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Abstract

This research investigates the influence of color-filtered lighting in relation to biophilic design, specifically within the preschool learning environment where design elements impact early childhood development. Among various architectural design components, research underscores the pivotal role of lighting in affecting children's pleasantness and energy levels. The experiment yielded three key findings: (1) discernible differences in pleasant and energy levels were observed between existing white lights and specific color-filtered lights; (2) varying pleasant and energy levels were noted among different color-filtered lights; (3) a relation was identified between external conditions (confounding variables) and pleasant and energy levels in the context of color-filtered lights. Subsequently, the study delved into the interplay between the effects of color-filtered lighting and natural light, specifically focusing on the Correlated Color Temperature (CCT) level. There is an opportunity to refine and innovate lighting elements of learning environments through the interplay between indirect experience elements of biophilic design, attention restorative theory (ART), and perceived emotional experience. The study offers valuable insights into the relationship between specific lighting conditions and elevated energy and pleasantness levels suggesting a meaningful avenue for further research and practical application in educational settings.

Introduction

The field of educational facility design has remained largely unchanged for decades despite compelling evidence suggesting that the interior environment significantly influences its occupants' learning, mood, and behavior (Scargall, 1999). Design elements in the learning environment play a pivotal role in eliciting various emotions in children, especially during this sensitive developmental stage. The utilization of different colors and lighting within a space can profoundly alter its overall perception, impacting how individuals feel within that environment. The potential for varied colors and lighting to evoke emotions ranging from calm and relaxing to energetic and exciting has been demonstrated in studies (Suh et al., 2020). Consequently, learning environments are increasingly recognized as spaces that can be optimized for diverse spatial experiences, influencing students' ability to learn at their optimum capacity (Fielding, 2006). If colors and lighting can indeed influence mood and behavior, this realization may have significant implications for the design of educational spaces.

In the context of early childhood education, particularly within the Montessori classroom, the concept of the 'prepared environment' takes on special significance. Rooted in the principles of Montessori early childhood education, this concept refers to a meticulously designed space intended to nurture independence, exploration, and a love for learning (Montessori, 1967; Lillard, 2017). One facet of the prepared environment involves incorporating elements of nature and aesthetics into the classroom design, creating a tranquil and inviting atmosphere (Montessori, 1967).

Numerous studies have explored the impact of color on mood, behavior, performance, and the perception of space. The influence of color changes on social interactions in college social spaces and off-task behavior in college students has been documented (Kurt and Osueke, 2014; Johnson & Maki, 2009). Historical research focusing on 4- to 5-year-old children reveals correlations between color and positive and negative attributes in their spatial experiences (Sexton et al., 1974). The impact of lighting on learning fluency, motivation, and concentration has been observed in 7- to 8-year-old children (Mott et al., 2012). While warm and cool white lights have traditionally dominated interior design, a growing availability of various colors of light allows for a broader spectrum of mood changes within interior spaces. Different colors of light are now strategically employed to create specific moods or support emotional states based on the intended purpose of a space. For instance, chromotherapy rooms integrate specific colors of light to induce relaxation and alleviate stress (Minguillon et al., 2017). Research indicates that colors of light can affect the responsiveness of the brain, particularly in young children, impacting their frontal lobe and influencing performance (Münch et al., 2014).

This study focuses on the impact of different color-filtered lighting in a preschool classroom, examining how the variations affect children's pleasantness and energy levels. Quantitative data on color-filtered lighting is collected using illuminance/CCT measuring equipment, while on-site preschool teachers document qualitative insights into children's emotions and behavior changes through daily surveys. The analysis of this study aims to provide guidance on the use of appropriate colors of light for specific learning activities in early child development. Given the connection between emotional intelligence and behavior, the study records students' energy levels and pleasantness using the Mood Meter, a tool associated with the RULER approach developed by the Yale Center for Emotional Intelligence (Brackett et al., 2013). Ultimately, this research contributes to our understanding of how color-filtered lights can mimic the indirect experience of biophilic design, particularly in early childhood education.

