Enhancing Classroom Environment's Sustainability and Efficiency through AI -Driven Measures

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Abstract

Emission of carbon footprints plays a major role in climate change and hence, the world is moving towards sustainable energy-based solutions. This paper investigates challenges in classroom environments, focusing on illuminance levels, indoor air quality, and temperature. The study introduces methodologies to enhance educational spaces, emphasizing advanced lighting for optimal illumination, addressing indoor air quality and efficient temperature regulation. Thereby aiming to create visually conducive environments, promoting concentration, and learning effectiveness. The research contributes to nurturing students' intellectual growth and well-being through sustainability.

Keywords: Indoor Air Quality; Lux Levels; Classroom environment; Humidity; Temperature; Energy Efficiency.

1. Introduction

The quality of the learning environment in educational institutions significantly impacts academic performance and the overall health of students [1]. The classroom environment plays an important role in forming the educational journey of students, and this paper explores the challenges associated with these factors, focusing on lux levels, air quality, and temperature. Lux levels, which encompass the quality of lighting within classrooms, are crucial for visual comfort and cognitive performance [2-3]. Inadequate lighting can lead to eye strain, reduced visual comfort, and hinder the cognitive processes necessary for education [4].

Addressing lux levels aims to provide students with an optimal visual environment that supports their academic endeavours and enhances concentration and learning effectiveness. Air quality is another paramount concern, as the concentration of carbon dioxide (CO_2) [5] and humidity levels directly influence the health and focus of students. High CO_2 concentrations have been linked to reduced cognitive function and attention, potentially impeding the learning process. Conversely, inadequate humidity levels may lead to respiratory discomfort [6].

Temperature regulation within classrooms also plays a significant role in student comfort, concentration, and overall well-being. If a classroom is too hot, it may induce discomfort and drowsiness, while a chilly one can led to distractions and reduced concentration. Strategies for regulating temperature efficiently are explored to foster an environment where students can thrive academically and feel comfortable throughout their educational journey [7-8]. By enhancing lux levels, air quality, and temperature in educational spaces, we can create an environment that nurtures the intellectual growth of students and promotes their well-being, leading to a brighter future for all [9].

As we delve into the integration of advanced lighting systems and ventilation measures, our focus shifts towards comprehending the dynamic interplay between environmental factors and classroom efficiency. Through the

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ongoing investigation of lux levels, air quality, and temperature regulation, we aim to elucidate their profound impact on student well-being and academic performance. Building upon these methodologies, our subsequent discussions delve into the nuanced analysis of specific parameters and their implications for creating sustainable learning environments.

2. Literature Review

The quality of the learning environment in educational institutions significantly impacts academic performance and the overall health of students (Shukla & Singh, 2018). The classroom environment plays a crucial role in shaping students' educational journey, with particular focus on factors such as lux levels, air quality, and temperature.

Lux levels, representing the quality of lighting within classrooms, are essential for visual comfort and cognitive performance (Sung & Hsiao, 2021). Inadequate lighting can lead to eye strain and reduced cognitive processes necessary for effective education (Al Athwari & Ali, 2014). Addressing lux levels aims to provide students with an optimal visual environment that supports their academic endeavours and enhances concentration (Gola et al., 2019).

Air quality, characterized by factors such as carbon dioxide (CO2) concentration and humidity levels, directly influences student health and focus (Macieira et al., 2021). Elevated CO2 levels have been linked to reduced cognitive function and attention, potentially impeding the learning process (Twardella et al., 2012). Conversely, inadequate humidity levels may lead to respiratory discomfort and health issues (Karimi et al., 2023).

Temperature regulation within classrooms is crucial for student comfort and concentration (Dong et al., 2018). High temperatures can induce discomfort and drowsiness, while cold environments can lead to distractions and reduced concentration (Martirano & Senior, 2014). Strategies for efficient temperature regulation include the use of energy-efficient HVAC systems and temperature sensors (Zhu et al., 2018).

Recent advancements in technology, such as AI-driven smart classroom automation systems and IoT-based solutions, offer innovative approaches to enhance classroom environments (Gupta et al., 2020). These technologies enable real-time monitoring of environmental parameters and automated adjustments to maintain optimal conditions (Khan & Kim, 2015).

Furthermore, the COVID-19 pandemic has underscored the importance of indoor air quality in classrooms (Shukla & Singh, 2018). Proper ventilation, filtration, and air quality measures are essential for reducing the risk of viral transmission in enclosed spaces (Al- Khafajiy et al., 2016).

