Assessment of Indoor Environmental Quality in Educational Settings: Insights in level of stress, attention and engagement

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Abstract

Indoor environmental quality (IEQ) significantly influences cognitive engagement, stress, and overall well-being in educational settings. This study examines the effects of three key IEQ factors—air temperature, relative humidity, and natural light—on students' attention and relaxation using electroencephalogram (EEG) monitoring in a controlled environment. Twelve participants engaged in experimental sessions under four scenarios: baseline conditions, exposure to natural light, increased humidity, and elevated temperature. Objective EEG metrics were complemented by environmental data, including air temperature, relative humidity, lighting levels, and carbon dioxide concentrations. The results reveal distinct effects of IEQ factors on cognitive and physiological responses. Exposure to natural light improved relaxation but reduced attention, indicating its restorative effects on stress recovery while potentially introducing distractions. High humidity levels negatively impacted both attention and comfort, reinforcing the challenges associated with exceeding recommended humidity ranges. Elevated temperatures enhanced attention but slightly impaired relaxation, suggesting that warmth may promote cognitive engagement at the cost of minor discomfort. Baseline conditions recorded the highest attention levels, underscoring the value of stable and unaltered environments in fostering focus. These findings demonstrate the nuanced interplay between environmental parameters and their psychophysiological impacts. This research highlights the importance of understanding how variations in IEQ factors influence mental states in learning spaces. While individual factors have distinct effects, the dynamic interaction between air temperature, relative humidity, and lighting requires careful consideration to create environments that support both cognitive performance and emotional well-being. These insights contribute to the growing body of knowledge on designing effective and student-friendly educational environments.

Keywords: Indoor Environmental Quality, Electroencephalogram, Stress, Attention.

Introduction

Educational facilities, where students spend a significant portion of their day, represent critical environments for fostering cognitive and emotional development. Within these spaces, indoor environmental quality (IEQ) profoundly influences students' learning outcomes and well-being. A conducive learning environment—defined as the physical and psychological conditions in which learning occurs—plays a pivotal role in enhancing academic performance. Among these, IEQ has been identified as a key determinant of cognitive outcomes, fostering improved performance and institutional excellence (Kim, Hong, & Yeom, 2020).

Learning is influenced by a constellation of factors encompassing pedagogical, social, individual, and environmental domains. Pedagogical factors include curriculum content and instructional methods (Schunk, 2012); social factors focus on peer and teacher relationships (Wentzel, 1998); and individual factors address stress regulation and intrinsic motivation (Ryan & Deci, 2000; Lazarus & Folkman, 1984). However, the impact of IEQ—comprising elements like lighting, temperature, humidity, indoor air quality (IAQ), acoustic conditions, and access to natural light and views—on students' cognitive engagement and emotional well-being remains paramount (Fisk et al., 1997; Wargocki et al., 2002; Kaplan, 1993). Among the IEQ factors, thermal conditions have received considerable research attention. Suboptimal thermal environments, such as uncomfortable temperatures or inadequate humidity levels, are associated with physiological stress, impaired attention, and reduced academic performance (Jiang et al., 2018). Recent research highlights the importance of maintaining optimal indoor thermal ranges to balance subjective comfort and cognitive efficiency (Corgnati et al., 2007; Vilcekova et al., 2017). Notably, psychophysiological mechanisms reveal that thermal discomfort elevates stress responses, increasing cognitive load and reducing learning adaptability (Hancock & Warm, 1989). These findings underscore the need for a more holistic understanding of how thermal environments influence both subjective and objective cognitive measures. In addition to thermal conditions, humidity levels play a critical role in shaping indoor comfort and health. Research has demonstrated that both excessively low and high humidity levels can have a negative impact on respiratory issues, impact vocal performance, and diminish concentration—key factors for educational settings (Wyon, 2004; Sundell et al., 2011). For instance, humidity levels outside the recommended range of [40, 60] % are linked to discomfort and increased susceptibility to airborne infections, which can undermine students' ability to focus and engage (Fisk, 2000). Another essential aspect of IEQ is natural light and views, which are critical for visual comfort and psychological well-being. Research has consistently demonstrated that exposure to natural light improves alertness, reduces fatigue, and enhances attention spans, particularly in learning environments (Figueiro & Rea, 2010). Access to windows with clear outdoor views further contributes to mental restoration and reduced stress, promoting cognitive performance and emotional resilience (Li & Sullivan, 2016; Ulrich et al., 1991). These findings emphasize the importance of optimizing classroom lighting and spatial design to support students' learning experiences. Finally, IAQ significantly affects students' comfort and academic outcomes. Poor ventilation and high levels of carbon dioxide (CO_2) concentration can lead to cognitive fatigue and decreased attention spans (Wargocki et al., 2002; Shield & Dockrell, 2008). In addition to environmental parameters, understanding the psychophysiological effects of IEQ on students requires precise, objective measurements.