Color and Light in Learning Environment for Young Children

Young children aged 3 and above spend over 6 hours daily within the school environment (Barrett et al., 2017). This setting significantly influences children's physiological and psychological development alongside their home environment. Among the myriad physical factors within the learning environment, color and light greatly impact individuals' psychological well-being within interior spaces (Küller et al., 2009). Young children, unconsciously and instinctively, are highly attuned to color and light as primary physical variables that define their visual and sensory experiences (Fielding, 2006).

As indicated by scientific research, color covers a vast array of interior elements and significantly influences children's moods, mental clarity, and energy levels (Engelbrecht, 2003). Thoughtful color design can enhance children's overall mood and well-being by modulating the stimulation level they experience (Barrett et al., 2017; Jalil et al., 2012; Küller et al., 2006). While experiments have shown that children are naturally drawn to colors resembling nature and human skin tones (Fielding, 2006), primary colors are prevalent in children's environments despite outdated perceptions of their effects (Fielding, 2006). A diverse palette incorporating different shades, tones, and saturation levels creates a stimulating learning environment. A balanced use of suitable colors proves crucial in fostering both learning and well-being in children (Jalil et al., 2012). The ultimate goal is to stabilize color stimulation to extend concentration during learning, enhance performance, and evoke positive emotions and perceptions (Gaines & Curry, 2011; Kristanto et al., 2016).

Light, a fundamental design element, adds dimensional complexity to the learning environment, influencing cognitive, emotional, and behavioral responses (Tomassoni et al., 2015). Children are particularly sensitive and responsive to nuances in both light and color (Fielding, 2006). Research indicates that light significantly impacts elementary students' progress in writing and math (Barrett et al., 2017), and beyond academic performance, it plays a role in emotional states during child development (Mahdjoubi & Akplotsyi, 2012). Varied temperatures of white light, coupled with specific colored walls, impact students' concentration and cognitive performance (Kristanto et al., 2016; Pulay et al., 2018). For instance, a blue-colored wall with a cool daylight lamp color temperature induces a calming effect, while an orange-colored wall with the same temperature increases concentration levels (Kristanto et al., 2016). However, emotional states and concentration levels are less affected by these two colored walls with warm white lamp color temperature.

Changing light and wall colors to suit specific emotional states poses a challenge, particularly in American school classrooms where budget constraints often limit updates to fluorescent lighting fixtures for extended periods (Evans et al., 2010; Uline & Tschannen-Moran, 2008). The ability to easily adjust the colors of light within existing fixtures to create specific learning environments could add flexibility in supporting children's emotional states. Key elements to consider in the space's color of light include illuminance and correlated color temperature (CCT) level. Illuminance gauges the amount of light on interior surfaces, while CCT denotes the color of light emitted from lamps in terms of color temperature (Veitch and McColl, 2001).

Varying CCT and illuminance levels have an impact on children's physical performance and perception of space (Georgieva et al., 2018). For instance, higher illumination levels with a high CCT increase alertness, arousal, and productivity compared to the same illumination level with a low CCT (Pulay & Williamson, 2019; Smolders & de Kort, 2014; Wei et al., 2014). The emotional states and behavior patterns of young children aged 3 to 6 may exhibit differences under varying illuminance and CCT levels of color-filtered light.

Biophilic Design Intersect with Attention Restoration Theory (ART)

The learning environment plays a pivotal role in shaping children's cognitive and emotional development. Attention Restoration Theory (ART) posits that exposure to nature can replenish cognitive resources and enhance attentional capacities (Kaplan & Kaplan, 1989). This theory intersects with the principles of Biophilic Design, an approach that incorporates natural elements into the built environment. This literature review examines the relationship between ART and Biophilic Design and the impact of such learning environments on children's reactions and cognitive processes.

