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The Impact of Indoor Environmental Quality (IEQ) in Design Studios on the Comfort and Academic Performance of Architecture Students

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Abstract: This study addresses the limited research on examining comfort levels among architecture students. Specifically, it seeks to evaluate indoor environmental quality (IEQ) within design studios to investigate the occurrence of health symptoms and ascertain the influence of these factors on academic performance. This study was conducted at a university in Jordan during the autumn semester. The research database encompassed objective measurements utilizing instruments, subjective aspects using questionnaires, and academic performance assessments. This study's results indicated a significant need for more satisfaction with the overall comfort levels encountered in design studios. The element of noise levels was considered the least satisfactory by the students, followed by the level of humidity, temperature conditions, lighting quality, and air quality. The findings revealed that the symptoms most frequently reported weekly throughout the autumn semester in design studios were decreased focus, dry skin, nasal congestion, and headaches. A significant positive link was seen between the degree of concentration and academic achievement. Moreover, a significant majority of students (77.4%) expressed their belief that enhancing IEQ will improve their academic performance.

Keywords: architecture students; indoor environmental quality; design studios; thermal conditions; air quality; academic performance; healthy built environment

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1. Introduction

The built environment's physical characteristics and architectural layout substantially influence the overall well-being of occupants inhabiting a particular area [1]. Numerous studies have indicated that substandard building conditions might harm occupants' physical and emotional health [2–5]. The notion of a healthy built environment was first articulated and linked to the field of architecture at the 14th International Union of Architects Conference held in Warsaw, Poland, in 1981. A study by Liu et al. [6] established a consensus and emphasized the connection between the built environment and human well-being. The primary objective of their research was to advance health outcomes and enhance productivity among individuals. The World Health Organization (WHO) defines a healthy building as an environment promoting holistic physical, mental, and social well-being [7]. On the other hand, an unhealthy building can be defined as a living or working space where people are exposed to various health risk factors and their associated attributes.

In the context of educational facilities, where students primarily occupy classrooms, the issue of poor indoor environmental quality (IEQ) arises. This encompasses indoor air quality and thermal, acoustic, and visual comfort [8–12]. The implications of inadequate IEQ are twofold: it can lead to health symptoms such as muscular soreness, headaches, and dizziness, as well as hinder academic performance due to the substantial influence on students' motivation and concentration [13–18].

Within the domain of architectural education, the design studio emerges as the preeminent instructional environment that distinguishes it from conventional classrooms, where students often spend approximately three hours per session. The significance of IEQ is heightened due to its impact on students' overall well-being. However, readily available information regarding thermal settings is scarce, so designers often rely on well-accepted classroom standards, such as ANSI/ASHRAE-55 [19]. Additionally, there is a notable lack of research investigating the comfort levels of architecture students as they participate in educational activities in classroom settings. This contrasts with the increasing body of scholarly literature exploring thermal comfort and air quality among students in academic institutions [20–22]. This research aims to assess IEQ within design studio classrooms, investigate the prevalence of health problems associated with IEQ, and determine the impact of IEQ on design outcomes and academic performance. This study's results will be used to draw recommendations to enhance IEQ and academic performance in design studios. The research was conducted within the premises of a university facility in Jordan, specifically during the autumn semester of the academic year 2022–2023, spanning from October to February. The research was centered on the design studio classrooms that facilitate architecture design classes, each lasting approximately three hours and occurring twice a week.

IEQ in Higher Education Buildings

The concept of IEQ is widely acknowledged in academic research as a comprehensive measure of comfort, encompassing various elements like thermal, acoustic, indoor air quality, and visual comfort. Ali et al. [23] conducted a study in educational institutions in Jordan, which revealed that indoor air quality (IAQ) problems can be attributed to deficiently constructed and maintained ventilation systems and inadequate management of interior sources such as art supplies and science materials. The presence of substandard qualities in buildings can have adverse effects on occupants, leading to the potential worsening of sick building symptoms [24], heightening rates of student absenteeism [25], and an increasing likelihood of infectious disease transmission [26]. Shendell et al. [27] highlighted the issues by concluding that increased classroom ventilation rates significantly decrease student absenteeism. Furthermore, the research conducted by Palacios, Eichholtz, and Kok [28] demonstrated that improvements in health and well-being are associated with a noteworthy increase in levels of student satisfaction and a substantial decrease of 2% in the frequency of sick leave.