In this study, electroencephalogram (EEG) devices were employed to assess students' attention and stress levels in a controlled environment (test room) under four scenarios characterized by different IEQ conditions: (i) closed windows shades, (ii) opened windows shades, (iii) increased air relative humidity level, and (iv) increased air temperature level. Additionally, EEG technology provides real-time monitoring of brain activity, enabling researchers to quantify cognitive engagement and stress under different environmental conditions. EEG studies have shown that specific brain wave patterns, such as alpha and theta activity, correlate strongly with attention and mental workload, while stress levels are reflected in beta wave alterations (Rabbi et al., 2012). This objective approach complements subjective self-reports, offering robust insights into how students respond to varying thermal, humidity, lighting, and visual comfort conditions.

The use of a controlled environment in a test room allowed the precise manipulation of environmental variables, including air temperature, relative humidity, and lighting, ensuring reliable assessment of their effects on cognitive performance. By monitoring students' brain activity, this method provides a deeper understanding of the psychophysiological interplay between environmental stressors and academic performance. Such insights are particularly valuable for designing educational spaces that optimize learning outcomes while minimizing stress.

Methodology

Participants

The study was conducted among individuals from the Department of Architecture, Design, and Urbanism. Data were initially collected from 12 participants. Following a comprehensive data screening and cleaning process to remove any noise or discrepancies, this resulted in a reliable and consistent final dataset. While none of the participants had prior experience using an EEG device, all were familiar with the lecture topics presented during the experiment.

Monitoring Campaign

The environmental conditions of the test room were monitored using 4 data loggers that recorded air temperature, relative humidity, and CO_2 levels at 15-second intervals during the trial sessions. Similarly, 2 outdoor data loggers were used to assess environmental conditions outside the test room at the same logging rate. The sensors were strategically located within the room to ensure a comprehensive evaluation of the environmental conditions, as depicted in Fig. 1. Additionally, they were installed in compliance with ASHRAE Standard 55 guidelines ("ANSI, ASHRAE. Standard 55 - Thermal Environmental Conditions for Human Occupancy." 2017), specifically at 0.6 m above the floor to ensure consistency for seated occupants. Three distinct interventions (scenarios) involving IEQ factors were implemented during the study to examine their effects on participants' cognitive and physiological responses. In the first scenario, the window shades were opened to allow natural light and provide a clear view of the external environment. The second scenario involved the use of a humidifier to regulate indoor humidity levels, while the third scenario employed two heaters to increase the room's air temperature. Prior to the experimental session, participants received a brief orientation from the research team before putting on an EEG device, which they wore continuously throughout the session to record brain activity. Detailed specifications for all equipment and devices utilized in the study are provided in Table 1.

Table 1. Monitoring devices utilized in the study.

Environmental variable and equipment	Brand and model
Temperature	HOBO® MX1101
Relative Humidity	HOBO® MX1101
CO_2	HOBO® MX1102A
Lighting	SEKONIC® C-700
EEG device	Flowtime® FT01-YHG001
Humidifier	Honeywell® HEV620B
Heater	Holmes® HCH4953

Procedure

This study was conducted in two trial sessions, each lasting two hours and fifteen minutes. Each trial session consisted of four experimental scenarios, each lasting 30 minutes, with a five-minute break between scenarios. The breaks served two purposes: to ensure participants were not fatigued or sleepy and to provide the research team with time to adjust the environmental interventions for the subsequent scenario. The study involved students from the Interior Design and Architecture programs, with six participants and two principal investigators present in each trial session. The experiment was conducted in a 16.7 m^2 room with a ceiling height of 4.9 m, shown in Fig. 1.