Addressing factors such as lighting, air quality, and temperature is essential for creating conducive learning environments in educational institutions. Integrating advanced technologies and adhering to recommended standards can significantly enhance the sustainability and efficiency of classroom environments, promoting student well-being and academic success.

3. Lux Levels and Lightning

Lux levels, or illuminance levels, are the amount of light incident on a surface and are typically measured in lux, which is equal to one lumen per square meter (lux). Intelligently designed lighting systems in classrooms are crucial for creating an optimal learning environment. Inadequate lighting can lead to eye strain, reduced visual comfort, and decreased cognitive performance, particularly in spaces where students need to read, write, or view visual materials. Fig.1 shows the Illuminance level, Limiting Glare Rating and Minimum Colour Rendering (R) of Various rooms.

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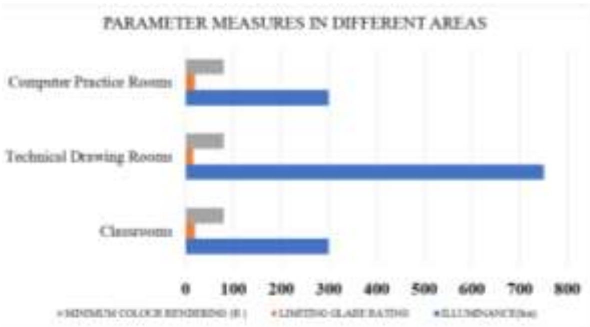

Figure 1: shows the Illuminance level, Limiting Glare Rating and Minimum Color Rendering (R) of Various rooms.

This paper discusses the integration of advanced lighting fixtures, such as LED lights, which are not only energy-efficient but also equipped with sensors and controls that enable dynamic adjustments of light intensity based on occupancy and natural light levels. LED lighting is more energy-efficient compared to traditional lighting technologies, thus contributing to cost savings [11-12].

Proper lighting in classrooms holds a pivotal role in facilitating a conducive learning environment. Its significance transcends mere illumination and extends to several aspects that profoundly affect the educational experience: cognitive performance, visual comfort, and concentration. Well-illuminated classrooms help students read, write, and engage with visual materials more effectively, enhancing their ability to understand and retain information [13]. Visual comfort minimizes eye strain, preventing discomfort and fatigue that can result from inadequate or harsh lighting conditions. Quality lighting fosters concentration, reducing the likelihood of students becoming distracted or disengaged [14].

Inadequate lighting can have adverse effects on both cognitive performance and visual comfort. Poor lighting can lead to reduced cognitive performance, making it challenging for students to read, take notes, or engage with visual materials, hindering their ability to grasp and retain information. Visual discomfort can cause headaches, fatigue, and even irritability in poorly lit environments, which not only affects learning but can also lead to health issues eventually.

Advanced lighting fixtures, such as LED lights, have emerged as essential components in enhancing classroom lighting. They offer several benefits, including energy efficiency, dynamic adjustment ability, and visual comfort [15]. Energy efficiency is closely tied to cost savings, allowing educational institutions to reduce their electricity bills and allocate resources to other important aspects of education.

4. Air Quality

Elevated CO_2 levels in classrooms can be caused by inadequate ventilation and human respiration, leading to reduced cognitive function and discomfort. Proper humidity control is crucial for student comfort and respiratory health, as low humidity levels can lead to discomfort and respiratory problems.

The Air Quality Index (AQI) is a standardized measure that provides information about the quality of the air in a specific location, based on the concentrations of various air pollutants. The AQI is associated with health impacts, and its results can help individuals and communities understand the potential risks of exposure to air pollution.

The AQI categorizes air quality into different levels, each associated with a specific range of pollutant concentrations. The AQI is presented as a numerical value on a scale that ranges from 0 to 500. The scale is divided into different color-coded categories, each representing a level of health concern. These are categorized into six different levels range from Excellent (0-50 AQI) to Critical (401-500 AQI) indicating the potential health impacts for the general population and sensitive groups. Also, temperature and humidity play a major role in the cognitive performance of the students inside the classroom. Table. 1 shows the various Air Quality Index (AQI) levels along with their corresponding health effects.

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Table 1: Various Air Quality Index (AQI) Levels along with their corresponding Health Effects.

AQI	Remark	Colour Code	Health Impacts
0-50	Excellent		Minimal Effect.
51-100	Acceptable		Sensitive persons may experience mild respiratory discomfort.
101-200	Moderate		Breathing difficulties in patients suffering from heart, lung, or asthma conditions.
201-300	Subpar		Most people experience breathing difficulties after extended exposure.
301-400	Inadequate		Respiratory disease after prolonged exposure.
401-500	Critical		Influence on both healthy individual and persons with alignment.