On the other hand, insufficient indoor environmental conditions, such as higher levels of carbon dioxide (CO_2), insufficient ventilation, high room temperatures, excessive decibel levels, inadequate quality of light, and increased relative air humidity levels, can potentially result in adverse health consequences. Table 1 provides a comprehensive compilation of studies that have explicitly investigated the impacts of IEQ on the overall well-being of those occupying indoor environments.

Table 1. Studies consider the health impact of IEQ on occupants.

Insufficient IEQ	Impact on the Health and Well-Being of Occupants	Studies
Higher levels of carbon dioxide (CO_2)	Asthma and respiratory symptoms.	[29]
Insufficient ventilation	Asthma, excessive tearing, headaches, fatigue, difficulty breathing, sinus congestion, coughing, sneezing, dizziness, nausea, irritation of the eyes, nose, throat, and skin, and respiratory symptoms.	[29–33]
Insufficient room temperatures	Elevated heart rates, adverse mood, weariness, asthma, itchiness and excessive tearing, headaches, throat irritation, influenza virus, and respiratory symptoms.	[29–31,34,35]
Excessive decibel levels	Cardiovascular illness, heightened stress levels, and disturbances in sleep patterns.	[36]

Table 1. *Cont.*

Insufficient IEQ	Impact on the Health and Well-Being of Occupants	Studies
Inadequate quality of light	Visual strain, eye irritation, blurred vision, and alterations in the circadian rhythm.	[37,38]
Insufficient relative air humidity levels	Asthma, elevated heart rates, adverse mood, weariness, dry cough, itchiness and excessive tearing, headaches, throat irritation, influenza virus, chest tightness, hoarseness, voice cord dysfunction, and respiratory symptoms.	[29–31,34,35,39,40]

Unfavorable indoor environmental conditions negatively impact the academic performance of students. Research has demonstrated that ventilation and thermal comfort levels affect attention [20], performance and learning abilities [41,42], cognitive functioning [43,44], stress and mental exhaustion [45], productivity [46], illness-related absences [47], academic achievement [48], and reading accuracy [49].

2. Materials and Methods

The data were gathered as a component of research aimed at evaluating the influence of thermal comfort and air quality on the health and performance of individuals in educational buildings in Jordan. The present investigation was conducted within the Faculty of Architecture and Design premises at the University of Petra in South Amman, Jordan. The structure comprises four floors, encompassing 3703 square meters, exclusively for educational activities. Design studios occupy 56% of this designated space. This study's primary focus was designing studio classrooms for architecture design courses. Each session in these classrooms typically lasts three and a half hours, and they are conducted twice a week throughout the fall and spring semesters. Each hall accommodates a maximum of twenty students and instructors, who collaborate to generate projects, cultivating effective communication, creativity, problem-solving skills, and interpersonal growth. This is achieved with various means, including one-to-one and group discussions, peer evaluations, critiques, sketching, drafting drawings, model making, and computer use [50–55]. Therefore, the metabolic rates of individuals attending design studios exceed those of students in regular classrooms.

The research comprises two phases. The first phase involved a preliminary assessment of the indoor environmental qualities of eight design studio classrooms distributed on different levels. A survey was undertaken within the confines of various studios, engaging a sample of 16 instructors and 117 students. This study aimed to assess and rate the design studios based on multiple factors, including thermal conditions, air quality, lighting quality, and noise level. In the second phase, this study identified the four studios with the poorest environmental performance, which were subjected to more investigation. All studios exhibit a consistent westward orientation and homogeneity in shape, style, and arrangement, as depicted in Figure 1. There are two studios, DS1 and DS3, situated on the ground floor, while the remaining two studios, DS2 and DS4, are on the third level. Each studio is equipped with a single expansive window, measuring 7 m in width, divided into three parts; one remains fixed, while the other two are designed as sliding windows, allowing for the inflow of natural ventilation into the room. The vertical distance from the floor to the ceiling measures 3.25 m. The cooling system relies on ceiling-mounted fans, whereas radiators provide heating. Every hall has a maximum occupancy of 20 students. The inside walls are covered with Celotex sheets, facilitating the display of students' works. Table 2 presents the characteristics of the design studio classrooms under investigation. The research was carried out during the autumn semester of the academic year 2022–2023, spanning from October to February, encompassing four months. This study's aims were pursued by implementing three distinct methodologies: instrumental (objective) measurements, human (subjective) measurements, and evaluating students' academic performance.

