

The impact of fluorescent and led lighting on students attitudes and behavior in the classroom

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Abstract

Introduction: This study examined empirical research on the effects of high correlated color temperature light-emitting diodes (LED) and fluorescent lighting on students in the classroom. LED is becoming the most recent lighting option for optimal energy efficiency over fluorescent technology.

Background: A review of the literature indicates correlated color temperature (CCT) of lighting has non-visual effects on students, with higher CCT positively impacting attitudes and behavior. The review also revealed current studies regarding dynamic or tunable lighting that adjusts CCT based on desired activity and mood. Data from an original survey analyzed teacher insights and perceptions regarding student attitudes and behaviors associated with existing classroom lighting and the impact of higher color temperature LED.

Methods: Participants were pre-K through high school qualified teachers from three schools and/or personal contacts of the principal investigator. Seventy-five teachers responded to the online questionnaire. The survey data suggests teachers perceive higher color temperature lighting positively impacts student alertness, attitude, and energy level; and adjusting light levels throughout a school day positively impacts student engagement.

Results and conclusion: Results supported the perception of higher correlated color temperature lighting positively impacting alertness, attitude, and energy level. Findings also supported the ability to change light levels throughout the school day to positively impact student engagement and mood. There were mixed results regarding higher correlated color temperature impacting attention and on-task/off-task behaviors. Results regarding the impact of sound and flickering from fluorescent lights were not significant.

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Introduction

Lighting within the built environment is an important factor on human development and functioning. Research has shown that daylight can impact human mood, performance, and well-being; including children and schools. “Light is the most important environmental input, after food and water, in controlling bodily functions” [1]. However, daylight must be supplemented with artificial lighting and today’s society is exposed to more artificial light than daylight [2]. For many

years fluorescent lighting has been the solution to provide energy efficiency and high illuminance for school environments, and have evolved to include full-spectrum lamps that simulate daylight. Recently, LED (light-emitting diodes) has come to the forefront due to their efficiency, longevity, and ability to provide a full, smooth, unbroken spectrum.

Studies have shown a major increase in positive perceptions and behavior within the work and classroom environment when incorporating LED

fixtures with higher correlated color temperatures (CCT); specifically, positive engagement and increase in on-task behaviors [3]. The implementation and effects of dynamic and tunable lighting is still being studied as to its long-term implications, however, when examining focus and concentration, Mott et al. and Slegers et al. [4-6] support the theory that high kelvin LED lamps can have a positive effect. Grangaard et al. [7-10] all implemented laboratory studies with results supporting the theory that high correlated color temperature (CCT) has positive effects on cognitive performance and on-task/off-task behaviors. Hawes et al. [10] specifically compared fluorescent and LED lamps which indicated better perceived performance and arousal states with high CCT LED lamps.

Children are expected to attend school to learn and perform at optimum levels. It's imperative to provide artificial lighting that enhances the classroom experience for children and teachers, enables strong cognitive function, and supports positive behavior.

Statement of the problem

Providing lighting that supports the various needs within a classroom continues to be a struggle and studies show that student behaviors and performance are impacted by classroom lighting. Fluorescent lamps have been the standard choice for school systems to provide efficient, quality lighting; however, LED lamps with higher correlated color temperatures (CCT) are the most recent high efficiency lamps to be integrated into the built environment and more studies are evaluating their positive impacts. The goal of this study is to provide insights for designing classroom lighting that positively impacts student attitudes and behavior.

Purpose

The purpose of this study is to examine insights and perceptions regarding attitudes and behaviors associated with classroom lighting, specifically the impact of fluorescent versus LED high correlated color temperature (CCT) lighting on students. The learning objects include teacher perceptions regarding: 1) impact on positive mood, attitudes, and alertness of students, 2) impact on student

engagement and on-task/off-task behaviors and 3) impact on student well-being.

Research question

Findings from existing literature suggest that lighting interventions within the built environment can affect behaviors, performance, and well-being of humans. It is hypothesized that higher color temperature LED lighting within a classroom positively impacts perceived attitudes and on-task behaviors of students.

Rationale

This study aims to obtain teacher insights and perceptions of classroom lighting based on their existing classroom situation and experience. Data from an original survey will examine perceptions of teachers and how lighting in the classroom impacts student attitudes and behaviors. It is expected that the survey data will support the theory that high correlated color temperature lighting positively impacts student on-task behavior and attitudes. Additionally it is expected that the survey data will support the need for further research within a controlled environment examining the impact of fluorescent lighting versus LED on students.

Assumptions

The questionnaire was implemented via Qualtrics and it is assumed all respondents met the introductory listed participation requirements, were truthful, and interpreted the directions and questions similarly. For questions that included images of classrooms, it is assumed the respondent focused on the light source illustrated rather than architectural design and/or finishes.

