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Differences between Daylighting and Electric Lighting in Affective Response

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Abstract: Humans are spending more time indoors than ever due to urbanisation and industrialisation, leading to higher electricity consumption in lighting systems. Recent research has demonstrated the significance of maintaining a balance between daylight and electric light to create an ideal learning environment that can significantly impact students' academic performance. The objective of this study is to analyse the changes in students' emotional response depending on the type of lighting in the classroom—whether it is daylight, electric light, or a combination of both. A field study was conducted with 521 university students to assess their affective response to the lighting environment inside their classroom. The results show that students prefer a Clear-efficient lighting environment for writing–reading tasks and a Soft-calm atmosphere for using electronic devices. For the paying attention tasks, a combination of daylighting and electric lighting is determined to be the best solution, while for the tasks of discussing–teamwork, students prefer daylighting. Daylighting is found to be the only lighting option that students like. Despite this, students still consider electric lighting and the combination of daylight and electric light adequate for a classroom. The findings of this study may help educators and designers create learning spaces that promote a positive and stimulating student environment by understanding the relationship between the lighting environment and students' affective responses.

Keywords: daylighting; electric lighting; lighting; affective response; classroom design; subjective assessment

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1. Introduction

Due to urbanisation and industrialisation, humans are increasingly spending a more significant proportion of their time inside buildings than ever before [1]. This trend has been attributed to the proliferation of urban settlements and the emergence of industries, which have considerably altered modern societies' physical and social landscape. Although daylight exposure is still present in humans' daily lives, many people have decreased their time under its influence [2]. Research indicates that up to 90% of people's time is spent inside buildings [3,4]. As a result, even in areas with ample daylight, people are exposed to electric light for extended periods and this source of light has become a crucial component of their daily routines [1]. The student population is no exception to this rule. Students are often referred to as "indoor species" due to the significant amount of time they spend within educational institutions, which accounts for approximately one-third of their time [5].

The adoption of these indoor habits is causing a notable surge in electricity usage, particularly in lighting systems, which consume around 19% of the total energy consumed in buildings [6]. Nevertheless, reducing the energy demand in buildings is crucial due to the existing worldwide energy crisis. Regarding energy consumption, university campuses present an even more complex situation. Universities require a substantial amount of energy to maintain a comfortable environment for their students, faculty, and staff [7]. Consequently, research has revealed that campuses consume significantly more energy per unit area than residential buildings, ranging from 5 to 10 times higher [8–11]. This critical waste of energy highlights the need for educational facilities to adopt energy-efficient strategies to reduce emissions [12]. Moreover, higher education institutions are essential in creating a sustainable future [13]. Incorporating sustainably designed or green buildings can promote awareness and serve as a model for communities [14]. Additionally, universities can aid governments in reaching emission reduction goals by researching sustainable practices [15]. Consequently, to successfully implement sustainable practices on campus, universities must prioritise reducing resource and energy consumption [16,17].

At university campuses, lighting accounts for almost one-fifth of the energy consumed [18]. This waste of energy presents a significant challenge in designing classroom lighting systems that balance energy efficiency and optimal learning conditions [19]. Given its crucial role in human live, indoor lighting design has become essential to educational building design [20]. In fact, light has long been recognised as fundamental in creating a conducive learning environment [21] and is known to play a critical role in educational centres [22]. It is well known that the aesthetics and psychological aspects of learning environments are heavily influenced by lighting, but its significance extends beyond basic visibility [23]. Of course, adequate lighting facilitates optimal visual comfort [24], but improved indoor lighting quality has also been linked to increased well-being [25,26], health [27–29], alertness [30,31], productivity [32,33], and cognitive performance [33–35] among students. Therefore, designing good classroom lighting is a crucial and complex challenge for designers. Moreover, incorporating daylight illumination into classrooms increases student satisfaction [36] and helps to conserve energy [37–39]. Nevertheless, daylight cannot be present throughout the entire teaching day due to several factors, such as weather conditions, time of day, and building design. Therefore, electric light must supplement daylight to ensure that adequate illumination is provided in classrooms. In this sense, whether through daylight or electric light, both must be thoughtfully considered and optimised to establish an environment that facilitates successful learning and education. Proper consideration and optimisation of daylight and electric lighting are essential in creating an environment that fosters effective teaching.

Regarding daylighting, numerous studies have consistently shown the importance of natural light in classrooms [40–50]. Daylight positively impacts students' cognitive performance [51,52], and enhances their connection to the outdoors [53]. Plympton [54] even found that students in university classrooms with greater exposure to daylight made more progress than those with less natural light. Daylight also provides various health benefits, such as regulating the body's circadian rhythm [55] and improving health [56], mood [57], and well-being [58]. Conversely, inadequate provision of daylight can lead to adverse effects such as fatigue [39], stress [56], eye strain [59], circadian phase shifting [60], and the advance of Seasonal Affective Disorder (SAD) [61]. Daylighting is essential to creating optimal learning environments that enhance sustainability, while minimising the potential harmful effects of electric lighting [59,62,63]. Nowadays, it is widely acknowledged that daylighting is the most optimal lighting solution, and when utilised correctly, it can significantly decrease energy consumption and maintenance expenses [64].

Electric lighting is also crucial in learning environments for several reasons. Electric lighting enables extended hours of learning, but it also can adapt to varying weather conditions and enhance the accessibility of visual aids. Moreover, it facilitates diverse learning activities and integrates the lighting environment with the use of technology. As a result, electric lighting ensures the safety and security of the learning environment, affords architectural flexibility, and provides consistent and reliable illumination. Apart from complying with regulations and normative standards [65], electric lighting in educational environments has also been the subject of numerous studies [66–68]. Re-search has analysed the impact of different variables of artificial lighting, such as illuminance [66] and colour temperature [23] and colour rendering [67].

The combination of natural and electric lighting is critical for creating versatile and comprehensive learning spaces, particularly in educational buildings, which can significantly impact students' learning processes and physiological states. With advancements in LED (Light Emitting Diode) technology, integrative lighting is now possible, enabling daylight and electric light combined throughout the day. LED systems offer high energy efficiency [68] because they permit more significant control potential and more precise brightness and spectral composition management [69]. These characteristics make LED technology ideal for optimizing light exposure to positively impact human functions that are affected by light [70]. Recent studies have demonstrated the significant impact of both daylight and electric lighting on students' visual comfort, positive predisposition to learn, and circadian rhythm [71]. With these considerations in mind, further research may be needed to find the right combination of daylight and electric lighting to create integrated lighting solutions to support students' health and learning.