Research indicates that children, like adults, benefit from exposure to natural environments in terms of attention restoration. Kaplan and Berman (2010) demonstrated that children who engaged with nature exhibited improved attention compared to those in non-natural environments. The cognitive demands of learning can be considerable for children, making the principles of ART particularly relevant in educational settings. Biophilic Design emphasizes integrating natural elements and has gained traction in educational settings. Studies by Kellert (2008) have highlighted the positive impact of Biophilic Design on children's well-being and academic performance. Incorporating features such as indoor plants, natural light, and nature-inspired textures can create an environment conducive to attention restoration and overall cognitive development. Empirical studies have explored how children react to learning environments infused with Biophilic Design elements. Findings suggest that children exhibit positive emotional responses, increased engagement, and a greater sense of well-being in spaces with natural elements (Bell & Dyment, 2008; Taylor, Kuo, & Sullivan, 2002). These reactions indicate the potential of Biophilic Design to create stimulating and supportive learning environments for children.

The relationship between attention restoration and academic performance is a crucial aspect of understanding the efficacy of Biophilic Design in learning environments. Studies by Taylor and Kuo (2009) have shown that exposure to nature is associated with improved cognitive function and academic outcomes in children. Integrating Biophilic Design principles into classrooms may create environments that foster sustained attention and enhance learning outcomes. Designing learning environments that effectively incorporate Attention Restoration Theory and Biophilic Design requires careful consideration of age-appropriate elements and functionalities. Balancing sensory-rich experiences with educational objectives is crucial. Researchers have emphasized the importance of providing diverse natural stimuli that cater to children's developmental needs and preferences (Dyment & Bell, 2007).

While the existing literature offers insights into the positive impact of Biophilic Design on children's reactions and cognitive processes, further research is needed to explore nuanced factors such as cultural variations, specific age groups, and long-term effects (Kellert & Calabrese, 2015). Challenges may include practical implementation in diverse educational contexts and ensuring that Biophilic Design interventions align with pedagogical goals. However, integrating Attention Restoration Theory and Biophilic Design in learning environments holds promise for positively influencing children's reactions and cognitive processes.

The literature supports the idea that exposure to nature and incorporating natural elements contribute to attention restoration, emotional well-being, and enhanced academic performance in children (Kellert & Calabrese, 2015; Kellert & Wilson, 2008). As research in this field continues to evolve, educators and designers can benefit from a nuanced understanding of creating learning spaces that optimize children's cognitive and emotional experiences. Collaborating these theories in educational settings provides a foundation for developing innovative and effective approaches to support children's learning and well-being.

In this study, we turn our attention to the profound implications of color-filtered lighting within the educational setting for children. The exploration centers on understanding the influence of varied color-filtered lighting on the learning environment and its potential to enhance or modify the educational experience. Recognizing the pivotal role lighting plays in shaping cognitive and emotional responses, this study delves into the nuanced interplay between color-filtered lighting and how it mimics the indirect experience of biophilic design in the learning environment. The ensuing analysis seeks to uncover the multifaceted effects of color-filtered lighting, emphasizing its potential to create an environment conducive to optimal learning outcomes for children.

Method

This quasi-experimental study took place in a Montessori preschool classroom. The total duration of this study was eight weeks. Active participants of this study were two teachers and 24 Montessori school students aged three to six. Teachers observed the students throughout the day, and then at the end of each class, they voluntarily completed the electronic survey that includes informed consent. At the beginning of each week during the experiment, light levels under different color light filters were recorded, and interior pictures were taken after classroom activities were finished.

In order to improve the internal validity of this quasi-experiment, 24 Montessori school children and two teachers were exposed to each color-filtered lighting environment for two weeks (10 days). Children are sensitive to changes in their environment (Macià-Gual & Domingo-Peñafiel, 2021). The Montessori school director recommended 10 days exposure time frame since young children need a bit more time to familiarize themselves with the change of the environment. This desensitizes the participants to the modified environment, subsequently reducing the Hawthorne Effect. The mean scores over time will also consider other confounding variables (e.g., having a bad day, having a good day, positive or negative events, course content, etc.).