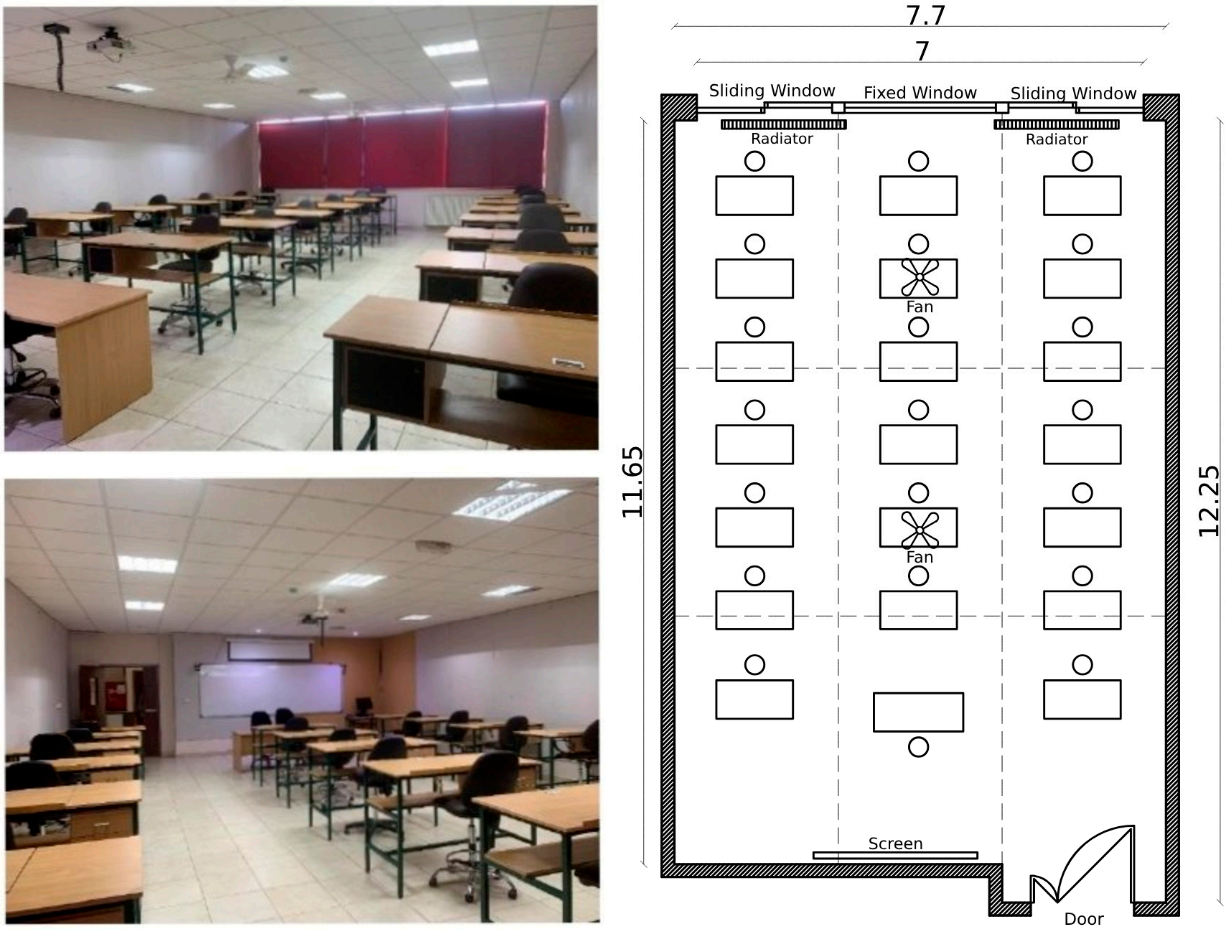

Figure 1. The layout of the studied design studio classrooms.

Table 2. Features of the investigated design studio classrooms.

Classroom	Area (m^2)	Location, Orientation of Widows	Ventilation Type	Cooling System	Heating System	No. of Occupants per Session	Duration of the Session	Time of the Session
Design Studio 1 (DS1)	89	Ground floor, west	Natural	Ceiling-mounted fans	Heating radiators	20	3.5 h	8:30 a.m.–12:00 p.m.
Design Studio 2 (DS2)	89	Third floor, west	Natural	Ceiling-mounted fans	Heating radiators	20	3.5 h	8:30 a.m.–12:00 p.m.
Design Studio 3 (DS3)	91	Ground floor, west	Natural	Ceiling-mounted fans	Heating radiators	20	3.5 h	8:30 a.m.–12:00 p.m.
Design Studio 4 (DS4)	91	Third floor, west	Natural	Ceiling-mounted fans	Heating radiators	20	3.5 h	8:30 a.m.–12:00 p.m.

