonly used materials and finishes are not very reflective, as one can see from the measurements below. Final finishes for surfaces common in interior spaces, such as wood, linoleum, and fabric (felt and linen), have a maximum of 40% Light Reflectance Value (LRV).

(Fig. 2) Furthermore, the colors most often used for interiors are in the low reflective ranges, because designers typically overestimate the reflectivity of colors, and most of the colors available in the commercial color palette are in these low reflectivity ranges. (Fig. 3) The availability of high reflective colors in the “*Off White*” palette is also rather limited.

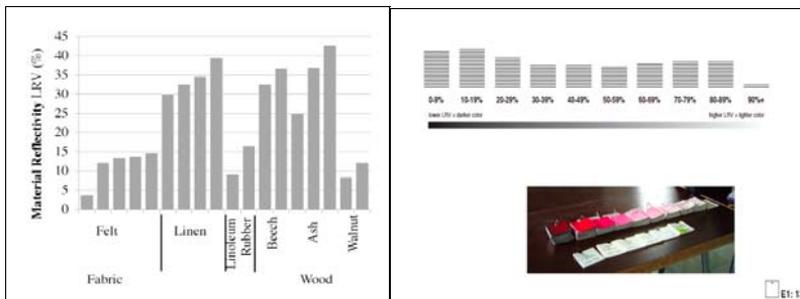


Fig. 2: Final finishes for surfaces common in interior spaces (left).

Fig. 3: Colors available in the commercial color palette are in low reflectivity ranges. Example: A manufacturer's color section: “Color Preview” (right).

4 Evaluation of reflectivity. “The ColorGame”

4.1 The First Experiment

The “Color Game” was an experiment set up to observe how people perceive colors, because their perception of color

influences their choice of color—an issue of special importance to an interior designer.

A set of 150 colors (matte surface) with a range of 0-90+% Light Reflectivity Value (LRV) were mixed up and divided

into five groups of 30 different color patches. A matrix (Fig. 4) consisting of 10 different pages for 10 reflectivity percentage ranges (0-9%, 10-19%, 20-29%, 30-39%, 40-49%, 50-59%, 60-69%, 70-79%, 80-89%, 90-99%) was hung on the wall in a horizontal continuous line. On each matrix page were two rows of each four cells, each the size of the color patches. Under each column was a line, indicating that the result will be noted there.

A group of 30 people was divided into six groups. Each group was given 30 color patches and had to rank the LRV of each one by putting it in the top row of the

matrix. They then checked their conclusions against the actual LRV of the colors. If they had chosen the right color, the patch remained in the top row. Otherwise, it was put in the appropriate category in the cells below, with a remark on the line where they had it before. For example, if the LRV was 20%-29% and they had the patch in 40%-49%, they indicated +II. (Fig. 4+5)

Out of thirty colors, each group on average correctly evaluated only five colors. Most of the other colors were perceived to have a higher LRV than they actually had. Most colors in the range of 30%-80% were perceived as having a 20% higher reflectivity than they actually had. This shows that designers tend to overestimate the reflectivity of colors. Colors in the LRV ranges of 0-9% and 90+% were usually correctly perceived. Obviously these colors are easier to evaluate. (Fig. 6)

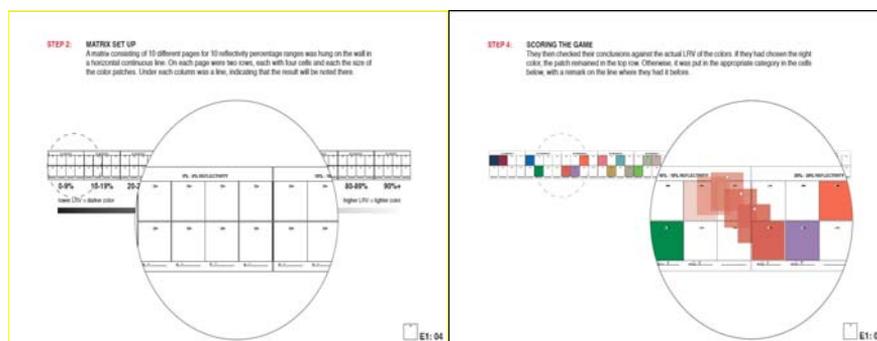


Fig. 4 (left), Fig. 5 (right): Matrix page for the “Color Game”. Set up: Step 2+4.