Data Collection Process

During the total duration of 8 weeks, each different color-filtered lighting was installed in the classroom for two weeks. The wall colors of the classroom were light off-white which made the changes by color-filtered lighting visible and clear in the space. Color-filtered lighting was created by covering existing light fixtures (T8 fluorescent lamp luminaire) with translucent colored fabrics. Three secondary colors of fabric were chosen: Orange, Green, and Purple. Research shows that young students are "particularly attuned to the colors of nature and human skin tones" (Fielding, 2006, p. 5), which are not in the range of the primary colors. Fielding (2006) also indicates that people find the primary colors harsh, so our study chose secondary colors for the experiment instead. Every two weeks, correlated color temperature (CCT) levels of three different color-filtered lighting conditions in the classroom were recorded. Students' pleasantness and energy level were documented by two teachers, along with short daily observations of students' emotional state and behavioral changes. Particular daily events were also recorded. The following is the sequence of introducing different color-filtered lighting each week. There was no particular reasoning behind the sequence:

Week I: Existing white light

Week II: Orange color-filtered light

Week III: Green color-filtered light

Week IV: Purple color-filtered light

After each week, the visual analysis of color-filtered lighting and survey results were analyzed.

Data Collection on Lighting Variations

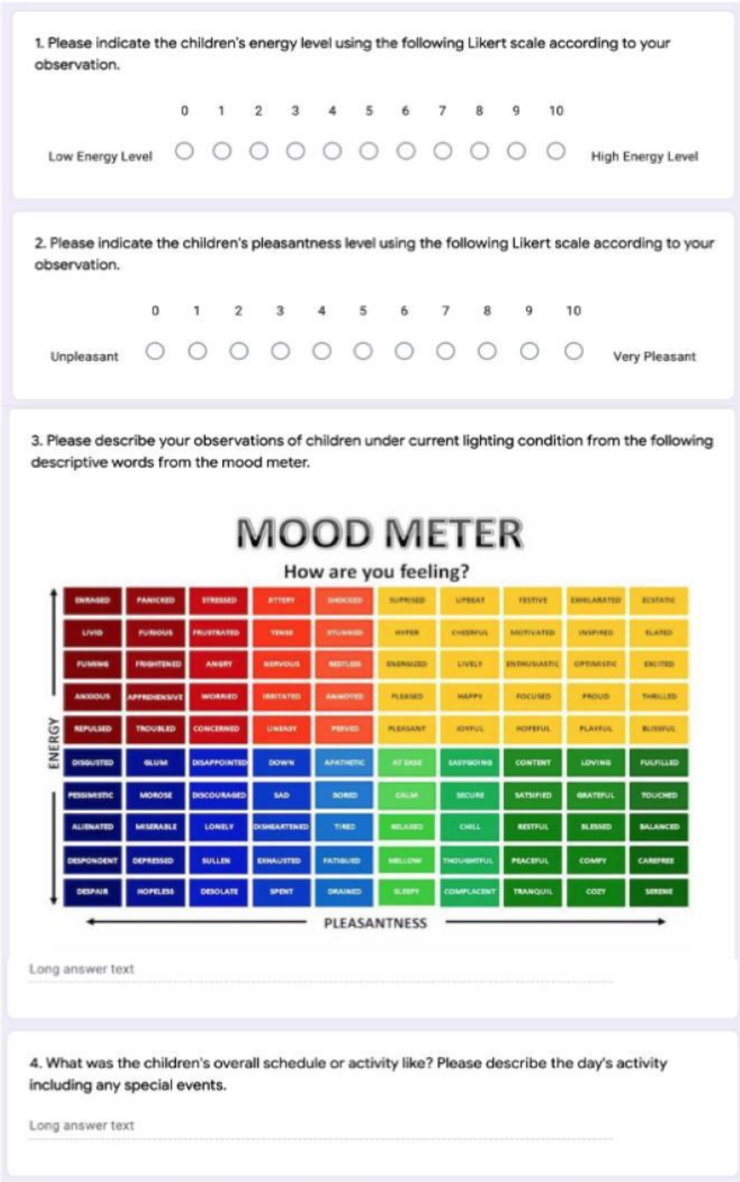
The light meter captured light levels (illuminance and color temperature) of different colors of light in the learning space. Lighting illuminance was measured in the unit, “footcandle (fc)” which shows the amount of light falls on the surface. 40-50fc on the horizontal work plane is generally recommended for a classroom setting (Mott et al., 2012). Correlated color temperature (CCT) was measured in the unit, “Kelvin (K).” It shows the quality of light hue range from “cool” (blue and white, 3100K-4500K) to “warm” (red and yellow, 2000K-3000K). This was the data that allowed us to understand the change of visual conditions under different color-filtered lights. At the beginning of each week, the investigator took photos of interior space under different color-filtered light without the presence of participants. These photos observed the ambiance of interior space under different color-filtered lighting.