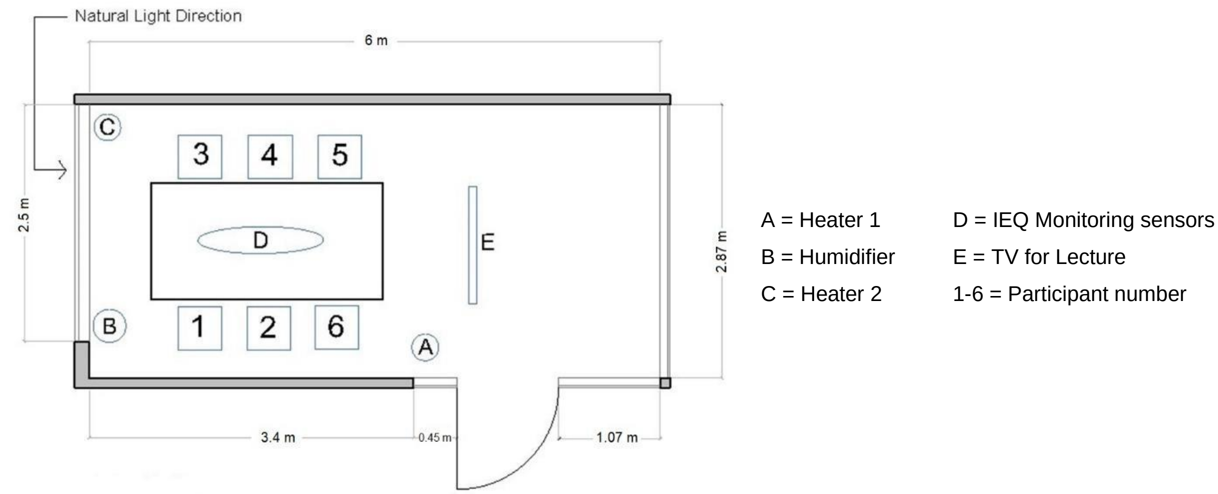

Fig. 1. Configuration of the test room for the trial sessions.

During each experimental session, participants continuously wore an EEG device to monitor their cognitive and physiological responses, such as heart rate, heart rate variability, attention, and relaxation, while engaging in predefined activities. Specifically, the attention and relaxation values recorded by the EEG device were assessed in this investigation. Each experimental scenario was structured into three phases: (1) completing pre-scenario questionnaires assessing indoor environmental factors, (2) attending a 10-minute lecture on a design-related topic, and (3) completing post-scenario questionnaires to evaluate participants' perceptions of the indoor environment. Across the four experimental scenarios, one environmental intervention was modified each time to isolate and analyze its specific effects on participants' attention, stress levels, and engagement. Fig. 2 schematically depicts the methodology of each trial session.

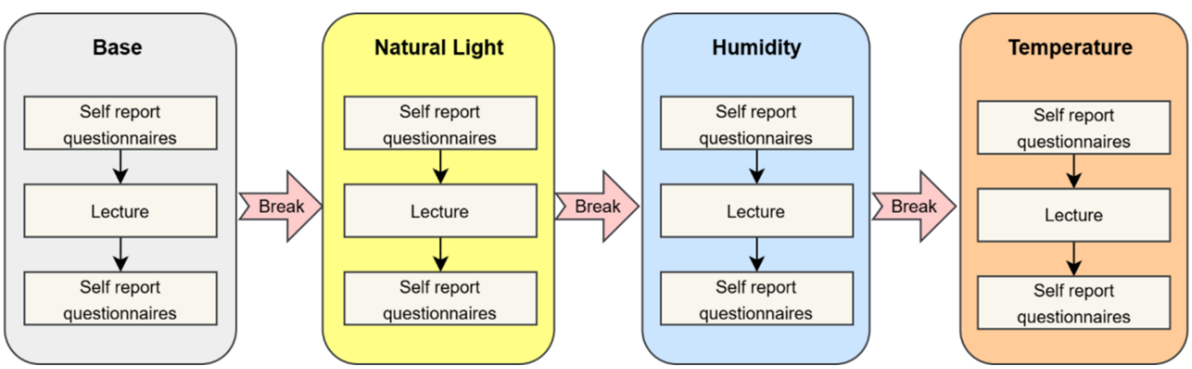

Fig. 2. Schematic description of each trial session.