Literature review

The following literature review evaluates fluorescent lighting and LED with regards to their impact on energy efficiency, health and well-being, and human behaviors and attitudes. Fluorescent and LED are the industry standard lighting solution used within school environments. Research continues to work to understand how these lamps affect humans and the built environment (Appendix C).

Fluorescent, LED, and correlated color temperature overview

Though the visual light emitted from LEDs and fluorescent lamps have the same visual appearance, LEDs emit more non-visual light within the blue spectrum (450 nm) compared with fluorescents with the same CCT level [11]. Fluorescent and LED both have the capability of meeting the various light out-put and coloring needs, however, fluorescent lamps use phosphor coatings to improve color perception, such as full-spectrum fluorescent, which emulates daylight and diffuse UV radiation.

Fluorescent lamps contain mercury which can be toxic and need to be disposed of appropriately so not to induce health risks [12]. LEDs can produce more light per watt than many fluorescents lamps, therefore having a higher efficiency they radiate very little heat. LEDs typically have a longer useful life; use phosphor coatings to convert colors to white light; and do not contain gaseous toxins.

Although LEDs are still priced higher than fluorescents, this is slowly changing due to new developments and life cycle cost analyses [13]. One study found that switching to LEDs could reduce energy usage by 30%-50% for lighting and 10%-20% for cooling [14]. It is reported that public schools in the United States spend over \$8 billion annually on energy; therefore, saving on energy expenses and developing efficiencies is exceedingly important [15].

Behavioral categories

Reducing energy output is an important factor for both environmental and economic reasons though some studies have found that energy savings was small due to high parasitic losses [11]. Thus, lighting technology needs to be evaluated on its benefits and expectations beyond/in addition to reduction of energy supply and costs. These non-visual effects include: 1) Attainment: improvements in curriculum; 2) Engagement: improvements in levels of attention, more on-task behaviors observed, decrease in distracted or disruptive behavior; 3) Affect: improvements in self-esteem for teachers and learners, increased academic self-concept, improvements in mood and motivation; 4) Attendance: fewer instances of lateness or absenteeism; 5) Health or Well-being: impacts on the physical self, relating to discomfort as well as minor ailments [16].

Non-visual effects: Health

Research supports that lighting systems can have non-visual effects on humans such as psychological stability [14], a 1992 study found there to be less dental decay, greater height and weight gains, and better attendance and academic achievement for students receiving UV light supplements versus those who were in the non-UV group. Groups under sodium vapor lighting had the slowest and lowest rates in all categories [17].

Other health risks continuing to be researched are radio frequency radiation and ultraviolet radiation of compact fluorescents (CFL) and tube fluorescent (T8 and T12). A survey indicated self-proclaimed electro-hypersensitivity (moderate to extremely sensitive) to be highest for headaches when exposed to both tube and compact fluorescent and lowest with LED [12].

Lastly, many studies have found that normally functioning fluorescents can be a source of flicker and have biological effects such as a general feeling of discomfort, illness, headaches, eye strain [18] and reduced speed of visual search and performance [19].

Non-visual effects: Behavior and performance

Lighting and the non-visual effects on behavior, and performance have been studied in relation but not limited to hyperactive behavior [20] color rendering, mood, focus, cognitive performance, alertness, and visual acuity. Color can produce both physical and psychological responses, and research has shown that colored lighting can have a positive influence on behavior and people's ability to concentrate [3]. One study indicated that the color temperature and illuminance induced a positive mood-enhanced performance in problem solving and free recall tasks. The subjects' mood and their cognitive performance varied significantly between genders, indicating that genders emotionally had different reactions to the color temperature (Experiment 1) and combinations of color temperature and illuminance (Experiment 2) at different CRIs [8].

Another study looked at the effects of correlated color temperature (CCT) on alertness and vitality in the morning vs afternoon [21]. The findings highlight that a person's current psychological state of fatigue may play a role in how they respond to bright light during the day and that further research

and development of dynamic and personalized lighting systems may assist with alertness and mental well-being.

Non-visual effects: Studies using LED versus fluorescent

The effects of lighting on humans have focused on fluorescent lamps, however, more recent studies are examining LEDs and their effects on the work and classroom environments, including dynamic or tunable lighting. Tunable lighting is a newer concept that allows the user to adjust the color temperature and illuminance via different lighting settings throughout the day. Tunable lighting has been shown to benefit the learning environment. There are typically four settings: standard (white), energy, concentration (blue), and rest (yellow) [14,22]. Three studies that evaluated dynamic lighting within children's classrooms had mixed results based on concentration performance of gender [6].

A study's results researching the effects of LED light sources on participant performance of visual spatial abilities and executive functions suggested that cooler light exposure improves cognitive abilities to deal with multiple tasks or task switching [23]. Another study researched LED versus fluorescent and their effects on worker performance and indicated that LED at higher color temperatures supports positive mood, wakefulness, and speed in performance of visual perception and cognitive tasks relative to traditional fluorescent at lower color temperature [10].