New technologies such as the integration of Information and Communication Technologies (ICTs) [72], augmented and virtual reality (VR) [73], and artificial intelligence (AI) [74] are redefining the way students learn [75]. Higher education institutions are adapting to changes caused by external and internal factors [76]. The external factors include changes in the job market [77,78], the consequences of the COVID-19 pandemic [79], and economic and social development [80,81]. Internally, universities are engaging in fierce competition to improve their rankings [82], reduce drop-out rates [83], and promote multicultural integration [84]. These shifts are having a profound impact on how higher education is managed and carried out. New teaching methods need to be implemented to adapt to these changes, requiring new teaching practices in the classroom [85]. With these new learning practices comes a greater level of interactivity and a focus on different tasks [86]. The combination of multimedia elements in today's classroom setting is unmatched. Multimedia learning entails obtaining or creating knowledge by handling a variety of representations, such as visual (static or dynamic illustrations) and auditory (spoken or written), at different levels of difficulty [87]. Therefore, it is critical to explore which lighting environment can best support all these new tasks [88]. Achieving this objective requires understanding how students evaluate their indoor lighting environment (ILE) and how it should be adapted for the tasks they actually perform in the classroom.

Taking all these considerations into account, the main objective of this study is to assess the differences between daylighting and electric lighting on students' affective responses. For this purpose, the set of subjective evaluation scales that students employ to evaluate the ILE of their classroom is evaluated.

Furthermore, this study evaluates the correlation between the tasks conducted by students in their classroom and their affective impressions of the ILE. Additionally, it compares the varying affective responses of students under different lighting conditions such as daylighting, electrical lighting, or a combination of both. The findings of this analysis contribute to a better understanding of how students' perceptions are influenced by the lighting conditions in their classroom, taking into account affective impressions, task factors, and the overall evaluation of the ILE.

2. Materials and Methods

Based on a field study, the methodology was developed to gather subjective evaluations from students about the lighting conditions in their classroom.

2.1. Field Study Settings

To ensure that the questionnaires were distributed in the most appropriate classrooms, a comprehensive list of Universitat Politècnica de València (39°28′50.3″ N 0°20′39.6″ W) classrooms was compiled. The classrooms were organised with great care and attention to detail, considering various factors such as classroom type and lighting. This categorisation process included all types of classrooms, dividing them by ceiling height, surface area, and type of teaching (including theory, practical, laboratory, and project work). The ILE was evaluated based on both daylighting and electric lighting. Regarding daylighting, window size, type of openings, and protection from direct sunlight were considered. Electric lighting was distinguished by several variables, including types of lamps, luminaires, average luminance, colour temperature, chromatic reproduction index, and other light characteristics. A comprehensive investigation of the university was performed following the production of the list, and on-site visits were conducted to confirm the appropriateness of the questionnaire test locations.

After an exhaustive evaluation process, 17 classrooms (Figure 1) were selected based on predetermined criteria, considering variability conditions and distinct lighting types (Table 1). These classrooms were representative and sufficiently differentiated to form part of the sample for the study. In order to extract affective impressions or semantic axes, it was necessary to establish relationships between multiple variables, which required a wide range of judgments. For this reason, students were asked to express their opinions on an extensive and diverse sample of classrooms. Although this set of design attributes may seem like confounding factors that need to be fully controlled and can introduce bias into the results, the solution randomly introduced the set of characteristics or attributes to reduce bias [89]. The reason for choosing each ILE and the classroom was that their characteristics were distinct and representative enough to be included in the sample.

Between April and May, the study was conducted in these 17 classrooms. These months were chosen to maintain a consistent and controlled climate to minimise any significant impact on the students' responses. This approach was also intended to mitigate the effects of variable weather conditions on the feedback received during the study. Measurements were only taken on clear and pollution-free days to avoid interference from external factors such as smog, precipitation, or clouds. If rainfall occurred or the temperature exceeded a narrow range of 22.5 ± 2.0 °C, the study was halted to prevent any potential interference with the participants' perception caused by ambient temperature [90].

2.2. Lighting Measurements Methodology

Lighting measurements were conducted on-site in real classrooms using a portable Asensetek Pro Standard ALP-01 spectrometer (NGL, New Taipei City, Taiwan), covering a measurement wavelength range of 380–780 nm. The range of illuminance was from 5 to 50,000 lux, reliable chromaticity was from 50 to 50,000 lux, optical resolution was 8 nm, with a repeatability (2σ) for x, and <0.0005, integration time from 6 ms to 16 s, and the storage range temperature was from −10 to 45 °C. The spectrometer was calibrated at Asesentek Laboratories (New Taipei City, Taiwan) providing a ±3% of uncertainty for measurements.

To obtain the measurements, the spectrometer was mounted on a tripod at a height of 0.85 m above floor level. Illuminance was measured using a grid of 1 m × 1 m. This measure was established taking into account that the maximum grid size (p) for classrooms with artificial lighting complied with the European Standard EN12464-1 [65], and the European Standard EN 17037 [91] for classrooms with daylighting.

The lighting design criteria that are specified in the European standard [65] include the following: average maintained illuminance, illuminance uniformity, and colour rendering index (CRI), which are shown in Table 1.

Table 1. Indoor lighting environments' characteristics of the classrooms.

	Dimensions (W × L × H) [m]	N. of Seats	Floor Level	Type of Light	N. of Windows	N. of Roof-lights	Total Window Area [m^2]	Orientation	Sun Shading System	Type of Lamp	N. of Luminaires	N. of Lamps	Lamps Power [W]	Em [lx]	$\bar{E}m._{wall}$ [lx]	U_0	CRI/Ra	Colour Temperature [K]
1	8.79 × 11.52 × 2.95	33	1st	Electric	2	0	-	-	-	Fluorescent	27	27	36	415	460	0.49	80	3210
2	11.71 × 12.46 × 2.93	20	1st	Electric	2	0	-	-	-	Fluorescent	31	34	36	480	495	0.46	80	3160
3	8.70 × 17.88 × 2.93	39	1st	Electric	0	0	-	-	-	Fluorescent	33	34	36	470	540	0.54	80	3050
4	8.74 × 17.67 × 2.9	34	0	Electric	0	0	-	-	-	Fluorescent	28	32	36	600	470	0.59	80	3110
5	8.72 × 17.56 × 2.90	27	0	Electric	0	0	-	-	-	Fluorescent	33	34	36	610	550	0.52	80	3180
6	8.70 × 7.82 × 2.82	25	1st	Electric	0	0	-	-	-	Fluorescent	29	35	36	420	415	0.60	80	3090
7	8.73 × 17.59 × 2.92	40	0	Daylight + Electric	10	0	18.26	Northeast	Aluminium blinds	Fluorescent	30	34	36	540	445	0.65	80	3150
8	8.70 × 17.74 × 2.94	11	1st	Daylight + Electric	5	0	5.79	South	Opaque roller shutter	Fluorescent	35	35	36	435	520	0.75	80	3220
9	8.66 × 17.78 × 2.91	13	1st	Daylight + Electric	3	0	3.93	Southwest	Aluminium blinds	Fluorescent	32	34	36	470	540	0.90	80	3050
10	5.81 × 11.88 × 2.96	7	2nd	Daylight + Electric	8	0	19.18	South	Aluminium blinds	Fluorescent	20	20	36	460	465	0.80	80	3340
11	5.89 × 8.92 × 3.00	20	1st	Daylight + Electric	3	0	9.38	South	Opaque roller shutter	Fluorescent	14	14	36	340	115	0.83	80	3340
12	8.80 × 10.20 × 3.25	63	0	Daylight + Electric	4	0	22.95	East	Opaque roller shutter	Fluorescent	36	36	36	750	340	0.66	80	3410
13	5.84 × 7.42 × 4.75	7	2nd	Daylight	1	1	12.68	West	Translucent glass	-	-	-	-	395	470	0.75	-	3940
14	7.85 × 35.93 × 4.73	37	2nd	Daylight	8	6	87.72	North	-	-	-	-	-	305	365	0.80	-	4000
15	4.86 × 8.89 × 3.74	48	2nd	Daylight	8	6	57.42	Southwest	Opaque roller shutter	-	-	-	-	980	890	0.86	-	3420
16	8.83 × 35.96 × 4.74	50	2nd	Daylight	3 + 6	6	16.32 + 64.47	Northeast	-/Translucent glass	-	-	-	-	385	420	0.78	-	3945
17	7.75 × 12.70 × 2.82	41	2nd	Daylight	9	0	35.88	Southeast	Opaque roller shutter	-	-	-	-	520	420	0.95	-	3940