Low humidity can cause dry air, and dry out mucous membranes in the respiratory system, making students more susceptible to respiratory infections while high humidity can make the air feel oppressive and uncomfortable. Maintaining the right humidity levels is essential for respiratory health. High humidity can create an environment where Mold and mildew thrive, potentially exacerbating allergies and respiratory issues. Table. I represents various Air Quality Index (AQI) levels along with their corresponding health effects.

Modern HVAC systems are equipped with humidity control features, which can regulate humidity levels by adding or removing moisture from the air. In cases where HVAC systems do not provide sufficient humidity control, standalone humidifiers can be employed to add moisture to the air, effectively increasing humidity levels in the classroom [16]. Regular monitoring of humidity levels in the classroom using humidity sensors and controls is essential to ensure that humidity remains within the recommended range for student comfort and well-being.

5. Temperature and Regulation

Temperature regulation in classrooms is crucial for students' comfort and focus. High temperatures can cause discomfort such as sweating and dehydration, drowsiness, and reduced cognitive performance, while cold environments can lead to distractions, shivering, and reduced dexterity, making it difficult for students to concentrate on lessons and reduced concentration. Strategies for regulating temperature while being energy-efficient include using energy-efficient HVAC systems, zoning, and the integration of temperature sensors and controls. To maintain an optimal temperature range and energy efficiency, strategies include installing energy-efficient HVAC systems, dividing the classroom into different zones, and integrating temperature sensors and controls. Table. 2 shows the Classroom Temperature Range and its Conditions.

Table 2: Classroom Temperature Range and its Conditions

Temperature Range	Colour indication	Condition	Actions Required
88°F		Too Hot to Occupy	The classroom must be vacated

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		Safely	entirely.
82°F		Extremely Hot	Steps must be taken to relieve extreme heat conditions.
65°F		Minimum Requirement	Maintain a minimum classroom temperature of 65°F.
50°F		Too Cold	Extremely low temperatures can have negative effects.

Energy-efficient HVAC systems can efficiently change the temperature of the classroom, providing a comfortable environment. Zoning allows for customized temperature control, focusing resources on areas where students are present while maintaining energy efficiency in unoccupied sections. Integrating temperature sensors and controls with HVAC systems enables real-time monitoring and adjustment of classroom temperature, maintaining it within the optimal range.

6. Analysis of Parameter

The increasing worry about indoor air quality (IAQ) in classrooms stems from its potential to induce health issues like headaches, fatigue, and respiratory problems. This study examines indoor light lux, carbon dioxide concentration, temperature, and relative humidity and corresponding recommended standards.

IAQ is crucial for students' health and well-being due to prolonged indoor exposure, health concerns, and recent events like the COVID-19 pandemic. Proper ventilation, filtration, and air quality measures are essential for reducing the risk of viral transmission in enclosed spaces. Recommended lux levels for educational spaces fall within 200 to 500 lux, which enhances concentration and overall learning effectiveness. Air quality standards vary based on location and organization, with common recommendations being below 1,000 ppm for good air quality. However, research suggests lower levels, such as 800 ppm or 600 ppm, are advisable for optimal cognitive function and well-being.

Temperature guidelines suggest a range of 73°F to 79°F (23℃ to 26℃), which is essential for creating a comfortable and conducive learning environment. Compliance with established standards and adherence to research findings are crucial in ensuring that lux levels, air quality, and temperature are maintained within ranges that promote optimal learning environments. These standards and research findings serve as guidelines to create healthier and more productive educational spaces.

7. Monitoring Campaign

The monitoring campaign was executed in a specific classroom environment, to maintain lux level, IAQ, humidity, temperature, and CO2. The placement of lights, fans and sensors is a critical part of the execution system. LEDs are crucial as they emit light and contribute to the overall lux levels in the room. They are strategically placed to assess how lighting conditions vary across different areas of the classroom. Fans are strategically placed to maintain uniform air quality and temperature throughout the classroom, ensuring consistent environmental conditions for all students. Windows are strategically placed to account for natural lighting and ventilation, providing an alternate light source for energy efficiency and visual comfort.