Others studied the effects of high intensity, glare free lighting (referred to as focus light setting). This type of lighting increased third grade student's oral reading fluency. The results found no effects of lighting on motivation, however, focus lighting of 6000K led to a higher percentage increase in oral reading fluency performances versus the control lighting [4].

LED lighting in school facilities creates a productive learning environment [14]. Various studies have examined how the built environment can affect children in the classroom such as empirical research regarding the impact of noise on children with Autism Spectrum Disorder (ASD) [24]. The results indicated a significant improvement of unwanted behaviors with the intervention environment of LED lamps. Another

study found that students displayed more engaged behaviors under LED lighting with students with developmental disabilities showing the most change in engagement behaviors [15].

Methods

The study sought insights from teachers regarding the impact of fluorescent versus LED high color correlated temperature (CCT) lighting on student emotions, attitudes, and behaviors in the classroom. Teacher populations were recruited through public and private schools as well as acquaintances of the principal investigator. Participants were required to be 18 years of age or older, have a minimum of 12 weeks teaching experience in the classroom, teach between levels Pre-K through 12, and be a full-time teacher, practicum teacher, teacher aide or full-time building substitute teacher.

Sample size

One hundred-ten teachers, levels Pre-K through 12, were provided an online Qualtrics survey. There was a 68% response rate with 75 responses received, establishing a 95% level of confidence and a 6.5% margin of error.

Instrumentation

Survey research was implemented using an original questionnaire (Appendix B). Questions and terms were generated as the result of sources from the literature review, specifically a questionnaire developed for teacher insights regarding acoustics and lighting for children with autism [25], and behavior and lighting terms used in other analyses [4,6].

The Qualtrics questionnaire consisted of twenty-three questions and was based in affective testing using attitude, Likert, semantic differential, and rating scales. Images of school classrooms assessed teacher insights and perceptions of student engagement, affect, and well-being. These were clustered and analyzed for higher reliability. Questions included multiple choice, 5-point Likert, open-ended, and images of classrooms with fluorescent lighting and LED ranging from 3000–6500K.

Teachers were asked to provide demographic information regarding gender, number of years teaching, whether teaching in public or private

school setting, and length of time teaching in current classroom. They also were asked to complete multiple-choice questions regarding the type(s) of lighting and fixtures currently in their classroom (i.e., overhead fluorescent or LED, windows, skylights, desk lamps, etc.) and identifying the lens cover types via images and descriptions. Multiple-choice questions were utilized to obtain data regarding how and when teachers adjusted the light level within their classroom (e.g. time of day, activity).

Multiple-choice 5-point Likert questions addressed perceived issues with light glare, flashing, flicker, brightness, and perceived student behavioral responses to lighting regarding attention, focus, and mood. A 10-point slider scale evaluated teacher insight and perceptions regarding student behavioral response to light fixture humming, intensity, brightness, and glare. The questionnaire also addressed teacher’s perceptions of images illustrating the same classroom implemented with fluorescent versus LED and lower versus higher kelvin temperature lighting. Teachers were asked to select between two images as to which classroom they perceived best for behaviors of engagement and affect. (i.e., enhanced alertness, positive mood, encourages focus and staying on-task). Additional multiple-choice questions also addressed teacher perception of student engagement and affect in a classroom with 6500K, 4200K and 3500K LED lighting with choices of 1) sit and listen; 2) move and interact; 3) relax and rest; 4) none of the above. A final open-ended question was provided to allow for any additional comments and insights.

Design and procedure

The questionnaire was implemented in Qualtrics and distributed online. An introductory statement regarding the purpose of the survey, the IRB approval number, and participant qualifying factors were included. The survey was designed to be completed in an average of ten minutes to increase the potential of a high response rate.

Two of three schools provided Letters of Support which resulted in high response rates. The principal investigator also distributed the survey via email to forty-eight personal contacts who were independent of the recruited school organizations with various response rates (Table 1).

All data was collected and stored on Ball State University’s Qualtrics site, secured with a password, and only available to the principal investigator and faculty advisor. Participant identities were kept anonymous and raw final data was securely maintained on a flash drive for analysis and support of future studies.

Table 1. Percentage of teacher response rate to survey request

Contacts	%
Ball State University	73
The Eman School	29.16
North Ridge Dallas Center-Grimes	100
Personal contacts	68.75

Data analysis

Descriptive statistics were used to organize survey data in tables and graphs via Qualtrics and Excel. Total scores, distribution of percentages, mean and standard deviation were analyzed. Inferential statistics used samples of the data to establish general statements and conclusions regarding participants’ thoughts, perceptions, and insights.

IRB approval

The Institutional Review Board (IRB) reviewed the study research protocols, determining it to be exempt from further review based on Exempt Category 2 (Appendix A). The study was approved and assigned IRB protocol #1213195-1.