Figure 1. Research classrooms.

2.3. Participants in the Study

According to Comrey and Lee [92], the sample size was established based on the requirement that participants must be regular users of the classrooms selected for the field study. Eventually, 521 students (Table 2) participated with a mean age of 20.75 years and a standard deviation of 14.57. All the individuals who participated in the study were in good health and did not have any significant visual impairment, except for myopia or astigmatism, which were treated with corrective lenses. The students participated in the study voluntarily and were not remunerated for their involvement.

Table 2. Participants.

	Age			Gender	
	Frequency	**Percentage**		**Frequency**	**Percentage**
<20	183	35.12%	Male	232	44.50%
20–24	304	58.35%	Female	289	55.50%
25–29	29	5.57%			
>30	5	0.96%			
Total	521	100%	Total	521	

2.4. Research Process

Participants in the study were fully "immersed" in their classroom's ILE while completing the questionnaire. Prior to beginning, each individual was informed of the purpose of the research and provided with clear instructions for proper completion of the questionnaire. The questions were randomised to prevent any potential bias in responses, and four different versions of the questionnaire were created. The completion time for each questionnaire ranged from 5 to 15 min. In the present study, a validated questionnaire developed in a previous study by the authors [88] using Differential Semantics (in the framework of Kansei Engineering) was used to analyse the affective impressions of university students. Following that questionnaire, the adjectives were evaluated using a 5-point-Likert scale, extending through totally agree, agree, neutral, disagree, and totally disagree.

2.5. Statistical Process

The data underwent statistical processing using the SPSS software package (https://www.ibm.com/products/spss-statistics, accessed on 10 April 2023). The analysis was segmented into three distinct phases (Figure 2) for a more comprehensive understanding of the results as follows:

Phase I: This phase aimed to determine the group of emotional impressions of the global assessment of the ILE. In the first place, the group of emotional impressions or semantic axes was identified using factor analysis [93]. This method can locate unrelated variables that describe the perception of a specific product, in this case, the ILE of a classroom. Each axis or factor combines concepts from the original set, indicating significant correlations in students' responses. Therefore, ideas with similar evaluations are grouped, representing common concepts that students use implicitly to assess their classroom. Finally, linear regression analysis was utilised to determine the effect of each axis on the overall assessment.

Phase II: The objective of this phase was to establish a correlation between the set of emotional responses, collected in Phase I, and the academic tasks carried out in the classroom. Factor analysis was used to categorise classroom tasks by assessing ILEs. After this, Spearman's correlation coefficient was employed to find the relationship between these tasks' factors and emotional responses.

Phase III: This phase aimed to investigate the impact of various lighting types on affective response, such as daylighting, electric lighting, and a combination of both. An ANOVA analysis was utilised to examine any significant differences between the different lighting types and the emotional impressions, the groups of tasks, and the global evaluation of the ILE.

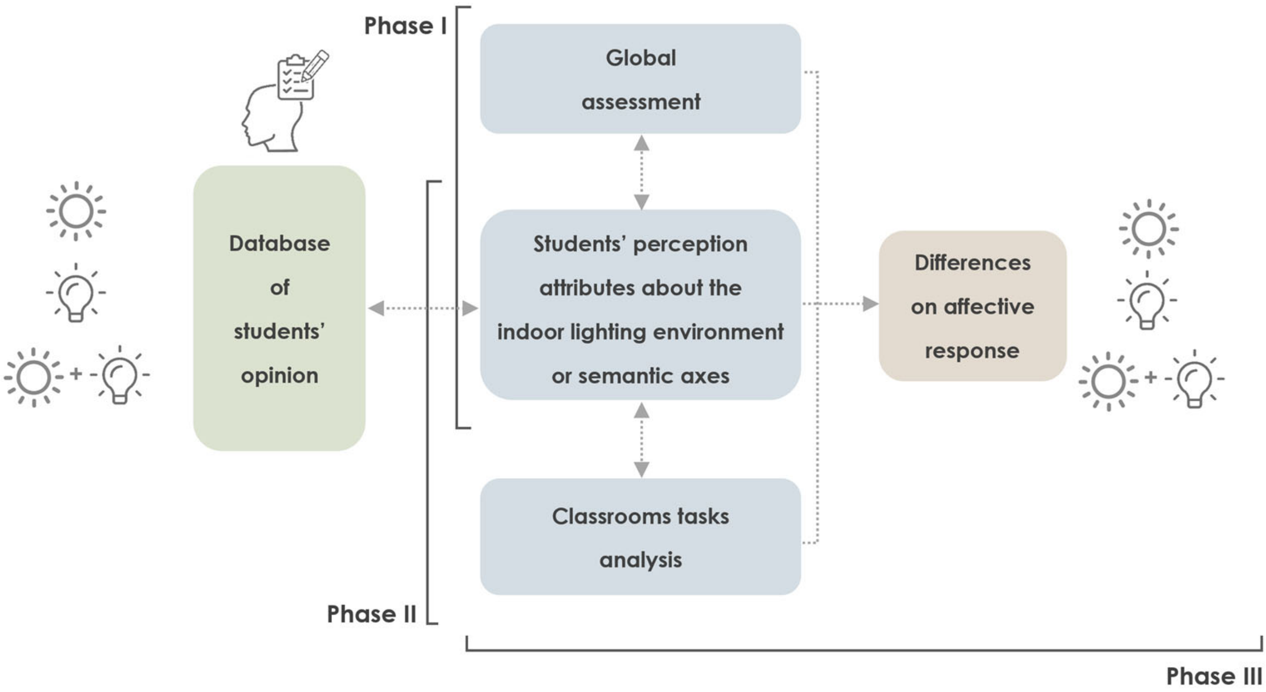

Figure 2. Study development.

