THE EFFECTS OF CORRELATED COLOR TEMPERATURE AND ILLUMINANCE ON STUDENT PERFORMANCE AND WELLBEING

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ABSTRACT

Interior lighting can have a positive or negative affect on student performance and wellbeing. In this paper, the effects of correlated color temperature (CCT) levels and illuminance levels are explored in depth. Could optimal balance of CCT levels and illuminance levels reduce negative physical effects and improve k-12 student performance and wellbeing? The research for this paper was conducted through analysis of secondary data in the form of research articles. CCT levels were reported to have an affect on student performance and wellbeing, but there is much debate among researchers as to what extent manipulating CCT levels could increase the performance and wellbeing of students. Illuminance levels in high quantities can have detrimental health effects on students. Brightness and glare are two side effects of illuminance levels that also impact student health and wellbeing and can cause decreases in student performance when it comes to reading, writing, and math skills. One area still developing in the lighting industry in dynamic lighting. Dynamic lighting is lighting where CCT levels and illuminance levels can be manipulated to best fit the needs of the users. However, research in this area is limited and needs to be thoroughly researched. Ultimately, the research concluded that optimal levels of CCT combined with optimal illuminance levels could positively impact student performance and wellbeing, but these specific levels are unknown, could change from student to student, and are also dependent on the activity at hand. Further research is needed to determine the specific CCT and illuminance levels for different settings.

KEY WORDS

Correlated color temperature (CCT), illuminance, dynamic lighting, students, wellbeing

INTRODUCTION

There are many indoor environmental factors that affect student health and performance. These include acoustics, maintenance, cleanliness of the school, color and color pattern, textures of the floors and walls, classrooms flexibility, safety, and lighting (Tanner & Langford, 2002, as cited in Samani & Samani, 2012). Light, according to Wurtman (1975, as cited in Tanner, 2008) “is the most important environmental input, after food and water, in controlling bodily functions” (p. 454). Lighting can be measured in different ways, but the two focused on in this paper are illuminance and correlated color temperate (CCT here on out). Illuminance is a measure of how much a light source illuminates a surface and is measured in lux. Standard lux levels are around 300 lux while levels of 1000 lux are highly excessive and even harmful to users (Goven et al. 2010, as cited in Sleegers et al., 2013; Winterbottom & Wilkens, 2009, as cited in Loew, 2017). CCT is the color of light emitted by a lamp that ranges from low levels (red light) to high levels (blue light) (Pulay et al., 2018). Proper CCT levels can promote student well-being and positive behaviors (Pulay et al., 2018). Improved lighting in schools could “enhance student learning performance and also motivate them to learn more” (Samani & Samani,

2012, p. 127). Therefore, lighting in learning spaces should be properly utilized to improve student academic performance and to support the students' wellbeing.

PROBLEM STATEMENT

Researchers debate whether lighting illuminance and CCT affect student wellbeing and performance. A few studies have been done testing different levels of both but contain many holes and are not complete. Too high illuminance has caused visual stress, and certain color temperature can reduce alertness and reading comprehension ultimately leading to students becoming off task, wanting to leave, or causing health effects. Optimal balance of CCT levels and illuminance levels could reduce negative physical effects and improve k-12 student performance and wellbeing. This paper compares these research articles, draws conclusions on optimal illuminance and CCT levels, and raises questions for future research.

METHODOLOGY

For this paper, secondary data in the form of existing research papers were gathered from Google Scholar. Key words started broad with 'interior lighting in schools', which produced around 123,000 results. Only the first four pages were reviewed, which was 40 different articles. Further, only articles with accessible PDFs were reviewed, which narrowed the results to 25 results. From there, articles with titles that related to k-12 schools, behavior, performance, and lighting were selected. This brought the results down to 10 articles. From there, the ten articles were assessed to find common themes, which led to CCT and illuminance and the correlation between the two. Key words such as 'correlated color temperature', 'illuminance', 'student performance and lighting', 'lighting and student behavior', and 'visual stress' were then searched on Google Scholar. Using the same process as mentioned above, the total articles reviewed was eighteen articles. These research papers were then thoroughly read and analyzed, and the findings are discussed in this paper. All details of these papers and research were extracted by the author of this paper. All data was analyzed to study quantitative and qualitative research relevant to student behavior and performance in schools. The papers used both quantitative and qualitative methodologies. Quantitative methodologies were commonly used, especially experimental design methodologies. Qualitative methodologies included surveys and research analysis similar to what was done in this paper.