The first scenario (S1) served as the baseline or benchmark. In this scenario, the window shades remained closed, and the air room's temperature and humidity were left unaltered. Baseline measurements of all indoor environmental factors that would later be manipulated were recorded during this scenario to ensure that subsequent adjustments were both significant and measurable. Additionally, environmental conditions outside the test room were recorded for comparison. The benchmark scenario provided a reference point for assessing the impact of environmental changes introduced in the subsequent scenarios.

The second scenario (S2) introduced the first intervention, natural light: the shades were opened, allowing natural light into the room and providing participants with a direct view of a main street and surrounding trees. This scenario was conducted during daylight hours at two time slots: 1:50–2:20 PM and 3:50–4:20 PM, in winter, on the East Coast of the United States. This intervention aimed to evaluate the effects of natural light and external views on participants' attention, stress, and engagement levels.

The third scenario (S3) examined the influence of relative humidity levels on participants. According to ASHRAE Standard 55, the recommended comfortable humidity and range for occupants is between 40 % and 60 %. During this scenario, a humidifier was used to manually increase the room's relative humidity to assess its impact on participants.

The fourth scenario (S4) explored the effects of temperature variation on participants' cognitive and emotional states. As per ASHRAE Standard 55, the optimal temperature range for occupant thermal comfort is between 21 °C and 25 °C. For this scenario, two heaters were utilized to elevate the room temperature, creating a warmer environment to investigate the relationship between thermal discomfort and participants' attention, stress, and engagement levels.

Results

This section presents the results from the two trial sessions conducted in this study. Specifically, Table 2 summarizes the average values and standard deviations of the IEQ factors, including air temperature, relative humidity, CO_2 levels, and lighting (illuminance and color temperature), as well as the attention and relaxation values recorded by the EEG devices in each scenario. Additionally, the values outside the test room for air temperature, relative humidity, and CO_2 levels remained approximately constant during the trial sessions, at 22.72 ± 0.02 °C, 17.26 ± 0.19 %, and 533 ± 100 ppm, respectively. Finally, it is important to note that the results presented in this table correspond to the duration of the 10-minute lectures given in each scenario.

Table 2. Average and standard deviations of the IEQ factors (air temperature, relative humidity, CO_2 concentration, lighting) and EEG metrics (attention, relaxation) during the given lectures in each scenario and trial session.

		T (°C)	RH (%)	CO_2 (ppm)	Illuminance (lx)	Color temp. (K)	Attention	Relaxation
SESSION 1	S1	22.90 ± 0.05	24.44 ± 0.26	1,205 ± 28	605	3,948	82.25 ± 17.7	31.51 ± 13.04
	S2	23.64 ± 0.06	23.72 ± 0.15	1,308 ± 17	715	4,622	39.72 ± 23.22	62.75 ± 17.51
	S3	23.85 ± 0.04	25.45 ± 0.50	1,279 ± 23	587	3,949	36.34 ± 23.74	61.63 ± 20.06
	S4	25.69 ± 0.24	21.91 ± 0.32	1,232 ± 24	587	3,949	70.86 ± 11.04	40.65 ± 11.52
SESSION 2	S1	25.54 ± 0.02	17.37 ± 0.19	786 ± 20	488	3,884	83.64 ± 8.63	32.25 ± 8.37
	S2	25.70 ± 0.03	18.08 ± 0.12	821 ± 15	534	4,294	86.28 ± 7.28	28.6 ± 6.57
	S3	25.41 ± 0.02	21.93 ± 0.54	1,025 ± 50	456	3,895	86.91 ± 10.51	23.97 ± 12.82
	S4	26.52 ± 0.21	21.64 ± 0.16	1,155 ± 15	456	3,895	76.21 ± 10.41	38.33 ± 9.2