Results

This study sought insights from teachers regarding the impact of lighting on perceived student emotions, attitudes, and behaviors in the classroom, specifically the impact of fluorescent versus LED high correlated color temperature (CCT) lighting on students. The learning objectives included: 1) impact on positive mood, attitudes, and alertness of students, 2) impact on student engagement and on-task/off-task behaviors, and 3) impact on student well-being.

Participant demographics

The survey was distributed to one hundred-ten teachers, levels pre-K through 12. There was a 68% response rate with 75 responses. The gender of raters was significantly higher for female versus male with a quantity of 65 females (86.67%) and 10 males (13.33%). Forty-one (54.67%) of the 75 respondents indicated having 11 or more years of teaching experience. Fourteen (18.67%) indicated having 6-10 years of experience; 13 (17.33%) had 1-5 years; and 7 (9.33%) had under 1 year of experience (Figure 1).

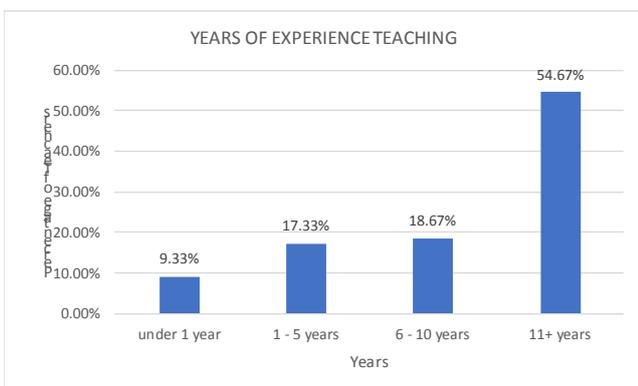


Figure 1. Year(s) of teacher experience in classroom

Teachers were recruited from public and private schools with 46 out of 75 teaching in public schools and 27 in private schools. Two respondents answered “other” with one specifying a lab school and the second ministry (Figure 2).

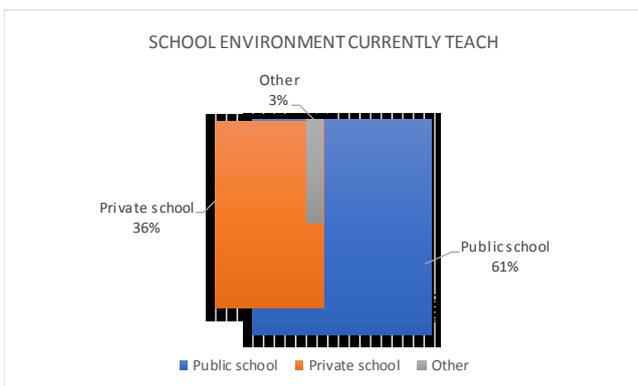


Figure 2. Percentage of teachers and type of school where they currently teach

The recruited population teach: Lower Elementary (28%); Upper Elementary (21.33%) and Middle School (21.33%). Kindergarten (5.33%) and High

School (8%) had the lowest number of respondents; Pre-K had a quantity of 12 (16%) (Figure 3).

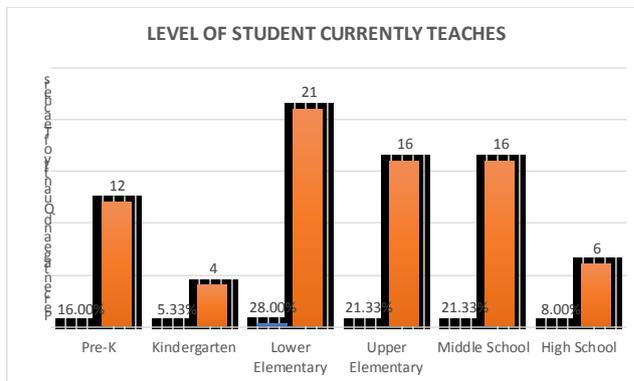


Figure 3. Percentage and quantity of teachers and level currently teaching

Existing classroom lighting

Responses indicated substantially more fluorescent lighting (62 of 75), and 2 indicated having LED in their classroom. Eight respondents did not know their classroom lighting type (Figure 4).

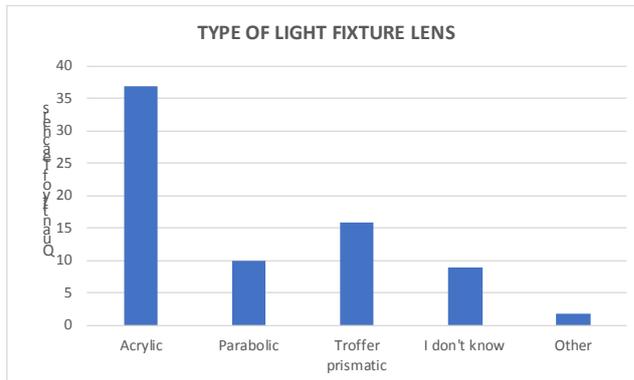


Figure 4. Teacher response number and type of overhead lighting in current classrooms