2.1. Instrumental (Objective) Measurements

The measurements for the IEQ parameters were undertaken throughout the winter season, specifically from 28 December 2022 to 15 January 2023. These measurements were taken within occupancy hours, from 8:30 a.m. to 12:00 p.m. The selection of measurement dates considered the prevailing cold climate conditions in Jordan. The typical daily time allocation in design studios determines the choice of measuring time.

Figure 2 illustrates the measuring tools used in this study. The measuring instruments were situated 1.2 m above the floor level, and data were gathered at consistent intervals of 30 min at nine designated locations (P1 to P9), as depicted in Figure 3. The parameters that were measured included indoor air temperature (°C), relative humidity (%), CO_2 concentration (PPM), noise level (dBA), and lighting intensity level (Lux). Before conducting any measurements, all instruments were calibrated according to the manufacturer's instructions. The specifications of these instruments were found to follow the ANSI/ASHRAE 55 [19], ISO 7730 [56], and IEC 61672-1 [57] standards. The chosen field research technique for this study involved placing the measurement probes 1 m above the floor and closest to the sitting respondents, as Brager & de Dear [58] described. The results were compared to the recommended values provided by ANSI/ASHRAE 55 [19] and the WHO [59].

Investigated variable	**Unit**	**Measuring tool**	
Indoor air temperature	°C		Temperature sensor Measuring range: −10 ~ 60 °C Accuracy: ±0.6 °C Resolution: 0.1 °C Time interval: 5 seconds
Relative humidity	%		RH sensor Measuring range: 0.1% ~ 99.9% Accuracy: ±3% RH (at 25 °C, 10~90% RH) Resolution: 0.1% RH Time interval: 5 seconds
CO_2 concentration	PPM		CO_2 sensor Measuring range: 0 ~ 30000 ppm Accuracy: 75 ppm + 3% of reading Resolution: 1 ppm Response time: 20 seconds
Noise level	dBA		Sound sensor Measuring range: 30 ~ 130 dBA Level range: 30–90 dBA, 50–110 dBA, 70–130 dBA Dynamic range: 60 dBA Accuracy: ±1.4 dBA Sampling rate: 2 times/sec
Lighting intensity level	Lux		Lighting sensor Measuring range: 0.0 to 1999 Lux Resolution: 0.1 Lux Accuracy: ±3% of reading Response time: 0.5 seconds

Figure 2. Instruments and sensors used to measure IEQ parameters in the design studios.

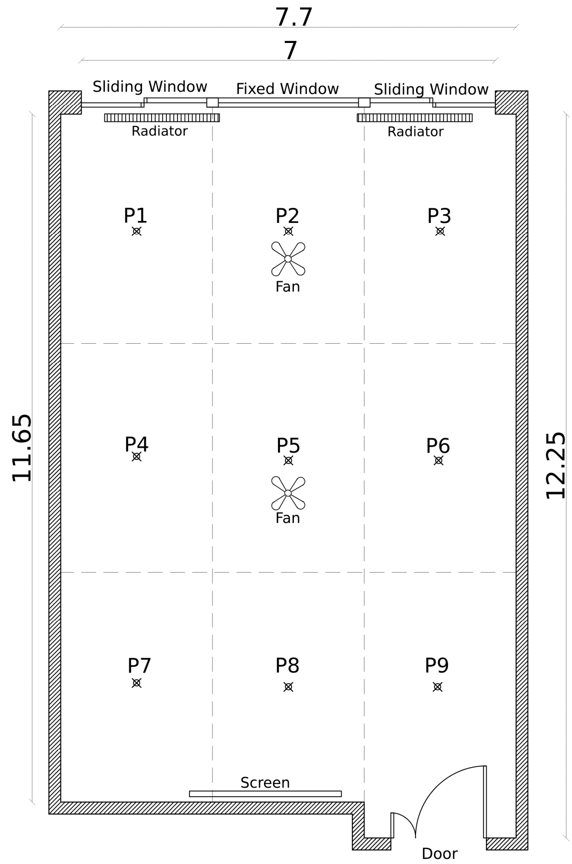

Figure 3. The spatial arrangement of measuring instruments within the investigated design studios.

2.2. Human (Subjective) Measurements

This study examined the perspectives of students. Enhancing comprehension of users' evaluation can facilitate the identification and assessment of both the advantages and disadvantages inherent in students' experiences. A survey instrument was developed based on a comprehensive literature study on IEQ and its effects on building occupants [29–41,43,60,61].