Trial Session 1

S1 recorded the lowest temperature among the different scenarios at 22.90 °C, and a relative humidity value of 24.44 %. Meanwhile, the CO_2 concentration reached 1,205 ppm, surpassing the 1,000-ppm upper limit usually associated with sick building syndrome and a decrease in office work performance ("ASHRAE Position Document on Indoor Carbon Dioxide" 2025). The lighting conditions for this scenario were 605 lx of illuminance and 3,948 K color temperature. Finally, the attention and relaxation recorded in S1 were the highest and lowest values among the different scenarios, at 82.25 and 31.51, respectively. It is important to note that these metrics, provided by the EEG device, range from 0 to 100.

Air temperature values slightly increased in S2 reaching 23.64 °C, mainly due to the presence of the participants and research team members in the test room. Moreover, the recorded relative humidity and the CO_2 levels were 23.72 %, and 1,308 ppm, respectively. The lighting conditions showed higher illuminance, at 715 lx, compared to S1, due to the opening of the windows shades in this scenario. The color temperature was also higher, recording 4,622 K. Notably, attention decreased, and relaxation increased, both by about 50 % compared to S1, reaching 39.72 and 62.75, respectively.

S3 recorded a similar indoor air temperature at 23.85 °C, and the relative humidity reached the highest value among the four scenarios at 25.45 %, associated use of the humidifier in this scenario. The CO_2 concentration followed a similar trend compared to the previous scenarios, averaging 1,279 ppm. Meanwhile, the lighting conditions returned to values similar to those in S1 due to the closing of the windows shades again. Finally, attention and relaxation values were similar to those in S2, at 36.34 and 61.63, respectively.

S4 recorded the highest temperature among the different scenarios at 25.69 °C, associated with the use of the heaters. Conversely, the relative humidity reached its lowest value of 21.91 % due to the inverse relationship between air temperature and the moisture it can retain. The CO_2 concentration was 1,232 ppm, showing similar values to those recorded in the other scenarios. The lighting conditions were identical to those in S3 due to the continued closure of the window shades. Notably, attention increased compared to the previous scenarios, S2 and S3, reaching a value of 70.86, slightly lower than in S1. Lastly, relaxation recorded slightly higher values than in S1, specifically 40.65.

Trial Session 2

This trial session was conducted 30 minutes after Session 1, during which the door of the test room was intentionally left open to primarily decrease the air temperature and restore the initial environmental conditions. Although this period was insufficient to fully replicate the hygrothermal conditions of the first scenario in Session 1, the differing starting conditions in Session 2 compared to Session 1 provided complementary and valuable insights into attention and relaxation values under different environmental conditions.

During S1 and S2, the door was intentionally kept open to restore initial environmental conditions. However, the air temperature remained approximately constant in both scenarios, at 25.62 °C. Meanwhile, keeping the door open impacted both relative humidity and CO_2 levels, decreasing their values compared to the same scenarios in Session 1. Specifically, the relative humidity and CO_2 level in S1 and S2 were very similar, averaging 17.7 % and 804 ppm, respectively. Finally, the lighting conditions for illuminance and color temperature in S1 and S2 were 488 lx and 534 lx, and 3,884 K and 4,294 K. The differences in these values correspond to the closing and opening of window shades in these scenarios. Notably, attention and relaxation levels were also very similar in S1 and S2, at 83.64 and 32.25, and 86.28 and 28.6.

In S3, the door of the test room was closed, and the humidifier was turned on. The air temperature was 25.41 °C while the relative humidity reached its maximum level at 21.93 %. Similarly, the CO_2 concentration increased to 1,025 ppm. Meanwhile, the lighting conditions returned to values similar to those in S1 due to the closing of the windows shades. Finally, attention and relaxation values were slightly higher than those in S1 and S2, at 86.91 and 23.97, respectively.

In S4, the door of the room was closed, and the temperature recorded its highest temperature among the different scenarios, at 26.52 °C, due to the use of heaters. In this case, the relative humidity was 21.64 %, and the CO_2 concentration reached its maximum value at 1,155 ppm. The lighting conditions were identical to those in S3 due to the continued closure of the window shades. Finally, attention and relaxation recorded their highest and lowest values, respectively, among the scenarios in Session 2, at 76.21 and 38.33.