Data Collection on Perceived Energy and Pleasantness Levels

At the end of each class, voluntary participants of two teachers completed an electronic survey that included informed consent (see Figure 1). They described students’ emotional states with emotive descriptors from the Mood Meter chart, developed by the Yale Center for Emotional Intelligence (Tominey et al., 2017). This is based on the RULER (Recognizing, Understanding, Labeling, Expressing, Regulating) approach to help students figure out their energy level (the Y-axis) and pleasantness level (the X-axis). The Mood Meter is often used to help students build the vocabulary of emotions to communicate and understand their emotional changes. For this study, teachers used descriptors of the Mood Meter to describe the changes in children’s energy and pleasantness levels. The last question on the survey aimed to understand if specific activities or events may have affected emotional states on certain days.

Results

Analysis of classroom lighting levels revealed notable differences between the color-filtered lighting and the existing lighting condition. Comparing the average illuminance level of existing lighting (71fc) to color-filtered lighting, there was a substantial reduction of over 30fc in the emitted lights. Considering the recommended illuminance level for the classroom environment (40-50 fc), the existing lighting was overlit, while color-filtered lighting provided ideal lighting levels in the classroom.



1. Please indicate the children's energy level using the following Likert scale according to your observation.

	0	1	2	3	4	5	6	7	8	9	10	
Low Energy Level	○	○	○	○	○	○	○	○	○	○	○	High Energy Level

2. Please indicate the children's pleasantness level using the following Likert scale according to your observation.

	0	1	2	3	4	5	6	7	8	9	10	
Unpleasant	○	○	○	○	○	○	○	○	○	○	○	Very Pleasant

3. Please describe your observations of children under current lighting condition from the following descriptive words from the mood meter.

MOOD METER

How are you feeling?

ENRAGED	PANICKED	STRESSED	JITTERY	SHOCKED	SURPRISED	UPBEAT	FESTIVE	EXHILARATED	ECSTATIC
LIVID	FURIOUS	FRUSTRATED	TENSE	STUNNED	HYPER	CHEERFUL	MOTIVATED	INSPIRED	ELATED
FUMING	FRIGHTENED	ANGRY	NERVOUS	RESTLESS	ENERGIZED	LIVELY	ENTHUSIASTIC	OPTIMISTIC	EXCITED
ANXIOUS	APPREHENSIVE	WORRIED	IRRITATED	ANNOYED	PLEASED	HAPPY	FOCUSED	PROUD	THRILLED
REPULSED	TROUBLED	CONCERNED	UNEASY	PEEVED	PLEASANT	JOYFUL	HOPEFUL	PLAYFUL	BLISSFUL
DISGUSTED	GLUM	DISAPPOINTED	DOWN	APATHETIC	AT EASE	EASYGOING	CONTENT	LOVING	FULFILLED
PESSIMISTIC	MOROSE	DISCOURAGED	SAD	BORED	CALM	SECURE	SATISFIED	GRATEFUL	TOUCHED
ALIENATED	MISERABLE	LONELY	DISHEARTENED	TIRED	RELAXED	CHILL	RESTFUL	BLESSED	BALANCED
DESPONDENT	DEPRESSED	SULLEN	EXHAUSTED	FATIGUED	MELLOW	THOUGHTFUL	PEACEFUL	COMFY	CAREFREE
DESPAIR	HOPELESS	DESOLATE	SPENT	DRAINED	SLEEPY	COMPLACENT	TRANQUIL	COZY	SERENE