The questionnaire was initially designed in English and then translated into Arabic, the predominant language among most students. A QR code was incorporated into the questionnaire to enhance the response rate, providing a convenient link for respondents to access an online survey. The questionnaire included 43 items that were grouped into six main categories:

1. The background information comprises the age, gender, years of using the current building, and classroom attendance hours per session of the students.
2. Study conditions, with a focus on the degree of difficulty of the study, considering the workload and concentration demands, as well as the collaboration among peers. Furthermore, the extent to which the classroom environment is stimulating and fascinating, as well as how it enhances the students' study conditions.
3. Classroom IEQ, including air temperature, relative humidity, air quality, noise, lighting conditions, and overall comfort level.
4. Health-related symptoms, encompassing both current and past symptoms such as headache, dry mouth, nausea/dizziness, difficulty concentrating, burning, irritation, stuffy nose, runny or stuffy nose, hoarseness, dry throat, cough, dry facial skin, scaling/itching of the ears, and dry, itchy hands.
5. The impact of IEQ on the quality of learning, encompassing learning productivity and performance.
6. Recommendations to improve the IEQ of classrooms regarding air quality, thermal conditions, acoustics, and lighting levels.

The participants in this study were a group of architecture students enrolled in the same design course. The survey was administered to the participants after they had attended a lecture for at least one hour. The participants were expected to be exposed to consistent indoor environmental conditions and maintain a stable metabolic rate throughout the survey. The researchers used SPSS to analyze the students' responses to ascertain the various uses and objectives of the spaces and evaluate the level of satisfaction expressed by the users. The reactions were examined concerning the four classrooms.

2.3. Academic Performance

The evaluation of students' academic performance was conducted by considering two key factors: (1) the allocation of grades based on the assessment of their ability to solve design problems, which necessitated abilities such as research, critical thinking, and sketching, and (2) the subjective evaluation of the influence of IEQ on their learning performance, as included in the questionnaire. The factors mentioned above pertain to the evaluation of study conditions, self-assessment, the level of comfort experienced in the classroom (including complaints about indoor environmental quality), and the potential influence of enhancing indoor environmental quality on academic achievement.

3. Results

3.1. IEQ and Comfort

A summary of the environmental conditions observed in the surveyed design studios is provided in Table 3, explicitly focusing on IEQ factors (air temperature, relative humidity, CO_2 concentration, lighting intensity, and noise level). These surveyed circumstances are then compared to the established international norms for comfort range, as shown in Figure 4. According to the thermal comfort ASHRAE 55 adaptive method, the air temperature in the design studios falls within the allowed range for comfort conditions. Specifically, the defined acceptable limits during the cold season are 19.4–27.7 °C, with a 90% acceptance rate. Nonetheless, the relative humidity levels in the classrooms fall within the acceptable range of comfort, as specified by the American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE), which recommends maintaining humidity levels between 40% and 60% for various uses. DS3 has the most unfavorable conditions, characterized by the lowest air temperature (17.3 °C) and the highest relative humidity (55.2%).

Table 3. Mean of indoor environmental quality in the surveyed design studios.

Classroom	Air Temperature (Ta) (°C)	Relative Humidity (Rh) (%)	CO_2 Level (ppm)	Lighting Intensity Level (lux)	Background Noise Level (dBA)
Design Studio 1 (DS1)	19	44.8	819	122	43.5
Design Studio 2 (DS2)	19.7	43.5	836	353	45
Design Studio 3 (DS3)	17.3	55.2	811	305.5	47.4
Design Studio 4 (DS4)	21.4	46.9	823	177.3	49.1
Mean	19.35	47.6	822.25	239.45	46.25
Comfort range	19.4–27.7 (ASHRAE)	40–60 (ASHRAE)	400–900 (ASHRAE)	500–1000 (ASHRAE)	45–50 (ASHRAE)/ 35–40 (NC curve)