The rationale behind the placement of these elements is to collect comprehensive data on various environmental factors within the classroom. Placing tube lamps in distinct locations enables the assessment of how artificial lighting impacts lux levels and visual comfort across the classroom, helping identify areas with potential lighting

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issues that may require adjustments or improvements. Fans contribute to air circulation, ensuring that air is distributed evenly, and reducing the likelihood of air stagnation and temperature variations. The positioning of windows accounts for the impact of natural light and outdoor conditions on indoor environmental quality, assessing the variability in natural lighting throughout the day, which can influence lux levels and energy efficiency.

8. Results and Analysis

The research examined how lighting and CO_2 concentration affect the classroom environment. Light intensity was measured using a dedicated light meter (HTC Lux meter), while carbon dioxide concentration was quantified using a specialized carbon dioxide meter (SENKO sampling pump). The average temperature and relative humidity recorded during the monitoring period were approximately 31.2ºC and 45%, respectively. According to IS 3646-1 (1992) standards, the interior illumination within educational spaces should ideally fall within the range of 200-500 Lux.

The measurements indicated variations in light intensity across different areas of the classroom. Students seated near windows experienced consistent light intensity, irrespective of interior lighting conditions. Conversely, students in the middle and left rows encountered significantly lower light lux levels, attributed to the placement of interior lights at the rear of the classroom. This disparity was attributed to the placement of interior lights at the rear of the classroom, resulting in students in the 2-back row receiving appropriate light intensity, while the front and middle rows received less illumination. Fig.2 shows the average light intensity inside the classroom settings.

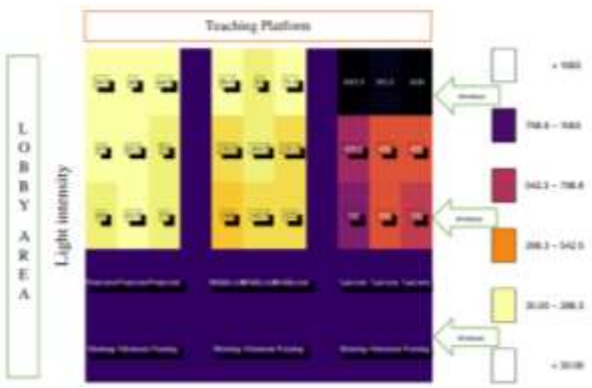

Figure 2: Average light intensity inside the classroom setting.

The results indicated that CO_2 concentrations remained well within permissible limits, as delineated by standards such as OSHA. This suggests that the classroom's ventilation and air exchange systems were effectively preventing the buildup of excessive CO_2. Additionally, classroom size and orientation significantly influenced indoor light levels and CO_2 concentrations.

The variation in light intensity due to the placement of LED highlighted the significance of lighting design within classrooms. Students located in areas with lower light intensity might experience reduced visual comfort and potentially hindered cognitive performance. The finding is that CO_2 concentrations were within permissible limits is positive, as elevated CO_2 levels can negatively impact cognitive function [17].

The study also noted that classroom size and orientation influenced indoor light levels and CO_2 concentrations, suggesting that larger classrooms or those with specific orientations may require different ventilation and lighting strategies to maintain optimal conditions for students. Fig. 3 shows the average CO_2 levels inside the classroom setting.

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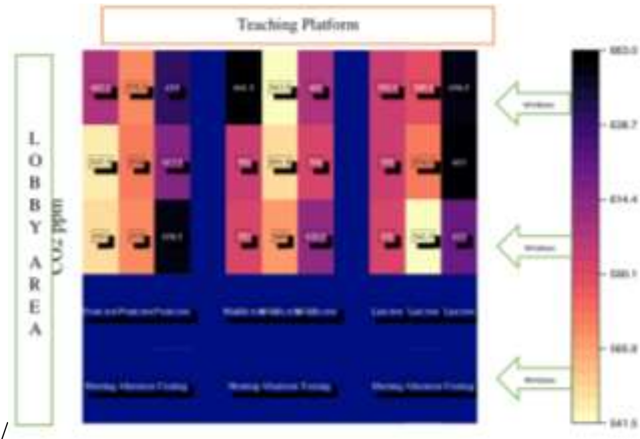

Figure 3: Average CO2 levels inside the classroom setting

A. Required Levels

The recommended levels for light intensity (lux), air quality, and temperature in educational spaces are based on relevant standards and research findings. Lux levels typically fall within the range of 200 to 500 lux, providing adequate illumination for tasks like reading, writing, and viewing visual materials. Lower CO2 concentrations are often recommended for optimal cognitive function and student well-being. Humidity levels range from 30% to 60%, ensuring student comfort and respiratory health.