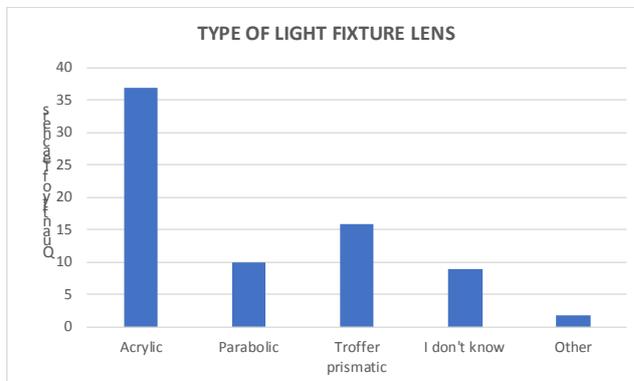


Figure 5. Type of light fixture lens in current classrooms of teacher respondents

Most respondents, 37 of 75 (50%), indicated that acrylic lenses were used in their current classroom. Troffer prismatic were the next highest quantity at 16 (21.6%), and parabolic at a quantity of 10 (13.51%) (Figure 5).

Sixty-four classrooms had windows (62.75%), according to the respondents. Fourteen of the respondents reported use of desk lamps (13.73%).

Lighting and affect: attitude, mood and alertness

Studies illustrated emotional/mood responses based on different kelvin temperature, with bluer/higher kelvin temperatures emoting alertness, focus, and arousal; and lower kelvin for calmness (Figure 6) [4,6]. This survey asked teachers to select images of classrooms that they perceived best for enhancing student alertness (Table 2); encouraging energy/arousal or moving and interacting (Table 3); and encouraging calmness (Table 4). Three additional classroom images illustrating different CCT; 4200K, 3500K and 6500K respectively had mixed results, suggesting no significance (Table 5).

Table 2. Percentage of teachers selecting LED 4200K classroom image versus fluorescent 3200K for enhancing alertness

Answer	%
LED 4200K	61.11
Fluorescent 3200	29.17
Neither, please explain	9.72
Total	100

Table 3. Percentage of teachers selecting 4200K classroom image for encouraging alertness- move/interact

Answer	%
Focus: Sit and listen	28.77
Alertness: Move and interact	50.68
Calm: Relax and rest	4.11
None of the above	10.96
Other, please specify	5.48

Total	100
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Table 4. Percentage of teachers selecting 3000K classroom image versus 5000K for enhancing calmness

Answer	%
LED 3000K	62.16
LED 5000K	31.08
Neither, please explain	6.76
Total	100

Table 5. Shows mixed results for teacher selection of affect or engagement for 3500K classroom

Answer	%
Focus: Sit and listen	30.56
Alertness: Move and interact	30.56
Calm: Relax and rest	33.33
None of the above	4.17
Other, please specify	1.39
Total	100

Table 6. Percentage of teachers selecting 6500K classroom image versus 5000K for enhancing focus during testing

Answer	%
5000K	38.36
6500K	54.79
Neither, please explain	6.85
Total	100

Table 7. Percentage of teachers selecting 3500K classroom image versus 5000K for encouraging on-task behaviour

Answer	%
3500K	72.6
5000K	16.44
Neither, please explain	10.96

Total	100
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Table 8. Percentage of teachers selecting 6500K classroom image for encouraging focus

Answer	%
Focus: Sit and listen	52.11
Alertness: Move and interact	25.35
Calm: Relax and rest	2.82
None of the above	14.08
Other, please specify	5.63
Total	100

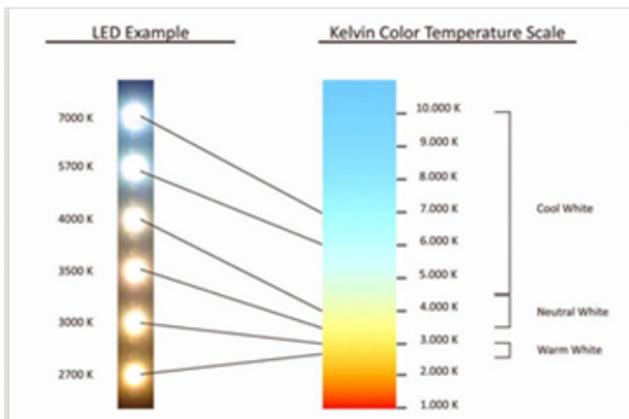


Figure 6. LED Lighting Kelvin Color Temperature Scale Chart, Source (LED Corporations, 2012)

Lighting and engagement: attention and on-task behavior

Several questions addressed engagement and on-task/off-task behaviors by using classroom images with different kelvin temperatures (Figures 7-9). The off-task behaviors included: 1) fidget in seat, unable to sit still; 2) not involved, appear to be daydreaming; 3) appear tired or lethargic; 4) become agitated or frustrated; 5) overtly act out, not attending to lesson. When asked to select between a 5000K and 6500K-lit classroom, the 6500K lighting was perceived as best for focusing during testing by 40 of 73 respondents (54.79%), while the 5000K classroom was selected by 28 of 73 respondents (38.36%) (Tables 6 and 7). Single images of classrooms illustrating 4200K, 3500K and 6500K respectively resulted in the image illustrating 6500K to be selected by 52.11% for

encouraging on-task behavior of sit and listen (Table 8).