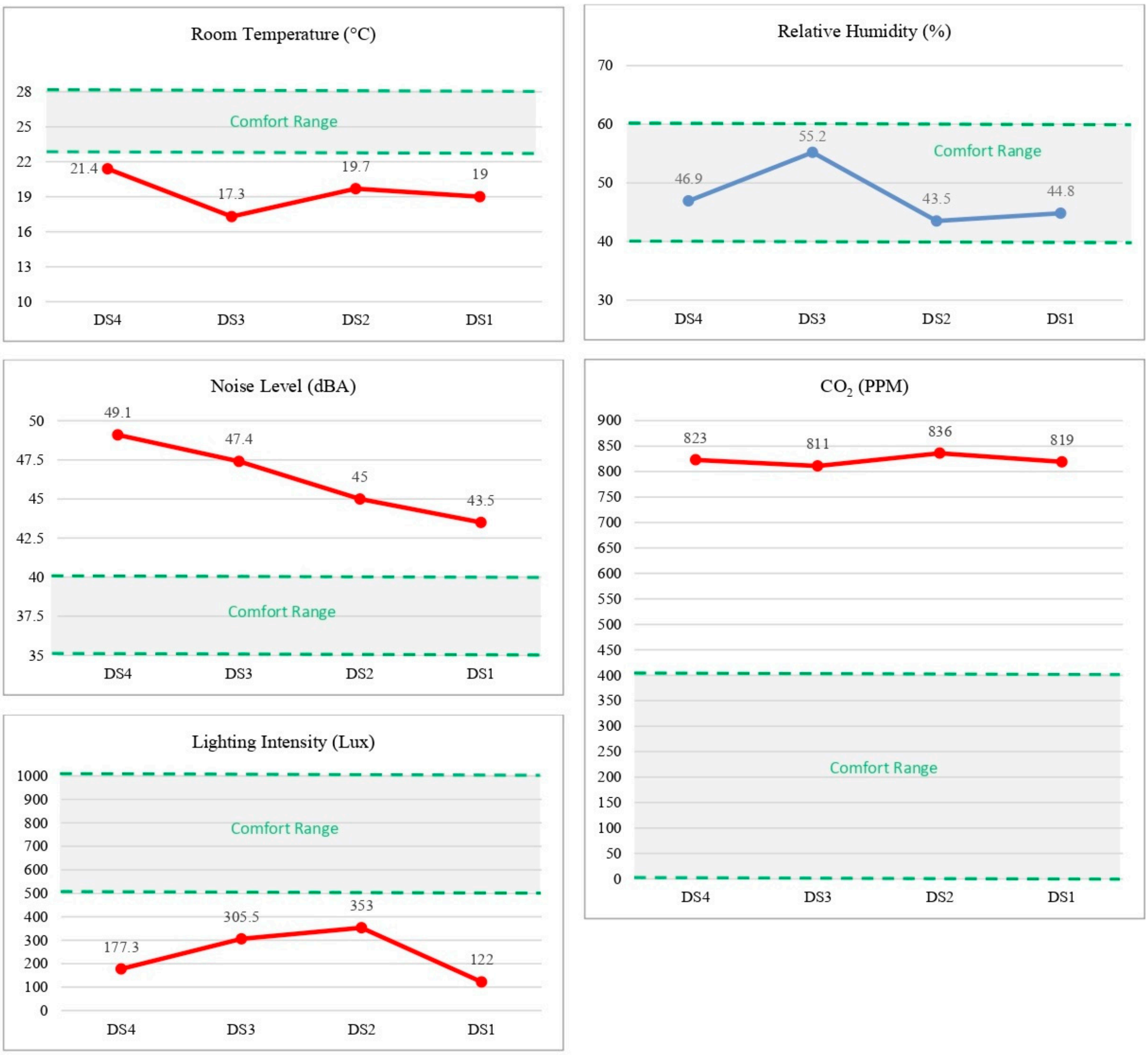

Figure 4. Mean of IEQ in the surveyed design studios in comparison to the standards comfort range. The red readings indicate that the prevailing conditions are outside the established comfort threshold, while the blue readings indicate situations within the comfort range.

The design studios observed measurements above the approved carbon dioxide (CO_2) limits regarding air quality. The concentration of CO_2 exceeded 800 parts per million (PPM) in the recorded data. According to ASHRAE and the National Ambient Air Quality Assessment (NAQQA), the average carbon dioxide concentration in ambient air is 400 PPM. However, ASHRAE suggests introducing fresh air when the CO_2 level exceeds 900 PPM, as outlined in the Demand-Controlled Ventilation (DCV) system specified in Standard 62.1 [19].

The acoustic environment within the design studio was measured to have a range of 45–49.1 decibels (dBA) in DS2, DS3, and DS4, but DS1 exhibited a recorded noise level of 43.5 dBA. The allowed ranges of recorded noise levels in educational labs are determined by ASHRAE guidelines, which propose a 45–50 dBA range. However, these ranges exceed the Noise Criteria (NC) curves, which specify the accepted noise limit as 35–40 dBA. The lighting intensity in the four design studios does not meet the established norms. To ensure optimal conditions for typical office tasks, computer work, library study, showroom displays, and laboratory activities, it is recommended that the illuminance level be maintained within the range of 500 lux (or 500 lumens per square meter). However, in the context of drawing activity, it is recommended that the thresholds for lighting intensity be increased to around 1000 lux [19]. The four design studios were observed to be associated with low illumination intensity. The design studio DS2 can be considered the most exceptional lighting installation among the examined classes, while DS1 is commonly perceived as the least desirable.