3. Results

3.1. Part I: Detection of Significant Affective Responses in the Overall Evaluation of the Indoor Lighting Environments of the Classroom

3.1.1. Reduction of the Number of Perception Variables

Factor analysis [93] was used to identify the uncorrelated variables that characterise the perception of the classroom's ILE. The group set of affective responses or semantic axes represents the set of subjective evaluation scales that students employ to evaluate the lighting environment of their classroom, adapted to the same language they use. Table 3 shows the variance of the semantic axes. These axes describe 59.73% of the variance in the original adjectives.

Table 3. Variance.

Component	Initial Eigenvalues		Rotation Sums of Squared Loadings		
	Total	% of Variance	Total	% of Variance	Cumulative %
1	11.24	29.57	6.07	15.97	15.97
2	4.56	12.00	3.86	10.15	26.12
3	3.10	8.16	3.67	9.66	35.78
4	1.58	4.16	3.39	8.91	44.69
5	1.13	2.97	3.37	8.88	53.57
6	1.09	2.88	2.34	6.16	59.73

Applying factor analysis [93] to the students' responses in the questionnaire, the original 37 adjectives were grouped into six uncorrelated factors (Table 4). These six axes symbolise the semantic space for students to their classroom's ILEs as follows:

- First axis: This axis has been interpreted as the perception of the ILEs as *Surprising–amazing*. It includes the adjectives "surprising", "amazing", "awesome", "stimulating", "interesting", "original", and "suggestive". This axe describes 15.97% of the variance.
- Second axis: This axis groups the adjectives "clear", "sharp", "efficient", "with quality", "bright", "pleasant", "satisfactory", and "convenient". This factor represents the dimension *Clear–efficient* and explains 10.15% of the variance.

- Third axis: This axis represents the dimension of *Soft–calm* and groups the adjectives "soft", "calm", "dim", "warm", "natural", "protector", and "cosy". It represents the 9.66% of the variance.
- Fourth axis: It characterises the perception of the ILEs as *Uniform*. The Kasei words that form this factor are "uniform", "homogeneous", "orderly", "balanced", and "functional". The variance explained by this factor is 8.91%.
- Fifth axis: The terms that contain this axis are "lively", "cheerful", "dynamic", "friendly", "colourful", and "beautiful". It shows the sensation of the ILE as being *Lively–cheerful*. This factor explains 8.87% of the total variance.
- Sixth axis: This axis congregates the concepts "brilliant", "glaring–dazzling", and "intense" and represents the impression of *Brilliant–glaring*. Variance explained by this factor ascend to 6.16%.

Table 4. Meaning of affective responses or Kasei semantic axes.

Axes	Meaning of the Axes	Concepts Included	Variance Explained	Cronbach's Alpha
1	Surprising–amazing	Surprising (0.851); amazing (0.820); awesome (0.801); stimulating (0.749); interesting (0.701); original (0.676); suggestive (0.563); enabling (0.462)	15.97%	0.91
2	Clear–efficient	Clear (0.705); sharp, defined (0.679); efficient (0.652); with quality, rich (0.650); bright (0.640); pleasant (0.498); satisfactory (0.460); convenient (0.415)	10.15%	0.85
3	Soft–calm	Soft (0.648); quiet (0.647); calm (0.646); dim, subtle (0.622); warm (0.526); natural (0.455); protector (0.453); cosy (0.430)	9.66%	0.80
4	Uniform	Uniform (0.772); homogeneous (0.729); orderly (0.720); balanced (0.683); functional (0.619)	8.91%	0.82
5	Lively–cheerful	Lively (0.711); dynamic (0.667); cheerful (0.582); friendly (0.525); colourful (0.518); beautiful (0.496)	8.87%	0.86
6	Brilliant–glaring	Brilliant (0.740); glaring (0.702); intense (0.692)	6.16%	0.70

In order to establish the reliability of these axes, Cronbach's alpha values were utilised (Table 4). These values, ranging from 0.70 to 0.91 for the first six dimensions, were found to be significant [94].

3.1.2. Ranking Affective Impressions According to Importance in the Global Assessment of the Indoor Lighting Environment

Linear regression analysis was utilised to rank the semantic axes or affective impressions based on their relationship with the variable "global assessment of the ILE of the classroom". The model contains five significant axes (Equation (1)), with an R coefficient of 0.720. Figure 3 shows the ranking of affective impressions, accordingly to the global assessment variable. In the first place, the perception of the classroom's ILE as being first *Clear–efficient*, with a coefficient of β = 0.474, has the greatest influence on the lighting global evaluation. Secondly, the perceptions of the light environment are *Uniform*, with a coefficient of β = 0.339. Thirdly, the axis is *Lively–cheerful*, with a coefficient of β = 0.241. Then, the axis is *Soft–calm* with a coefficient of β = 0.241. Finally, the axis is *Surprising–amazing* (s.l. = 0.175). In the model, the factor *Brilliant–glaring* is not significant (s.l. = 0.020) so it was excluded from the model.

$$\text{ILE global assessment} = 0.431 + 0.520\ (\text{Clear-efficient}) + 0.372\ (\text{Uniform}) + 0.264\ (\text{Lively-cheerful}) + 0.192\ (\text{Surprising-amazing}) \quad (1)$$

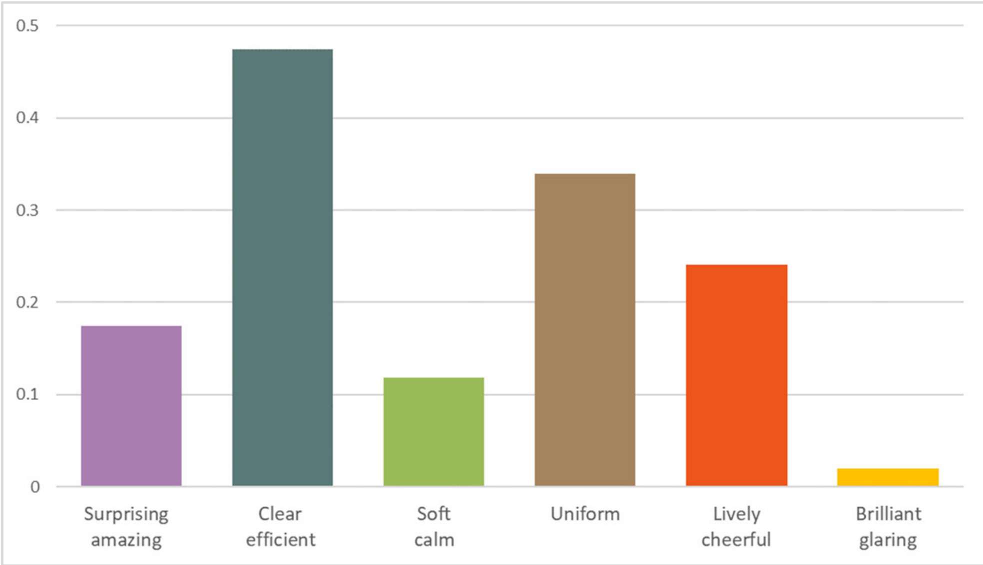

Figure 3. Ranking of affective impressions, accordingly to the global assessment variable.