RESEARCH

There has been research on different CCT, on different illuminance levels, and on preset illuminance and CCT levels to correspond to needed tasks in the classroom. There has been limited research on the effect of different CCT levels with the same illuminance level, which could possibly reduce unnecessary brightness, glare, eye strain, and visual stress by manipulating color.

CCT Levels

There are currently no standards for CCT levels in classrooms (IES, 2014, as cited in Pulay et al., 2020; Yang & Jeon, 2020). Higher CCT levels lead to an increase in brain function that occurs from the shorter wavelengths produced by the light not visible to the naked eye (Keis et al., 2014, as cited in Pulay et al., 2020). Pulay et al. (2018) explored the hypothesis that higher CCT levels would increase student alertness opposed to the currently lower CCT level lights common in schools. The current CCT levels in the school were around 3000K, which would be a warm yellow or orange light. The higher CCT level used in the experiment was 4100K. The study was done with 27 second graders and was evaluated by mapping on-task and off-task behaviors on a floor plan of the classroom. Ultimately, the study proved there was a positive correlation in higher CCT and on-task behavior. Illuminance levels were recorded, but not studied. The 3000K lamp was 711 lux and the 4100K lamp was 715 lux. The authors do acknowledge that high illuminance levels could contribute to the alertness of students. However, the illuminance levels were kept nearly consistent between the 3000K and 4100K lamps, so it can be assumed that CCT levels had a larger impact on the students than the slight change in illuminance. At the end of the paper, the question is raised about what effects higher CCT levels would have on students, and further research should take place.

Yang and Jeon (2020) also conducted an experiment that studied different CCT levels and different illuminance levels and the effects they had on the student participants. Ultimately, the illuminance levels were not found to have significant influence because they were kept within a close range. There was significance among the CCT levels, however. An optimum level of 4000K was found to maximize brightness and comfort levels. Satisfaction and acceptance were also tested but not found to be significant. Yang and Jeon's (2020) data also showed that CCT levels could potentially be more important than illuminance in moderate classroom conditions when testing the performance of students.

The effects of CCT are still considered to be unclear, however, because of the inconsistency in reports. Yang and Jeon (2020) cited many different research papers and experiments that tested CCT levels. Some found that CCT was significant to student performance, and others found CCT was not significant to student performance. One issue that may cause this inconsistency is that currently there is not a national standard on CCT levels in the classroom, as mentioned earlier (Yang & Jeon, 2020). There has been evidence that different regions around the world prefer different CCT levels, but this also has not been thoroughly studied to determine a cause (Yang & Jeon, 2020). Through speculation, it may be caused by different climates, altitude, latitude, or cultural preferences. Even though experts claim to not have a correlation on CCT and student performance, many studies have proved there is a significance and CCT should still be a major factor when determining appropriate lighting for schools.

Illuminance Levels

Illuminance is a measure of how much a light source brightens a surface. Loew (2017) argues that too much illuminance is a serious problem because lighting levels of illuminance are too high. Increases in fluorescent light brightness negatively correlate with student levels of literacy and numeracy. A study that Loew (2017) references saw a rise in unexplained reading and learning disorders soon after the introduction to fluorescent lights in the school. Another study in Loew's (2017) paper is 5-12% of students experience moderate symptoms of hypersensitivity to brightness. This condition was termed Meares-Irlen syndrome, also known as visual stress. High illuminance levels are speculated to come from outdated and underdeveloped lighting practices (Berman et al., 1996 as cited in Loew, 2017). A study done in the UK tested illuminance levels of 90 classrooms in 17 schools and found that 88% of the classrooms greatly exceeded illuminance recommendations and 84% had high excessive illumination, or more than 1000 lux (Winterbottom and Wilkens, 2009 as cited in Loew, 2017).