4.2 The Colorfulness of Color

Colorfulness and Chroma is described by Mark C. Fairchild as comprising one dimension of color (the others being hue and brightness/lightness). In his description, “Colorfulness is to chroma as brightness is to lightness...Colorfulness describes the intensity of the hue in a given color stimulus. Thus, achromatic colors exhibit zero colorfulness and chroma, and as the amount of color content increases (with constant brightness/lightness and hue), colorfulness and chroma increase)” [3].

- Colorfulness is the “attribute of a visual sensation according to which the perceived color of an area appears to be more or less chromatic.”
- Chroma is the “colorfulness of an area judged as a proportion of the brightness of the similarly illuminated area that appears white or highly transmitting.”

4.2.1 The Second Experiment:

In this experiment, I looked at techniques that have been used architecturally, such as reflective surfaces. I used a set of

experimental measurements to test anecdotal knowledge about the perception of color in space.

Seven identical boxes, or models, were built out of black foam board so that no light could go through the edges. The inside was covered in white for high reflectivity. Each box was 8 x 8 inches in plan and 8 x 8 inches in elevation.

One side had a central opening: a 2-inch square aperture, or “window.” On the opposite side was a central view port of half an inch diameter. The side, or “wall,” with the 2x2” opening was colored in a range of 7 different commercial colors, varying in Light Reflectivity Values from 0% to 99%. The colors are listed below, along with their LRVs (percentages).

Exotic Pink	68.3%
Flamingo’s Dream	40.2%
Calypso Orange	37.8%
Red	11.7%
Strawberry Red	14.2%
Red	13.2%
Raspberry Truffle	8.5%
Chestnut	7.2%

In this experiment 30 participants were tested for their perceptions of color. The boxes, each with a different shade of red on the inside surface of the wall with the window, were observed in different light levels. Observations (monocular) were made at a distance of 5 to 6feet. Despite the actual performance of the Light Reflectivity Value in the color range of seven shades of red, the boxes with the “Flamingo’s Dream LRV 40.2% and Calypso Orange LRV 37.8%” were perceived by most of the observers to be the most colorful. This result contradicts the assumption that colors with the lowest reflectivity values are the most colorful. (Fig. 7)

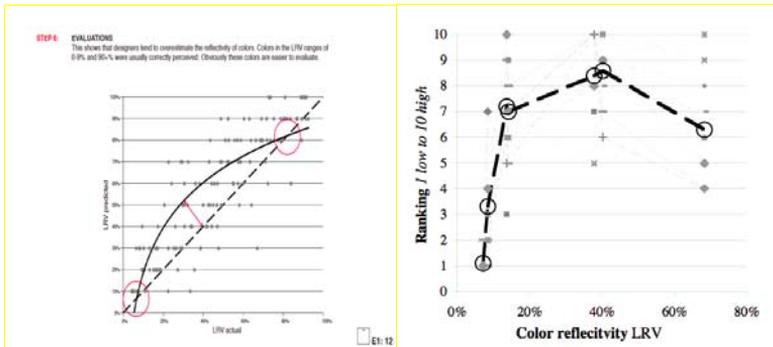


Fig. 6: The graph of “The Color-Game” shows color in the range of 30%-80% were perceived as having a 20% higher reflectivity as they really have (left).

Fig. 7: Observers perceived a room to be the most colorful wall when it was in the reflectivity range of 30%. (right).