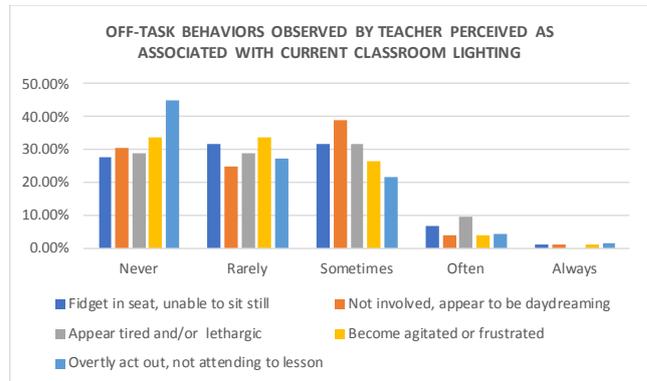


Figure 7. Percentage of teachers who perceive current classroom lighting impacts observed off- task behaviors of students

Lighting and health and well-being: sounds and flicker

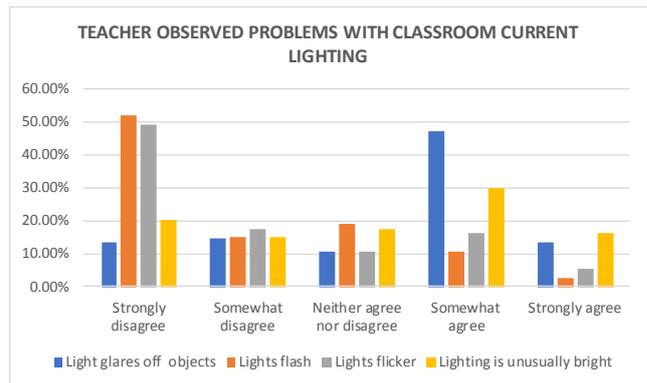


Figure 8. Percentage of teachers observing negative issues with existing classroom lighting

Teachers were asked if they perceived negative issues with existing lighting in their classroom regarding 1) light glares off objects, 2) lights flash, 3) lights flicker, 4) lighting is unusually bright. There wasn't a significant response of agreement regarding a perceived issue with lights flashing or flickering. Light glare and unusual brightness of lighting did have a higher response of agreement and significance with a quantity of 10 (13.51%) "Strongly agree" and 35 (47.30%) "Somewhat agree." Teachers rated the issue of "lighting being unusually bright" with a quantity of 12 (16.44%) "Strongly agree" and 22 (30.14%) "Somewhat agree" (Figure 8).

Teachers were also asked to rate what extent they perceive the following lighting issues impact students: 1) notice the hum of electronic noise from

the light fixtures; 2) are bothered by the hum of the lights; 3) perceive the intensity or brightness of lights; 4) are bothered by the intensity or brightness of the lights; 5) perceive the glare of the lights; 6) are bothered by the glare of the lights. Findings suggest no significance of perceived student impact (Figure 9).

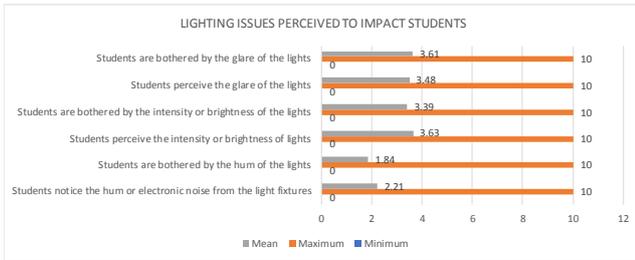


Figure 9. Summary of the mean values of lighting issues and teacher perceived impact on students

Light levels and behavior

Research has shown that adjusting light levels within a classroom can affect children’s behavior [14,22]. Teachers were asked if they adjust the light level in their classroom to enhance the environment for students. Significantly, 81.08% responded “yes,” with a quantity of 60 out of 74 responses. A quantity of 5 (6.75%) responded “no,” and 9 (12.16%) indicated they do not have the ability to adjust the light level (Figure 10).