Perceived brightness comes from other sources besides just high illuminance produced from lamps. In the 1990's, there was an increase of need of copy paper. Paper companies tried to constantly outdo each other and eventually arrived at paper with whiteness and brightness levels that were literally off the chart (Loew, 2017). The CIE Whiteness Index is the most commonly used whiteness index internationally according to Loew (2017). A perfect-reflecting non-fluorescent white material could get a score of 100. Today's paper gets a score of 150-170. This is because chemicals in the paper absorb non-visible light and then reflect it into the readers eyes as visible light. These high levels of illuminance and brightness negatively impact student and human health as they can cause visual distortions of print, deterioration of reading speed and accuracy, headaches, anxiety with hyperactivity, and early onset visual fatigue, all of which are symptoms of visual stress (Irlen, 1994; Robinson, 1994 all cited in Loew, 2017).

While illuminance is the main topic in Loew's (2017) research, there is also some mention of color. Another way to increase perceived brightness is to increase the amount of blue light, which has been used by detergent companies who add small bits of blue dye to their products (Loew, 2017). However, the color is in no way related to CCT levels of lamps; color was discussed in terms of dyes. It is clear through Loew's (2017) research that illuminance alone can have a negative effect on student health leading to visual stress.

Dynamic Lighting

Dynamic lighting, or tunable lighting, is lighting that provides different settings with specific illuminance and CCT levels to support mental alertness and relaxation. Dynamic lighting has been found to have a positive effect on student visual performance, arousal levels, and overall wellbeing (Iszo, 2001a; Iszo 2001b; Majoros, 2001, all cited in Sleegers et al., 2013). Sleegers et al. (2013) discuss positive levels of illuminance, around 500 lux, on basic class skills for children such as math, reading, and writing (Goven et al. 2010, as cited in Sleegers, 2013). Positive CCT levels range between 4000K and 17000K

and have various physical and psychological health benefits for children including attendance, alertness, and academic achievement (Hathaway, 1994.; Rautkyla, 2010, all cited in Sleegers et al., 2013).

In an experiment executed by Sleegers et al. (2013), lighting conditions with illuminance levels of 300 lux to 1000 lux and CCT levels between 3000K and 12000K were explored and utilized dynamic lighting. Sleegers et al. (2013) experimented using preset dynamic lighting at four different levels. The energy setting had an illuminance level of 650 lux and a CCT level of 12000K, making the lighting appear cold in a blue-rich white light. The focus setting had an illuminance level of 1000 lux with a CCT level of 6500K, making the light a bright white color. The calm setting had an illuminance level of 300 lux with a CCT level of 2900K, which made white light with warm red undertones. Last, the standard setting had an illuminance level of 300 lux with a CCT level of anywhere between 3000K to 4000K, which is standard white light used in workspaces. Three different studies were conducted, and two out of the three proved a positive correlation in the focus setting lighting and the students' concentration levels. While the work done by Sleegers et al. (2013) helps prove illuminance and CCT levels influence student health, only one type of their lighting presets, the focus setting was proven to have a positive correlation. The other three settings, energy, calm, and standard were not discussed. Further, while preset options make things simpler for research and for teacher use, there was no exploration of a constant illuminance level and varying CCT levels or vice versa to explore how these different settings influence each other.

Much more research needs to be done on dynamic lighting, but it is getting positive feedback from teachers (Morrow & Kanakri, 2018). Morrow and Kanakri (2018) conducted a survey that asked about lighting, lighting levels, and student performance; 75 teachers responded to the survey. When asked if they adjusted lighting levels in their classrooms to enhance the environment for their students, 81.08% responded yes. 68.4% believed adjusting the lighting levels was important to encourage engagement, promote positive moods, and contribute to the overall wellbeing of their students. Light effects may also be situational, dependent on situation, task, or time (Sleegers et al., 2013). Morrow and Kanakri (2018) also notes that dynamic lighting should be researched further to determine if the amount of light or the CCT affects the positive behaviors and engagement levels.