ENERGY

PLEASANTNESS

Long answer text

4. What was the children's overall schedule or activity like? Please describe the day's activity including any special events.

Long answer text

Figure 1. Survey in Google Form

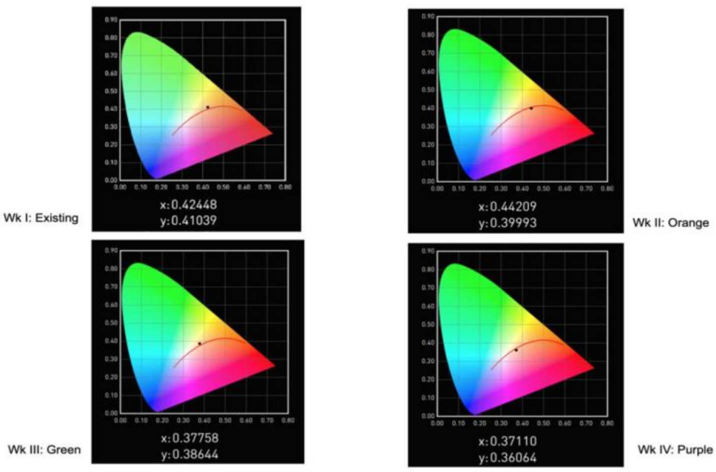


Figure 2. CCT (Correlated Color Temperature) of Montessori Classroom

The locations of black dot on the red curve (Planckian Curve) indicate the color temperatures of different lighting conditions which revealed a slight shift from the existing white lighting condition (see Figure 2). Under existing white light, the dominant color was orange-yellow, with an average CCT value of 3017K. Orange color-filtered light exhibited more orange-red tones, with a slightly lower CCT value of 2848K. Green color-filtered light introduced blue-yellow tones, resulting in an average CCT value of 4139K. Purple color-filtered light provided a more blue and white tone, with an intermediate CCT level of 4168K. Notably, the CCT values for green and purple color-filtered lighting fell within the range of natural light (4000K to 6500K) (Oh et al., 2020), aligning with the blue tones present in natural light. The study's findings underscore the significant impact of color-filtered lighting on lighting levels and color temperatures within the classroom environment. When compared to existing white light, color-filtered lighting provided more suitable illuminance levels and introduced shifts in color temperature that aligned with natural light characteristics.

Teachers' observations, recorded as frequency results of descriptors from surveys based on the Mood Meter, provided valuable insights into students' emotional states. The Mood Meter, with its four quadrants representing overall energy and pleasantness levels, featured 25 descriptors for teachers to choose from (see Figure 3). The original colors on the Mood Meter had no direct correlation with the visual lighting data. Teacher-reported descriptors analyzed qualitatively offered a nuanced understanding of how color-filtered lighting influenced students' emotional states and behavior.