3.2. Students' Satisfaction/Self-Assessment of IEQ

This study's sample size was composed of 80 students. A total of 77 students participated in the questionnaire within the surveyed design studios, resulting in a sample percentage value of 96.25%. The confidence intervals (CIs) for the prevalence data were determined at a 95% confidence level using the following formula:

$$\mathrm{CI} = p \pm \left(1.96 \times \sqrt{((p \times (1-p))/n)}\right) \tag{1}$$

where the symbol "p" represents the sample percentage value, "n" denotes the sample size, and the constant "1.96" is utilized for constructing 95% confidence intervals.

Therefore, the 95% confidence interval calculation yields a range of [0.921, 1.000], with the point estimate being 0.9625 ± 0.0416. The confidence interval ranges from 92.1% to 100% in percentage.

The age distribution of the questioned students encompassed individuals between the ages of 18 and 21 years, representing a majority of around 60% of the total sample. Additionally, students falling within the age range of 22 to 25 years constituted approximately 32% of the sample. The demographic composition of the study population was primarily characterized by female students, accounting for about two-thirds of the overall sample. Table 4 presents detailed background information on the participating sample.

Table 4. Students' background information in the surveyed design studios.

No of Respondents = 77				Frequency	Percentage (%)
Background information	Participant information	Age	18–21 years	46	59.74
			22–25 years	25	32.47
			26–29 years	4	5.19
			≥30 years	2	2.60
		Gender	Male	29	37.66
			Female	48	62.34
	Experience in place	Years in the current building	1–2 years	36	46.75
			2–4 years	33	42.86
			≥5 years	8	10.39
		Hours in current classroom/session	≤1 h	0	0.00
			1–2 h	10	12.99
			2–3 h	59	76.62
			≥3 h	8	10.39

The findings of this investigation revealed a notable deficiency in the satisfaction levels about the overall comfort experienced in design studios, as assessed using a five-point Likert scale ranging from very uncomfortable to very comfortable. A mere 56% of the student population expressed satisfaction, with a mean value of 2.44 out of 5. An examination of the results indicates that DS1 and DS2 demonstrated the highest percentage of positive comments from students on indoor environmental conditions, comprising around 62% of the total. Following this, DS3 earned over 56% positive replies, but DS4 obtained 44% of such input. However, the differences in the mean values were minimal (2.54, 2.47, 2.54, and 2.22, respectively). Concerning the grievances received during the preceding three-month period, the students were assigned to assess the indoor environment within the design studios, emphasizing thermal conditions, humidity, air quality, lighting quality, and noise levels. The survey revealed that the mean satisfaction scores for the five components of IEQ ranged from 2.18 to 2.62. This study showed that a modest 51% of the students needed more interest in relative humidity. Similarly, it was observed that 54% of the student population displayed indifference toward variations in air temperature. Furthermore, most students (65%) needed to demonstrate a discernible level of attention toward the air quality. Moreover, a minority of students, precisely, less than 45%, indicated their pleasure with the noise level, whereas a majority of 60% expressed contentment with the lighting quality, as depicted in Table 5. Despite the suboptimal lighting quality levels in the design studios, respondents' self-reported happiness with the illumination did not indicate dissatisfaction. This phenomenon may be attributed to the prevalent usage of computers by students for design-related tasks.

Table 5. Students' self-assessment of IEQ during the last three months in the surveyed design studios.

Classroom	Overall Comfort Level			Evaluation of the Five Components of IEQ									
	Mean	SD	% of Satisfaction	1. Thermal Conditions		2. Level of Humidity		3. Air Quality		4. Lighting Quality		5. Noise Level	
				Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
DS1	2.54	0.19	61.68	2.48	0.55	2.36	0.80	2.61	0.50	2.73	0.47	2.73	0.65
DS2	2.47	0.20	61.62	2.36	0.71	2.44	0.80	2.74	0.53	2.33	0.87	2.33	1.00
DS3	2.54	0.09	56.36	2.53	0.55	2.65	0.50	2.57	0.51	2.70	0.48	2.10	0.74
DS4	2.22	0.18	44.16	2.29	0.88	1.93	0.74	2.57	0.60	2.14	0.90	1.57	0.53
Mean	2.44	0.17	55.96	2.41	0.67	2.35	0.71	2.62	0.54	2.48	0.68	2.18	0.73
Overall percentage of satisfaction	55.96%			53.85%		50.52%		65.00%		60.28%		44.62%	
Percentage of dissatisfaction	44.04%			46.15%		49.48%		35.00%		39.72%		55.38%	