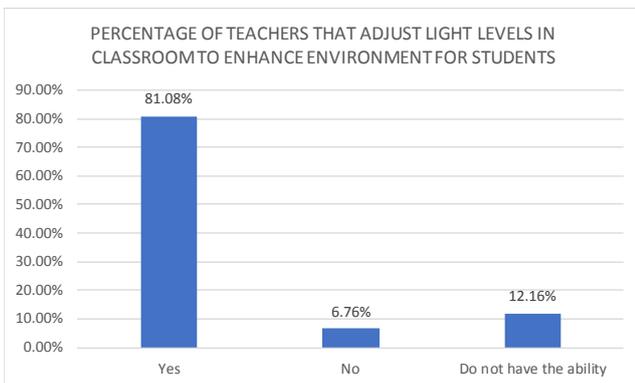


Figure 10. Percentage of teacher that adjust classroom light level to enhance environment

Teachers were asked during what times of day they adjust light levels in their classroom with a quantity of 43 (33.86%) responding “during morning hours” and a quantity of 35 (27.56%) during afternoon hours (Figure 11). Fifty-five (31.98%) adjust light levels “during viewing of digital display” and a quantity of 41 (23.84%) adjust light levels during quiet time (Figure 12).

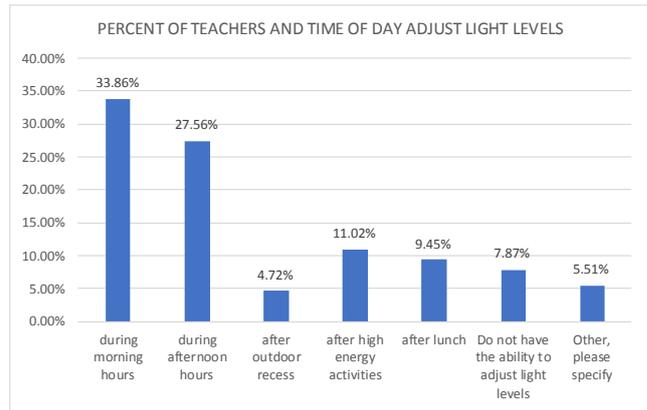


Figure 11. Percentage of teachers adjusting classroom light levels during school day

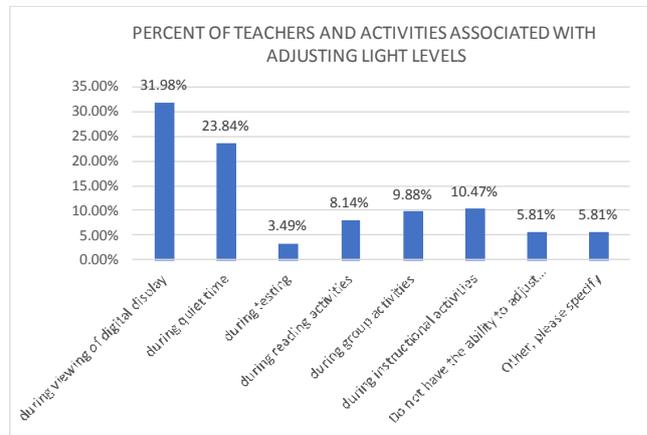


Figure 12. Percentage of teachers adjusting classroom lighting associated with activities

Summary

Significant and mixed results from the teacher survey were found regarding the impact of lighting on mood, attitude, and engagement. There was also mixed support for the hypothesis that higher correlated color temperature LED lighting versus fluorescent lighting within a classroom positively impacts perceived attitudes and behaviors. The most significant outcomes are:

- Impact on positive mood, alertness, and energy:

Most teachers selected classroom images with higher kelvin temperature as encouraging positive affect, alertness, and energy.

- Impact on calm and restful mood:

Most teachers selected the classroom image with lower kelvin temperature as encouraging calm: 3000K lighting was selected by 62.16% of respondents

Over the same classroom image with 5000K. A separate individual classroom image at 3500K received mixed results with only 33.33% response as encouraging relaxation and rest, and 30.56% responding as encouraging engagement or energy. This suggests that the difference of 500K may impact perceived mood, however, these results cannot be considered significant.

- Impact on student engagement and on-task/off-task behaviors:

Mixed results were found regarding focus and on-task behaviors.

However, teacher responses to perceived student off-task behaviors due to lighting issues were not significant.

- Impact on health and well-being:

A quantity of 3 out of 19 teachers provided comments addressing concerns and insights regarding lighting and well-being.

- Impact of adjusting light levels in classroom:

Most teachers, 81.08%, indicated they adjust light levels within their classroom to impact mood, attention, and engagement regarding specific activities and times of day. Thirteen of the 19, 68.4%, responses addressed the importance of adjusting light levels to encourage engagement, positive mood, and well-being.

Discussion

The purpose of this study was to examine insights and perceptions regarding attitudes and behaviors associated with classroom lighting, specifically the impact of fluorescent versus LED high correlated color temperature (CCT) lighting on students.

Impact on positive mood, attitudes, and alertness of students

Much theoretical research has focused on our body's natural clock, or circadian rhythm, which regulates our sleep/wake cycle; indicating our body responds/awakens to bluish light as experienced in morning hours, and warmer light causes the brain to release melatonin which prompts us to relax and prepare our bodies to sleep [26,27]. Aptly put by the director of the Division of Sleep Medicine at Harvard Medical School Charles A. Czeisler:

“Light affects our circadian rhythms more powerfully than any drug” [14].