The results summarized in Table 2 from Session 1 indicate that the absence of exterior views and an increase in air temperature (in that order) positively influence attention levels, as evidenced by the highest attention level recorded in S1, followed by S4. However, the findings from Session 2 reveal comparable attention levels across all scenarios. A key difference between the two sessions is that the scenarios in Session 2 consistently featured higher overall temperatures. Consequently, these findings suggest that increased air temperature has a more significant positive effect on attention than the absence of exterior views.

Impact of the different scenarios on an individual: a representative example

To gain a deeper understanding of the impact of the IEQ factors analyzed in this study on individual cognitive performance, Fig. 3 illustrates the results for attention (blue line) and relaxation (orange line) metrics provided by the EEG device for the same participant during the four scenarios in Session 1, as a representative example. Monitored values of indoor air temperature (red dashed line) and relative humidity (green dashed line) are also depicted to observed correlations with the EEG metrics. Finally, the grey-shaded regions in each graph correspond to the time of the lecture given in each scenario. It is important to note that the same analysis was performed for a selected participant in Session 2; however, it was not included in the text due to space limitations.

The attention in S1 showed a clear pattern, increasing a few minutes before the start of the lecture and then sharply decreasing when the lecture ended. As complementary quantities, the relaxation followed the opposite pattern. On the other hand, the temperature remained approximately constant at 22.8 °C, while the relative humidity continuously increased, reaching above 24 %.

In S2, the attention and relaxation patterns were completely different compared to the previous scenario, with lower attention level and higher relaxation level. As the air temperature and relative humidity levels remained approximately constant during this scenario, the observed decrease in attention can be attributed to the opening of the window shades and the possibility of having exterior views.

The main feature of S3 was the use of a humidifier to intentionally increase the relative humidity. Additionally, the window shades were closed. The relative humidity showed higher variability and reached its maximum value of around 26 % due to the humidifier. Meanwhile, the air temperature remained approximately constant at 23.8 °C. Therefore, the decrease in attention can be associated with the higher variability and increasing relative humidity levels.