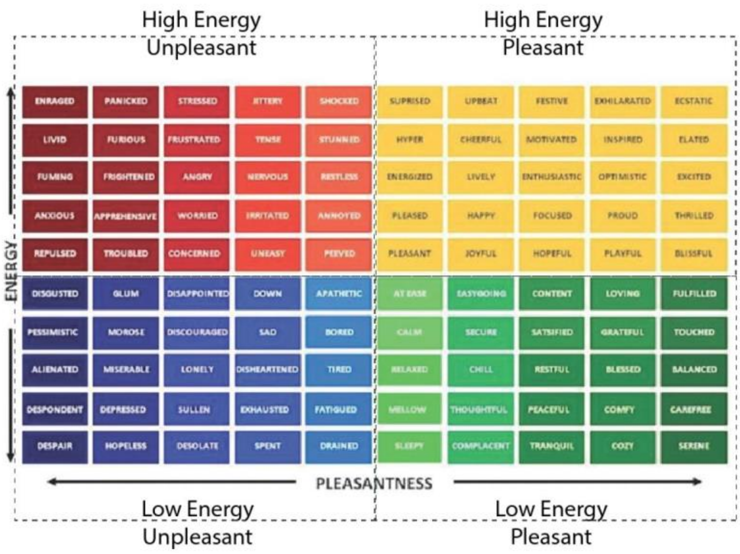


Figure 3. Four Quadrants and Emotive Descriptors of Mood Meter

Under existing white light, the most frequent descriptors reported by teachers were "excited," "happy," and "playful" (see Figure 4). Despite the overlit condition, students generally perceived this lighting as a positive experience, with their emotional states predominantly falling in the "high energy and pleasant" quadrant on the Mood Meter. Under orange color-filtered light, "pleasant" emerged as a significantly popular descriptor for students' emotional states. Additional descriptors included "joy" and "annoyed," with the latter falling into the "high energy and unpleasant" quadrant on the Mood Meter. While there were opposite perceptual differences in pleasantness, high energy remained consistent under this lighting condition.

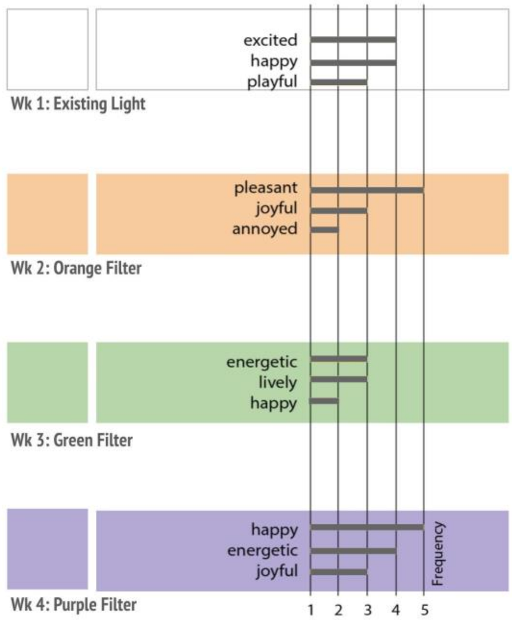


Figure 4. Teacher’s Observation Report under Different Lighting Conditions

Figure 5. Comparative Map: CCT Level & Level of Energy and Pleasantness

Green color-filtered light resulted in descriptors such as "energetic," "lively," and "happy" being frequently used. These descriptors all fell into the "high energy and pleasant" quadrant of the Mood Meter. Despite variations in energy levels, the overall pleasantness remained consistently positive under green color-filtered lighting. Under purple color-filtered light, "happy" was the most frequently reported descriptor, followed by "energetic" and "joyful." Descriptors like "calm" and "easygoing" indicated a "low energy and pleasant" state. In particular, descriptors like "festive" suggested the highest energy and very pleasant states on some days. Generally, emotional states and behavioral patterns predominantly stayed in the "high energy and pleasant" zone under purple color-filtered light. Teachers' observations, captured through the Mood Meter descriptors, enriched the understanding of how these lighting variations influenced students' emotional experiences. The results have practical implications for optimizing lighting conditions in educational settings to enhance young children's overall well-being and learning experiences.