Other Factors

Recently, there has been debate on using fluorescent lights or light-emitting diodes (LED) in the classroom. LEDs are more efficient, last longer, and can provide a smooth, unbroken light spectrum (Morrow & Kanakri, 2018). One of the biggest complaints with fluorescent lighting is the flicker caused by the broken light spectrum. Fluorescent lights are also hotter and use more energy (Morrow & Kanakri, 2018). However, LEDs remain the expensive choice. Pulay et al. (2018) claim that it is unlikely schools will change from fluorescent lamps to better technologies because of the high prices. Morrow and Kanakri

(2018) argues though that LED lighting will become more common because the prices are decreasing, and LEDs are more sustainable. Fluoresecent lighting can be harmful to human health because most contain mercury (Morrow & Kanakri, 2018). LEDs can reduce energy consumption by 30-50% and reducing cooling costs by 10-20% (TCP Inc., 2017, as cited in Morrow & Kanakri, 2018).

The CCT levels and illuminance levels used in a space can have an impact on the way interior finishes and furnishings appear. Loew (2017) mentions that highly reflective whiteboards can produce glare which can irritate student levels of concentration and even tolerance for looking at a whiteboard. Earthman (2004, as cited in Woolner et al., 2007) claims that ceiling height can have an effect on how lighting appears in a space. The lighting could be designed with adequate CCT levels and illuminance levels in a classroom but may ineffective because of the tall ceiling height.

CONCLUSION

It is very clear from the research analyzed above that there is still much to study when it comes to interior lighting in school spaces. CCT and illuminance levels have significant impacts on the health, mood, and wellbeing of students, but it is still unclear whether the CCT or illuminance levels affect student performance more. Illuminance levels have a standard, but CCT levels are yet to have a standards. Many classrooms are overly bright and can cause damaging health effects on students. To study this further, many tests should be done keeping CCT levels constant and manipulating illuminance levels and vice versa. The author speculates that testing higher CCT levels and lower illuminance levels will create perceived brightness and will reduce eye strain and visual stress.

The best recent practice is dynamic or tunable lighting. Dynamic lighting allows the user to manipulate CCT levels and illuminance levels to best fit their needs. Many dynamic lighting systems come with preset levels to promote energy levels, focus levels, or calmness among students. However, one perceived problem of dynamic lighting is that it still cannot be personalized for individual users. The system is typically connected to overhead lights that influence entire classrooms rather than individual students. Every person has different preferences on lighting and lighting affects every person differently. Lighting practices need to continue to evolve to meet the needs of all students rather than just the majority.

When applicable, school facilities should look into different lighting types to figure out what would best benefit the school. There is a debate over whether schools can implement LEDs into their lighting system or if it is too expensive. This is a common debate across many different sustainable features in the built environment. In the long run, sustainable measures are most often the best option because they will save money and promote health and wellbeing. Morrow and Kanakri (2018) noted this in their paper that LEDs could potentially reduce energy use by 50%. LEDs are a better option for student performance when coupled with CCT levels. LEDs have also been proven to reduce flicker

commonly found in fluorescent lighting. However, it is reasonable to speculate schools do not have proper informants on the best practices when it comes to lighting. Now is the time for school staff to take ahold of the wellbeing of students and faculty, and this can be done through hiring sustainability experts or using consultants to stay up-to-date on this ever changing field.

Many interior finishes and furnishings can also affect the amount of perceived brightness in a room. Designers should be aware of this to determine where to place lights and what surfaces to select in schools so that glare is reduced.

Another factor outside the scope of this paper is daylighting. Daylighting has been proved to significantly increase the wellbeing of humans and has improved many health issues. However, not all interior spaces have access to windows or exterior lighting. Daylighting is also unreliable because of the changing seasons and weather patterns. When possible, daylighting in a classroom should be optimized, but interior lighting must still be fully functional and up-to-date to promote student wellbeing.

Future research on CCT levels and illuminance levels that optimize student behavior and performance should focus further on dynamic lighting usefulness, CCT standard levels, and types of lamps that could optimize CCT and illuminance levels.

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