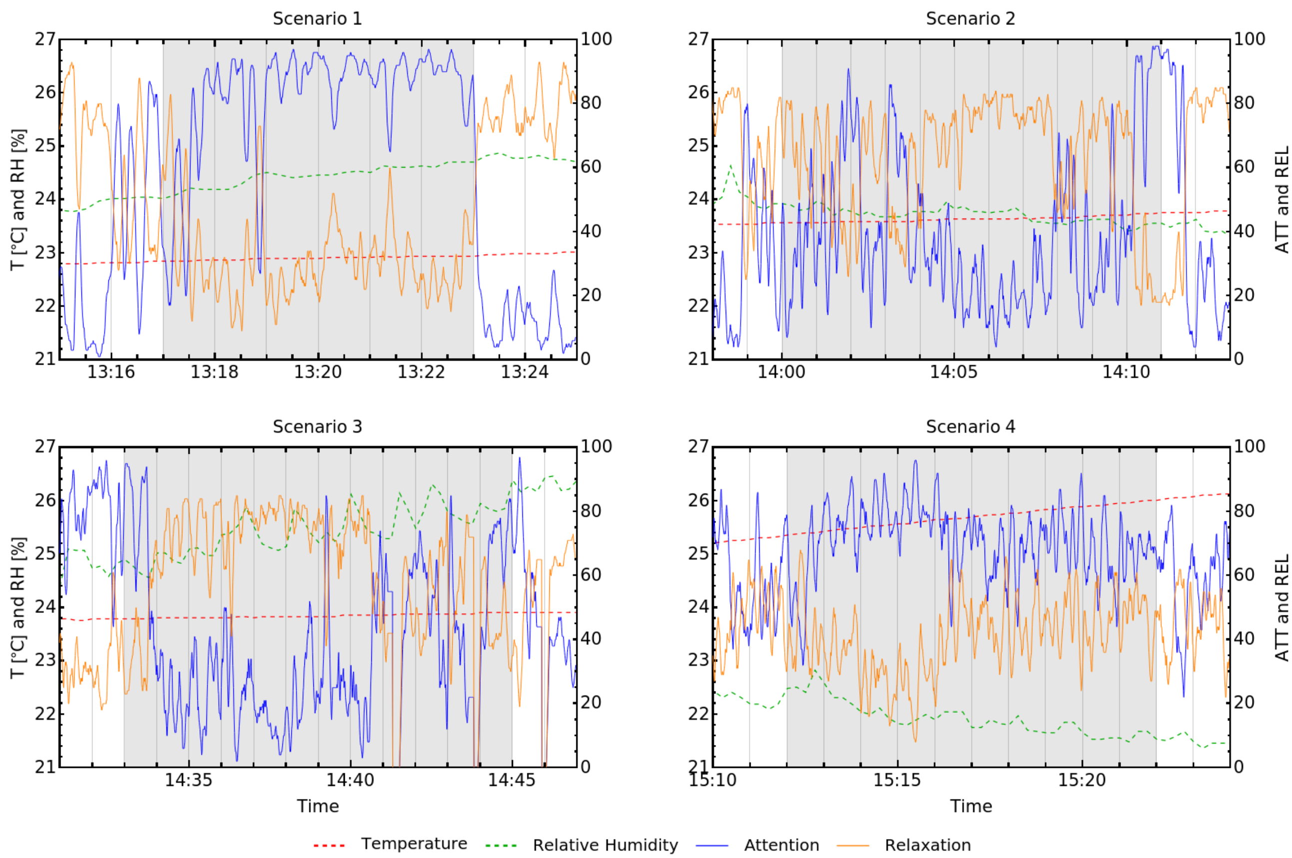

Fig. 3. IEQ factors (temperature, relative humidity) and EEG metrics (attention, relaxation) for the same participant during the four scenarios in Session 1. The grey-shaded region corresponds to the time of the lecture given in each scenario.

In S4, the air temperature continuously increased to its maximum value of around 26 °C due to the use of heaters. Conversely, the relative humidity level continuously decreased because of the inverse relationship between air temperature and the amount of moisture the air can hold. Finally, the attention level increased compared to S2 and S3, although it reached slightly lower values than in S1. This result suggests that an increase in air temperature may have a positive impact on attention.

Conclusions

The findings of this study emphasize the critical role of IEQ in influencing cognitive engagement and relaxation in educational settings. Exposure to natural light (S2) improved relaxation but reduced attention levels, suggesting that while natural light promotes stress recovery, it may also introduce distractions. Elevated humidity levels (S3) negatively impacted both attention and comfort, supporting previous research linking excessive humidity to cognitive fatigue. In contrast, increased temperature (S4) had mixed effects, enhancing attention while moderately impairing relaxation. Baseline conditions (S1) resulted in the highest attention levels, underscoring the importance of stable, controlled environments for focus.

These results reveal the delicate balance required in optimizing environmental conditions for learning spaces. While natural light, moderate temperatures, and controlled relative humidity enhance comfort and performance, deviations outside recommended ranges may undermine cognitive outcomes. This study also highlights the importance of leveraging objective psychophysiological measures, such as EEG, to assess the nuanced effects of IEQ on students. Future research should expand on these findings by including larger sample sizes, varied educational contexts, and additional environmental factors to design holistic, adaptive learning environments.

Limitations and Implications for Future Research

While this study offers valuable insights, its limitations must be acknowledged. The small sample size and controlled environment may limit generalizability to real-world settings. Furthermore, external environmental factors, including seasonal and diurnal variations, could influence the observed outcomes. Future research should expand the sample size, incorporate diverse educational contexts, and examine additional factors such as noise and IAQ to provide a holistic understanding of IEQ's impact on learning.

These findings have direct implications for educational facility design. Incorporating adjustable lighting, maintaining humidity within recommended ranges, and moderating temperature variations can significantly enhance student well-being and performance.

Overall, these results highlight the need for a balanced approach to classroom design, prioritizing thermal comfort, appropriate lighting, and controlled humidity levels to enhance cognitive engagement and minimize stress. Ultimately, this study underscores the critical role of environmental optimization in fostering effective and healthy learning spaces, paving the way for future advancements in educational design standards.

Notes:

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