3.2. Part II: Correlation Analysis between Affective Impressions and Classroom Tasks

3.2.1. Identifying Task Factors

The factor analysis grouped the 14 main tasks that students perform in the classroom into four factors or axes based on the assessment of their lighting conditions. These factors explain 70.39% of the variance (Table 5).

Table 5. Task factor analysis.

Factor	Meaning of the Factors	Concepts Included	Variance Explained	Cronbach's Alpha
1	Writing–reading	Writing (0.867); reading (0.825) drawing (0.822); reviewing notes (0.658)	21.91%	0.91
2	Discussing–teamwork	Discussing (0.816); teamwork (0.716); correcting (0.630); asking the teacher (0.602); reflecting (0.554)	20.22%	0.85
3	Paying attention	Paying attention to the board (0.838); paying attention (0.745); looking at the projector (0.606)	15.04%	0.80
4	Using devices	Working on the computer (0.768); using the telephone, tablet (0.770)	13.22%	0.82

The analysis aimed to identify the concept associated with each variable's contribution to the factors. The following four factors were identified:

- First factor: This factor represents the *Writing–reading* tasks performed by students in the classroom. It is positively correlated with the tasks of "writing", "reading", "drawing", and "reviewing notes". This factor accounts for 21.91% of the initial variance.
- Second factor: This factor groups the tasks related to *Discussing–teamwork*. This factor is formed, with positive correlation, by the tasks of "discussing", "teamwork", "correcting", "asking the teacher", and "reflecting". It explains 20.22% of the variance.
- Third factor: The third factor represents the tasks of *Paying attention*. It is positively correlated with tasks such as "paying attention to the board", "paying attention", and "looking at the projector". Of the sample variance it explains 15.04%.
- Fourth factor: This factor represents the tasks *Using devices* performed by the students in the classroom. It is positively correlated with the tasks of "working on the com-

puter "and "using the telephone, tablet, . . .". This factor accounted for 21.91% of the initial variance.

The consistency of the perceptual space was confirmed using Cronbach's Alpha. The reliability coefficient values for the first four factors were between 0.91 and 0.82, an indication of the high reliability of these scales [94].

3.2.2. Relationship between Affective Impressions and Factors of Tasks

The relationship between the groups of tasks perform currently in the classroom and affective impressions was established with a Pearson correlation coefficient (Figure 4).

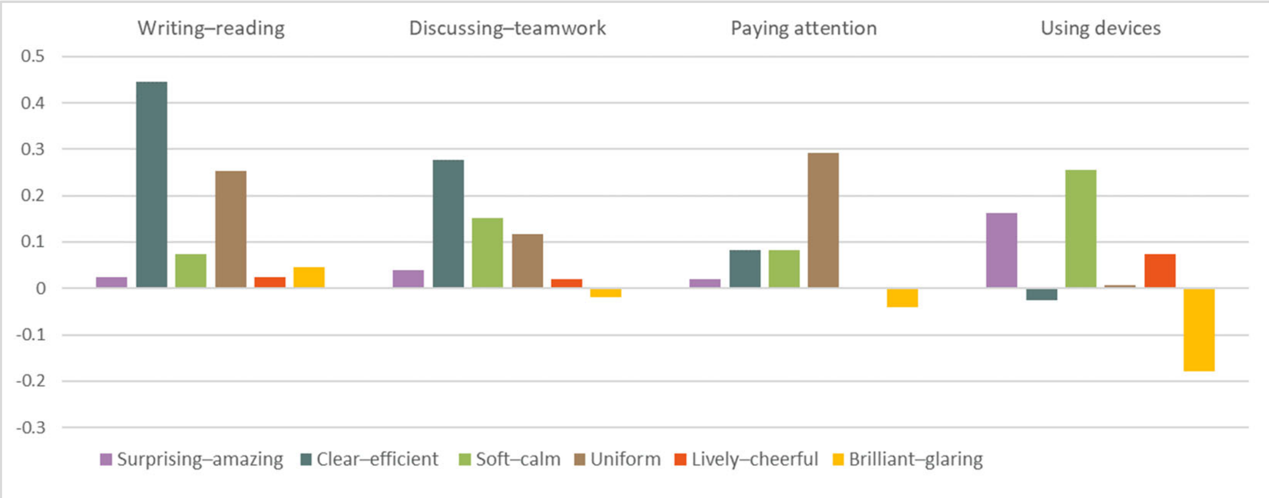

Figure 4. Relationship between emotional responses and task factors.

The results show that different tasks in the classroom require different lighting conditions.

In the first place, generating the sensation of the ILE being *Clear–efficient* is mainly required for the *Writing–reading* tasks. The ILE should also generate the sensation of being Uniform, although to a lesser extent. There is no significant correlation between the factor of *Writing–reading* and the sensations of *Surprising–amazing*, *Soft–calm*, *Lively–cheerful*, and *Brilliant–glaring*.

In the second place, the task factor *Discussing–teamwork* shows significant correlations with the set of affective impressions *Clear–efficient*. This factor is linked to the sensations of the lighting conditions of being *Soft–calm* and *Uniform* to a lesser degree. The other impressions, *Surprising–amazing*, *Lively–Cheerful*, and *Brilliant–glaring*, show no significant correlation with this factor.

In the third place, the task factor of *Paying attention* is mainly related to the ILE generating the sensation of *Uniform*. The rest of the set of impressions show no significant correlation with this factor.

Finally, the task factor of *Using devices* shows significant correlations with the impressions of the lighting conditions as being *Soft–calm*. With lower correlations, *Surprising–amazing*. At the same time, it has a negative correlation with the axis *Brilliant–glaring*.

3.3. Phase III: Differences on Affective Response between Types of Lighting Conditions

3.3.1. Relationship between Affective Impressions and Type of Lighting Conditions

To explore the differences in perception, a discriminant analysis was conducted using "daylighting—electric lighting—daylighting + electric lighting" as the grouping variable and the affective impression scores as independent variables. Thus, it was possible to confirm the hypothesis that students possess distinct perceptual structures, enabling them to categorise different types of ILE based on their responses. The mean scores for each axis were then determined for various ILE types. Finally, ANOVA was employed to establish the significance of the differences (s.l. < 0.05) (Table 6). Results indicate that, depending on the type of ILE, there were significant differences in five of the six axes: *Surprising–amazing*, *Clear–efficient*, *Soft–clam*, *Uniform*, and *Lively–cheerful*. However, there were no significant differences in the *Brilliant–glaring* axis, indicating that regardless of the presence of daylighting or electric lighting, the perception of glare remained unchanged.

Table 6. Comparison of axes scores across ANOVA analysis type of lighting results.