Parameter	Symbol	Unit	Min	Max	Mean	Standard
Occupants	*O*	Nos	1	75	38	65
Area	*Ao*	M2	6	90	48	60
Air quality	*AQI*	__	51	155	103	25
Air Temp.	*T*	C	22	42	32	28
Rel. Humidity	*RH*	%	21	100	71	45
Wind Speed	*Ws*	m/s	1.3	23.1	12.2	14.9
Indoor Co2	*CO2*	Ppm	445	572	508	500

Figure 4: The recommended levels for lux, air quality, and temperature.

Temperature standards can vary slightly based on local regulations, but a general guideline is a temperature range of 73°F to 79°F (23°C to 26°C) for classrooms. It is important to consider regional and seasonal variations in temperature and adapt heating and cooling systems to maintain the recommended temperature range. Local building codes and regulations may provide specific temperature guidelines for educational facilities. Adhering to these levels is crucial for creating an ideal learning environment that fosters student well-being and academic success. Fig.4 shows the recommended levels for lux, air quality, and temperature.

B. Strategies for Improving Classroom Environment

Achieving an optimal classroom environment is crucial for students' well-being and learning experiences. Educational institutions can implement strategies that focus on ventilation, lux levels, and air quality. These strategies include innovative ventilation systems equipped with air quality and occupancy sensors, which

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automatically adjust ventilation rates based on occupancy levels and real-time data. Regular maintenance of ventilation systems is essential for their continued effectiveness.

Energy-efficient lighting solutions are also essential for conserving energy and enhancing visual comfort. Classrooms with abundant windows and skylights maximize natural light influx, reducing reliance on artificial lighting during daylight hours. Regular maintenance protocols ensure that strategies continue to operate at peak efficiency, promptly addressing any issues.

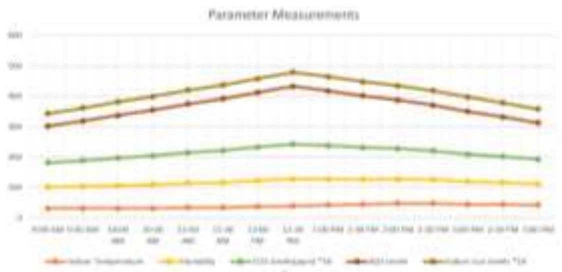

Figure 5: Parameter Measurements Before Implementing the Strategies.

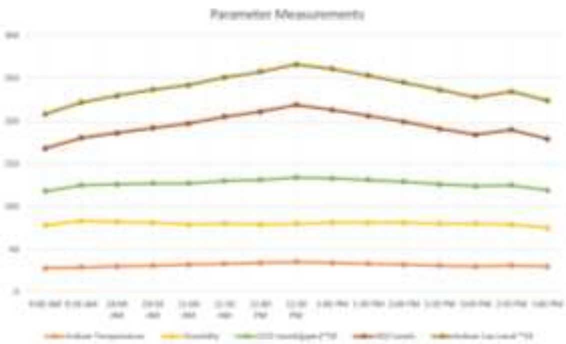

Figure 6: Parameter Measurements After Implementing the Strategies.

Data-driven insights from energy meters, occupancy sensors, and air quality sensors can provide valuable resources for identifying trends, assessing the effectiveness of implemented strategies, and making data-informed decisions to continually enhance the classroom environment. Implementation challenges include initial costs, maintenance, compatibility with existing electrical systems and infrastructure, architectural constraints, and glare and heat.

Regular maintenance protocols offer benefits such as sustained performance, extended lifespan, and reduced operational disruptions. However, implementation challenges include budgeting for ongoing maintenance, operational disruptions, and maintenance costs.

The lux level, Temperature and Humidity, and Air Quality Index was measured before and after implementing the strategies for improving the classroom environment. There was a gradual change in the measurements of the parameters. This will ensure a healthy learning space for both the students and the teaching staff leading to a better classroom environment. Fig.5 and Fig. 6 show the parameter measurements before and after implementing the strategies.

The study's findings underscore the importance of prioritizing environmental considerations in educational settings to create conducive learning environments. By addressing factors such as lighting, air quality, and temperature, educational institutions can promote student well-being and academic success.

9. Conclusion

This study advocates integrating advanced technology and sustainable design for optimal classroom environments. Emphasizing proper lighting, ventilation, and temperature regulation. It aligns with standards to

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create healthier, cost-efficient spaces. The integration of technology fosters positive learning experiences, contributing to improved academic performance and student success. Future research endeavours aimed at further understanding and enhancing the classroom environment hold the potential to significantly advance the field of educational technology and pedagogy.

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