Overall, both energy and pleasant levels were higher in color-filtered lighting conditions than in white lighting. In particular, the pleasant level was lowest in the green-filtered lighting condition. Differences in energy levels were observed among color-filtered lighting conditions: purple (highest), green (middle), and orange (lowest). After examining the teachers' comments, a mix of positive and negative events occurred during class sessions. The week when purple-filtered lights were installed saw mostly positive events. Conversely, the week of green-filtered lighting witnessed the highest number of negative events, but the pleasant level remained fairly high. The observations under different lighting conditions reveal various emotional states and behavior patterns. Color-filtered lighting, despite variations, consistently maintained positive emotional experiences with high energy and pleasantness levels. The comparative analysis provides a comprehensive understanding of the interplay between lighting conditions, color temperatures, and students' emotional responses, offering valuable insights for optimizing classroom environments.

Discussion

The quantitative lighting measures validate that color-filtered lighting, reflective of specific pigmented colors in the filters based on CCT data, significantly influences the learning environment. The experimental outcomes support the hypothesis that discernible differences in pleasant and energy levels would be observed between existing white lights and specific color-filtered lights. Students consistently reported feeling energetic and pleasant under color-filtered lighting conditions, aligning with the recommended lighting conditions for work areas (40-50 fc). The improvement over the over-lit condition under existing white lights further emphasizes the positive impact of color-filtered lighting.

The impact of color-filtered lighting on young children's moods is evident, with purple color-filtered lights being particularly effective in eliciting the highest levels of energy and pleasantness. Even during the week of green color-filtered lighting, characterized by negative events, students maintained elevated energy and pleasantness levels. This resilience can be attributed to the ability of color-filtered lights to mimic natural light, as reflected in their CCT levels characteristic of natural light (4000K and up). The positive outcomes underscore the indirect experience of biophilic design created by both green and purple color-filtered lights, contributing to cognitive functioning and well-being.

The unique aspect of this study lies in the indirect experience of biophilic design created by both green and purple color-filtered lights. Research indicates that features of nature promote cognitive functioning and well-being. By mimicking natural light's spectral and dynamic qualities, color-filtered lights contribute to an indirect experience of biophilic design. The study aligns with the idea that as long as artificial light replicates the characteristics of natural light, the benefits associated with biophilic design can be achieved. The findings suggest that the pleasantness levels of students may remain high under green color-filtered lighting despite negative events, emphasizing the potential for color-filtered lighting to enhance comfort and productivity. The study contributes to understanding the impact of color-filtered lighting on children's emotions in the learning environment. While the study acknowledges potential emotional variables and individual differences, it provides a foundation for future studies to explore controlled experimental settings and consider developmental variations among students of different age groups.

Conclusion

The integration of colored or color-filtered lighting in interior spaces unveils new possibilities for the creative use of light and color. In settings with predominantly white wall surfaces, color-filtered lighting presents an innovative opportunity to infuse dynamic and multi-dimensional aspects of color and light. By moving beyond static applications on walls, the application of color-filtered lighting introduces a vibrant and evolving element to interior spaces. The increasing availability of creative color-filtered lighting enhances flexibility, allowing for dynamic changes in the ambiance of spaces.

In the context of early childhood emotional intelligence development, exploring color-filtered lighting's impact on emotional states is paramount. Recognizing the significance of the learning environment in EI development, this study sheds light on how color-filtered lighting can influence the emotional well-being of occupants. Leveraging tools like the Mood Meter, with its clear layout based on energy levels, pleasantness, and a comprehensive set of emotional descriptors, facilitates a detailed understanding and communication of emotional states.

The study's outcomes underscore the positive effects of green- and purple-colored lighting conditions, where both energy and pleasantness levels were consistently high. The introduction of cool color-filtered light emerges as a beneficial factor, contributing to improvements in both physical and psychological states in connection with the indirect experience of biophilic design. Color-filtered lighting emerges as a valuable environmental tool that modulates energy levels and pleasantness to create desired learning environments tailored to specific content. The relationship between specific lighting conditions and elevated energy and pleasantness levels suggests a meaningful avenue for further research and practical application in educational settings. The intricate interplay between indirect experience elements of biophilic design, attention restorative theory (ART), and perceived emotional experience exists an opportunity to refine and innovate lighting in the learning environments.

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