		SS	df	MS	F	Sig
Surprising–amazing	Between Groups	16.033	2	8.016	8.241	0.000
	Within Groups	499.967	514	0.973		
	Total	516.000	516			
Clear–efficient	Between Groups	19.315	2	9.657	9.994	0.000
	Within Groups	496.685	514	0.966		
	Total	516.000	516			
Soft–calm	Between Groups	35.754	2	17.877	19.134	0.000
	Within Groups	480.246	514	0.934		
	Total	516.000	516			
Uniform	Between Groups	11.965	2	5.983	6.101	0.002
	Within Groups	504.035	514	0.981		
	Total	516.000	516			
Lively–cheerful	Between Groups	16.986	2	8.493	8.748	0.000
	Within Groups	499.014	514	0.971		
	Total	516.000	516			
Brilliant–glaring	Between Groups	0.144	2	0.072	0.072	0.931
	Within Groups	515.856	514	1.004		
	Total	516.000	516			

According to Figure 5, analysing the averages reveals that classrooms with daylighting evoke a stronger sense of *Surprising–amazing* compared to those with electric lighting. Similarly, classrooms with daylighting also receive higher ratings for feeling *Clear–efficient*, whereas classrooms with electric lighting receive negative ratings. In terms of *Soft–calm*, classrooms with daylighting receive the highest ratings, while those with electric lighting receive negative ratings.

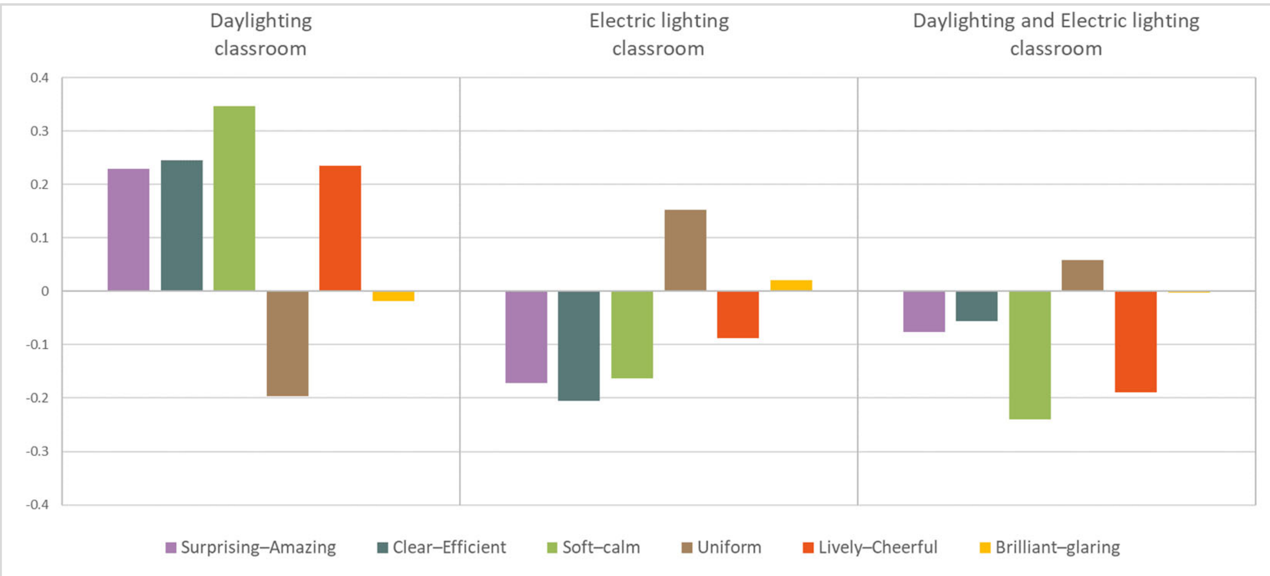

Figure 5. Relationship between affective impressions and type of lighting conditions.

In contrast, the feeling of *Uniform* is mainly achieved in classrooms with electric lighting and has an almost neutral effect in classrooms with daylight and electric lighting. Classrooms with natural light do not generate this feeling of uniformity. The feeling that the lighting environment is *Lively–cheerful* is mainly succeeded in classrooms with daylighting and not in classrooms with electric lighting or a combination of both. Finally, the *Brilliant–glaring* axis does not generate significant differences concerning the assessment of the lighting environment.

3.3.2. Relationship between Task Factors and Type of Lighting Conditions

The data presented in Table 7 indicate the existence of significant differences in the lighting evaluation if the classroom is used for *Discussing–teamwork* and *Paying attention* tasks. However, there are no significant differences for *Writing–reading* tasks, and the differences are nearly significant for *Using devices* tasks.

Table 7. Analysis of variance (ANOVA) to compare the task factors and type of lighting scores.

		SS	df	MS	F	Sig
Writing—-reading	Between Groups Within Groups Total	0.753 518.247 519.000	2 517 519	0.376 1.002	0.375	0.687
Discussing–teamwork	Between Groups Within Groups Total	14.329 504.671 519.000	2 517 519	7.165 0.976	7.340	0.001
Paying attention	Between Groups Within Groups Total	7.717 511.283 519.000	2 517 519	3.858 0.989	3.902	0.021
Using devices	Between Groups Within Groups Total	5.114 513.886	2 517 519	2.557 0.994	2.572	0.077

Figure 6 shows the mean results for each group of tasks based on the classroom's lighting type. The *Writing–reading* tasks receive a positive rating primarily in classrooms with daylighting. The *Discussing–teamwork* tasks exhibit significant differences depending on the lighting type. Classrooms with daylighting are optimal for these tasks.

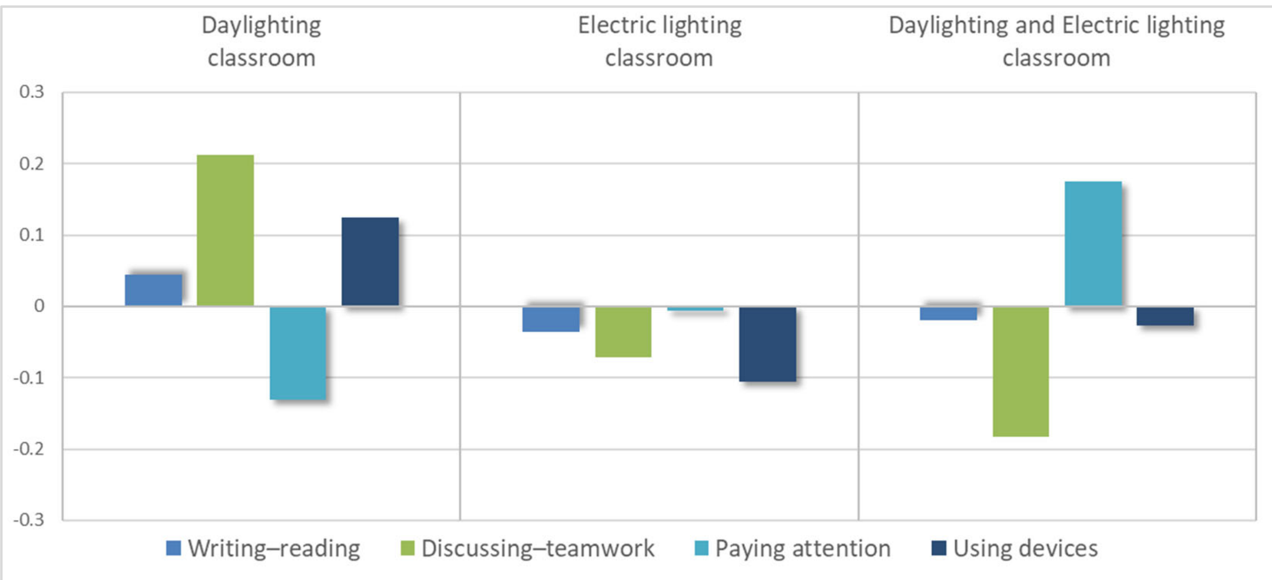

Figure 6. Relationship between task factors and type of lighting conditions.