4.2.2 The Third Experiment:

In this experiment, I built a series of boxes (as in the second experiment), or models of interior rooms, to address the question of reflectivity under changing room configurations. Each of the boxes represents a room with a window on one side, as described in the previous experiment. One set of boxes had the color at the window side. Another set of boxes had the color on all five sides except the window side. (Fig. 7) The project was designed to study the relationship between the amount (size) of color—and its location and reflectivity—and the human perception of it, along two variables: (Fig.8)

- How the daylight factor changes under the same light conditions; and
- How people perceive the color of a room as the amount, location, and reflectivity changes.

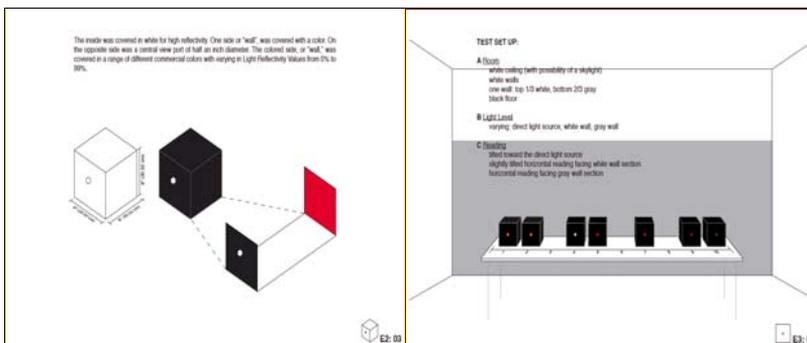


Fig. 7: The “Appearance of Color” – The Box (left).

Fig. 8: Observations were made at a distance of 5 to 6 feet from specific light levels (right).

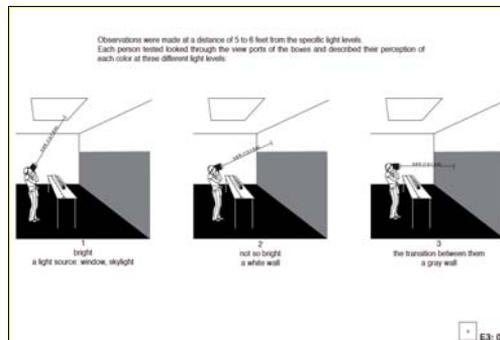


Fig. 9: Observations were made at a distance of 5 to 6 feet from specific light levels.

The boxes provided a limited point of view. Participants could not see the whole space; they could only see the opposite wall with the window and a quarter of the neighboring walls.

The experiment shows that the Average Room Reflectivity (ARR) changes very little within the range of colors from an LRV of 7% to 68% if only one wall is colored. But the ARR changes dramatically when all five sides are colored.

The question asked was: Which is the most colorful room? Each version of the boxes tested (1-walls colored or 5-walls colored) showed the same result, which indicates how important the field of view is and that controlling the view is a way to make a space appear colorful. (Fig.9)

Conclusion

These experiments showed that the eye is capable of making separate judgments about color reflectivity, and therefore the results provide a proof of my hypothesis:

1. That designers/people overestimate colors and can't tell their Light Reflectivity by just looking at the color or the surface.
2. That the most colorful colors are not necessarily the darkest ones.
3. That the average rooms can appear very colorful without changing room reflectivity.

The implications from these results are that designers should not rely on their intuition but need tools to optimize color reflectivity and the use of other surfaces and materials of higher reflectivity in interior spaces to improve lighting efficiency and visual comfort without losing the design effect.

Daylighting is well documented, as is the architectural role of reflectivity, but the connection between daylighting and reflectivity and color reflectivity needs to be further explored.

Further testing will be done to determine how position affects the perception of color. My hypothesis is that low reflective interior surface effects like rich color can be achieved with little change to the space's overall reflectivity. In the case of rich colors, some surfaces (for example, walls) play a less important role in delivering average room reflectivity than others and are candidates for locating color if those same surfaces are primary to the perception of the overall color of the space.

These results will be evaluated to find a rule for the perception of color, which will lead to design applications for the use of color in interior spaces. This will be pursued further in a large experiment.

Acknowledgement

The author would like to thank Professor G.Z. Brown and Professor Daniel Herbert, University of Oregon, for their contributions to this paper.

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