Studies illustrated emotional/mood responses based on different kelvin temperature, with bluer/higher kelvin temperatures emoting alertness, focus, and arousal; and lower warmer kelvin for calmness [4,6,14]. Most teachers selected classroom images with higher kelvin temperature as encouraging positive attitude, alertness, and energy. With 61.11% selecting 4200K for alertness over 3200K, and 50.68% selecting 4200K for activity of movement and interaction.

Survey results were mixed regarding impact of kelvin temperature on encouraging calm. The classroom illustrating 3000K was selected by most teachers (62.16%) for enhancing calmness over the classroom using 5000K. Another image illustrating 3500K had mixed results with the largest percentage (33.33%) identifying this classroom lighting best for encouraging restfulness (relax and rest), 30.56% identified it best for both activeness/arousal (move and interact) and focus (sit and listen). These results may support the findings that kelvin temperature 3000 and lower can induce calmness [4,6]; and that the difference of 500K is perceived as cooler and whiter, and not as calming. However, these results cannot be considered significant.

Impact on student engagement and on-task/off-task behaviors

Studies [6,10] found that LED lighting at a higher correlated color temperature has a perceived positive impact on behaviors during activities that require focus such as taking a test. Another study [28] demonstrated that 6500K compared to 4000K enhanced levels of attention and concentration [10]. Most teachers selected the LED 6500K classroom for on-task behaviors and engagement. With 54.79% selecting 6500K over 5000K for encouraging focus during testing, and 52.11% selected a separate image illustrating 6500K as best for encouraging on-task behavior of sitting and listening. However, a third image with a lower color temperature image of 3500K was selected by most for encouraging “on-task behaviors” over the 5000K image, suggesting no significance was found. The results regarding teacher perceptions of how lighting impacts student off-task behaviors also did not provide significant findings. A 2012

study found on average that student concentration increased with 6500K, but findings also indicated improved concentration may be based on grade level, with grade 4 students more affected than grade 6 [6].

Impact on health and well-being

Most teachers, 82.67%, responded as currently having fluorescent lighting within their classroom. Many studies have found that normally functioning fluorescents can be a source of flicker and have biological effects such as a general feeling of discomfort, illness, headaches, eye strain [18] and reduced speed of visual search and performance [19]. The perceived impact of sounds and flickering on student comfort and well-being were mixed and not significant. The “glare of lighting off objects” was rated highest as a perceived problem, with 47.30% rating as “somewhat agree” and only 13.51% as “strongly agree.” The next highest rated problem was “lighting is unusually bright” with a response rate of 30.14% “somewhat agree” and 16.44% as “strongly agree.”

Impact of adjusting light levels for engagement, affect and well-being

Most teachers, 81.08%, indicated they adjust light levels within their classroom to impact mood, attention, and engagement regarding specific activities and times of day. A quantity of 19 additional comments was received regarding teacher insights and perceptions of the impact of classroom lighting. Thirteen of the 19 responses (68.4%), addressed the importance of adjusting light levels to encourage engagement, positive mood, and well-being. These results support findings [4,6,10] that dynamic or tunable lighting within the classroom may benefit children’s behaviors and performance. This concept would need to be further studied as to whether it is the “amount of light” or the correlated color temperature that affects perceived attitude and behavior.

Conclusion, limitations, and recommendations

The purpose of this study was to examine perceptions, attitudes and behaviors associated with classroom lighting, specifically the impact of fluorescent versus LED high correlated color temperature (CCT) lighting on students. Lighting

within the built environment can have an impact on the well-being, behavior, and performance of humans [21]. Many studies have examined fluorescent and LED lighting at various correlated color temperatures within work environments and classrooms.

Survey data based on teacher insights and perceptions supported the perception of higher correlated color temperature lighting positively impacting alertness, attitude, and energy level. Findings also supported the ability to change light levels throughout the school day to positively impact student engagement and mood. There were mixed results regarding higher correlated color temperature impacting attention and on-task/off-task behaviors. Results regarding the impact of sound and flickering from fluorescent lights were not significant. The issue of “lights glaring off objects” was selected as “somewhat agree” by the highest percentage surveyed.

The study presents limitations due to the subjective manner implicit in teacher reviews and in self-reported insights and perceptions. Classroom images utilized may be subjective due to the inability to control consistency of computer monitor color displays used by participants. Additionally, sample sizes were too small to run significant results thus a lack of statistical significance throughout.

It is suggested that further research and other methodologies occur to better understand the impact of higher correlated color temperature LED versus fluorescent lighting on students in the classroom. Methodologies should include controlled laboratory and classroom settings with monitored observation, directly measuring behaviors and attitudes.

The concept of dynamic or tunable lighting has limited empirical research and needs to be further studied based on its impact in the classroom as well as establishing guidelines for use. Understanding the impact of classroom lighting on student behavior, attitudes and engagement is important for ensuring student academic success, as well as physical, emotional, and cognitive well-being.

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