Regarding tasks that require *Paying attention*, the type of lighting in the classroom plays a significant role. According to students, a combination of daylighting and electric lighting is the most suitable for these tasks. Conversely, a classroom with electric lighting is almost neutral in this assessment and it becomes worse if the classroom has only daylighting.

Tasks that require the *Use of devices* exhibit almost significant differences. According to students, daylighting is the most suitable for these tasks, while electric lighting is less effective. However, assessing these tasks improves if the classroom has both daylighting and electric lighting, although it remains negative.

3.3.3. Analysis of the Overall Assessment of the Lighting Environment Depending on the Type of Lighting Conditions

As for the overall lighting assessment, ANOVA was used to determine whether the differences were significant (for a significant level < 0.05). Table 8 shows significant differences in almost all global assessment variables.

Table 8. Analysis of variance (ANOVA) to compare the global assessment and type of lighting scores.

		SS	df	MS	F	Sig
I like it	Between Groups Within Groups Total	71.806 600.072 671.877	2 518 520	35.903 1.158	30.992	0.000
Well illuminated	Between Groups Within Groups Total	13.838 612.385 626.223	2 518 520	6.919 1.182	5.853	0.003
Adequate lighting	Between Groups Within Groups Total	17.976 465.912 483.889	2 518 520	8.988 0.899	9.993	0.000
Adequate lighting for theory	Between Groups Within Groups Total	4.967 496.991 501.958	2 518 520	2.484 0.959	2.589	0.076
Adequate lighting for practice	Between Groups Within Groups Total	47.624 604.057 651.681	2 518 520	23.812 1.166	20.420	0.000

According to Figure 7, students clearly prefer daylighting when illuminating a classroom. Daylighting appears to be the only lighting option that students like. Conversely, electric light appears to be the only light source that students dislike, regardless of whether or not it is combined with daylight. Nonetheless, despite the clear preference for daylighting, students still consider both electric lighting and the combination of being adequate for a classroom and the classroom still being well lit.

Figure 8 shows significant differences in the lighting assessment for practical classes compared to theory classes. Students prefer a classroom with daylight for practical lessons and electric lighting for theory lessons. However, the ratings are similar if the classroom has a combination of natural and electric lighting. Despite this distinction, the overall ratings remain comparable when daylight and electric lighting are present in the classroom.

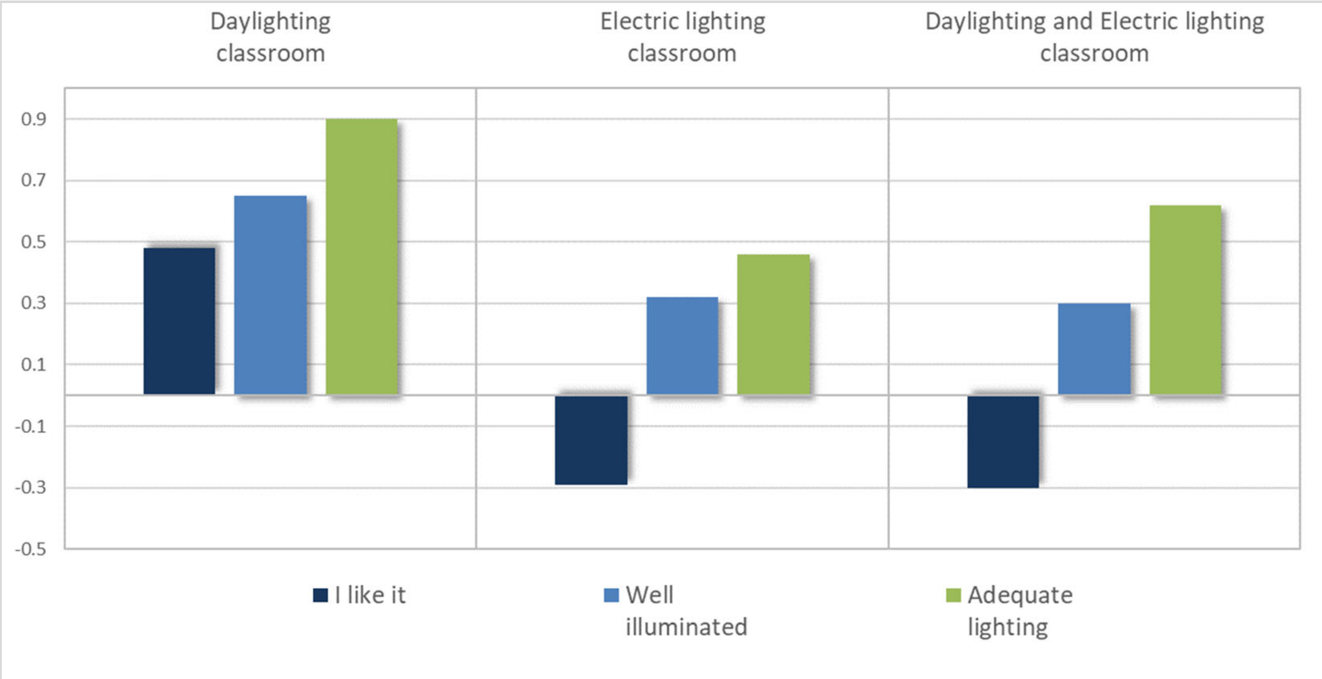

Figure 7. Relationship between lighting global assessment and type of lighting conditions.

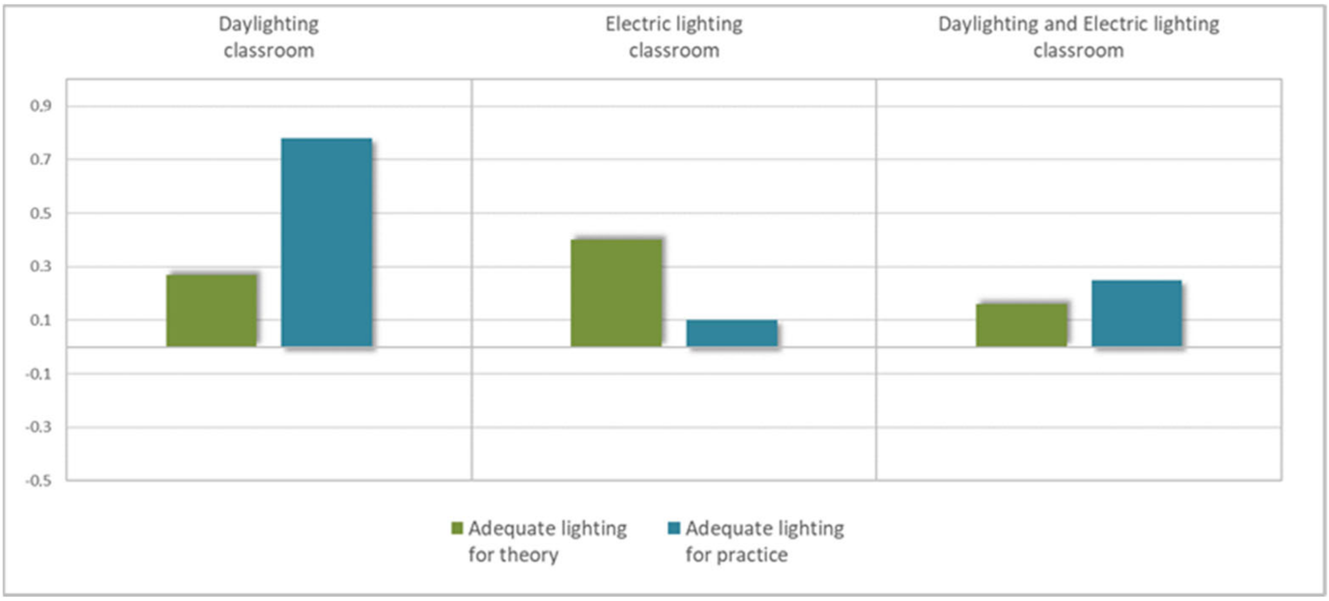

Figure 8. Relationship between lighting global assessment and type of lighting conditions, depending on whether the classroom is dedicated to theory or practice.

4. Discussion

This study aims to analyse the differences in affective response between daylighting and electric lighting when students evaluate the ILE of their classroom. In regards to the contribution to application, the findings of this study provide important outcomes and offer essential understandings of how students' perceptions are affected, considering elements such as affective impressions, task factors, and overall evaluation of the ILE.

To begin with, this study underscores the significance of daylighting concerning students' affective response towards the ILE of their classroom, which can ultimately affect their learning outcomes. Other studies also have shown the importance of daylight in educational environments [50,95,96]. The right balance between daylight and electric light is crucial for optimal classroom performance [97].

The relationship between affective impressions and type of lighting conditions showed significant differences in assessing all axes of affective impressions across different lighting conditions. Daylighting is mainly associated with *Soft–calm* feelings, followed by *Clear–efficient*, *Lively–cheerful*, and *Surprising–amazing* sensations. Conversely, electric lighting is only related to the *Uniform* sensation. The same is observed when daylight and electric lighting are combined.

In addition, students prefer different lighting environments based on the tasks they are carrying out in the classroom. This connection plays a crucial role in the belief that the ILE should elicit different sensations to suit the various tasks performed in the classroom. The outcomes of variable lighting in educational settings are consistent with these findings [98].

For *Writing–reading* tasks, the ideal lighting environment is *Clear–efficient*, *Uniform*, and *Soft–calm*. These results are in accordance with the lighting standards, like UNE-EN 12464-1 [65], which regulates the parameters of illuminance, uniformity, and glare in educational spaces. For tasks involving using electronic devices, students prefer a *Soft–calm* atmosphere.

There are also significant differences in the relationship between task factors and type of lighting conditions. Students mainly associated daylighting with tasks such as *Discussing–teamwork* and *Using electronic devices*. According to students, electric lighting is unsuitable for any task factors. A combination of daylighting and electric lighting is the best solution for paying attention. Conversely, a classroom with electric lighting is almost neutral in this assessment and worsens if the classroom only has daylighting.

Similarly, there are significant differences between lighting conditions in almost all global assessment variables. Students prefer daylighting when it comes to illuminating a classroom, and daylighting appears to be the only lighting option students like. Previous studies have shown that individuals generally form a positive perception of a space that is naturally illuminated [99]. On the contrary, electric light appears to be the only light source that students dislike, regardless of whether or not it is combined with daylight. Nonetheless, despite the clear preference for daylighting, students still consider both electric lighting and the combination of daylight and electric light adequate for a classroom and that the classroom is still well lit.

The findings of this study may enable designers and educators to create learning spaces that promote a positive and stimulating student environment by understanding the relationship between the lighting environment and students' affective responses.

As limitations of the present work, it is worth noting that the field study was conducted in actual university classrooms, which combined various elements that may have influenced perception. At this stage, diversity is prioritised over consistency. The primary objective of this study is to derive independent semantic axes using a set of stimuli evaluations. For accurate and representative outcomes, it is imperative to have a sufficient number of individuals and stimuli that cover a wide range of evaluations for each adjective and their relationships. The methodology employed in this study follows Kish's [89] approach, which involves controlling experiments by randomly introducing variables. This procedure assumes that chance will produce equivalent distributions of units in all variables under study, thereby rendering any resulting bias negligible. In the same vein, controlling the time of day during the study was not feasible due to the need for a large sample size. Typically, Spanish universities utilise their classrooms for extended periods from 8:00 a.m. to 9:00 p.m. Future investigations may explore implementing interventions at different times to determine if comparable outcomes can be achieved at various times of the day.

The process of gathering students' opinions and conducting in situ evaluations of classroom ILEs has provided valuable insights. Nevertheless, it is essential to recognise that the combination of natural and electric lighting can significantly impact the values of lighting variables. Therefore, further research is necessary to determine the specific lighting parameter values that contribute to positive affective responses and establish any potential relationships between these affective impressions and visual performance.

Another potential avenue for further investigation is incorporating LED light sources instead of the fluorescent sources studied in this research. It is worth highlighting that despite their comparable colour temperatures, differences in the light sources' spectra and wavelengths could lead to variations in the affective response and visual performance.

This research will deepen our understanding of factors that influence individual affective responses toward ILEs, ultimately aiding in the design of more effective learning environments.

5. Conclusions

This study aimed to explore the impact of various types of lighting, such as electric light, daylight, or a combination of both, on students' emotional responses in the classroom. The research findings suggest that students prefer a *Clear-efficient* lighting environment for *Writing–reading* tasks. For using electronic devices, a *Soft–calm* atmosphere is preferred. A blend of daylight and electric lighting is considered the most suitable option when paying attention is required, whereas daylighting is preferred for teamwork and discussion activities. Although students prefer daylighting, electric lighting and a combination of both are also acceptable in the classroom. This research can help educators and designers understand the connection between lighting and students' emotional responses and create learning spaces that promote a positive and engaging atmosphere for students.

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Informed Consent Statement: Informed consent was obtained from all subjects involved in the study. The invitation to the survey emphasises that participation is voluntary, anonymous, and optional. The participants could leave the survey at any time during the process and were also informed that the data would only be used for academic purposes.

Data Availability Statement: The data presented in this study are available on request from the corresponding author. The data are not publicly available due to privacy restrictions.

Conflicts of Interest: The authors declare no conflicts of interest.

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