An analysis of the results illustrated in Figure 5 reveals the subsequent findings. Most students (75%) provided positive assessments about air leakage in the design studios. Furthermore, most students, precisely, over 65%, expressed satisfaction regarding dust exposure and passive smoking. However, it is essential to acknowledge that only 40% of the participants in this study reported satisfaction with the olfactory conditions in the classrooms. A significant majority of the student body, including more than 65%, articulated discontent with the inconsistent air temperature observed within the design studios. Moreover, it was found that over half of the students exhibited dissatisfaction with the ambient temperature within the design studio throughout both the summer and winter seasons.

In other respects, there are notable correlations between the overall comfort level and certain factors about the internal environment within the surveyed design studios. The findings presented in this study were derived using the Chi-Square statistical test. Table 6 comprehensively summarizes the key factors that impact students' comfort in the studio environment: air temperature, dust and dirt, air circulation, and olfactory conditions. The computed probability (p) values for these aspects were below the preset significance level of 0.05. In contrast, the findings indicate no statistically significant associations between the level of comfort and various factors, including gender, duration of classroom attendance, and other variables about the indoor environment, such as noise levels and the quality of natural or industrial lighting.

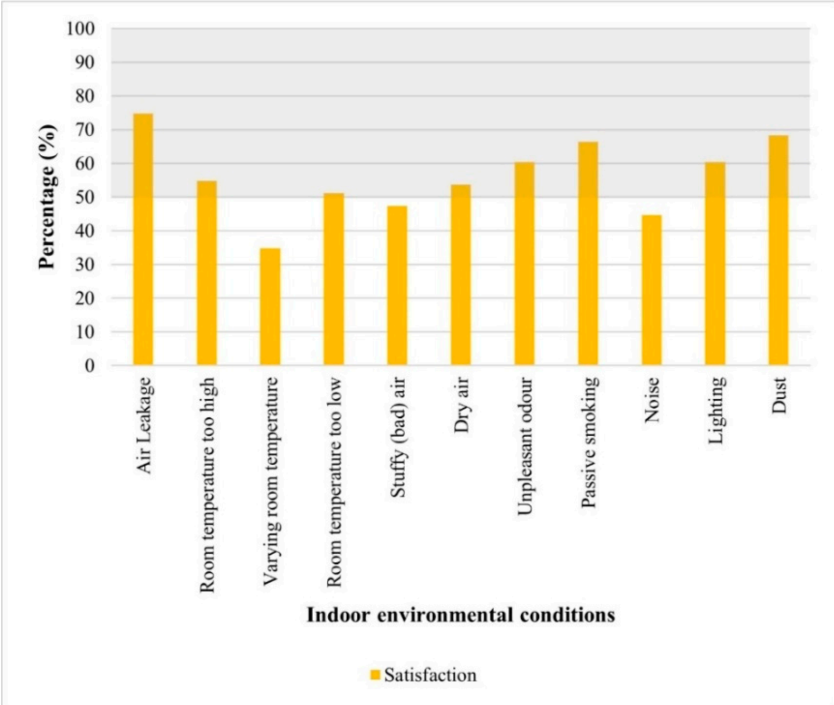

Figure 5. Students' self-assessment of overall indoor environmental conditions in the surveyed design studios.

Table 6. Correlations between the overall comfort level and the internal environment within the surveyed design studios.

Dependent Variable	Independent Variables	Significant Value (According to SPSS Chi-Square Tests)	Association between the Two Variables	
			Yes	No
The overall level of comfort	Gender	0.208 (≥0.05)		x
	Time spent in the classroom	0.997 (≥0.05)		x
	Classroom air temperature	0.049 (<0.05)	√	
	Air quality	0.952 (≥0.05)		x
	Odors inside the classroom	0.008 (<0.05)	√	
	Dust/dirt conditions	0.048 (<0.05)	√	
	Air movement	0.001 (<0.05)	√	
	Noise levels	0.239 (≥0.05)		x
	Quality of natural daylighting	0.119 (≥0.05)		x
	Quality of artificial lighting	0.920 (≥0.05)		x

3.3. Health and Well-being Symptoms

The built environment's impact on the well-being of occupants is evident and significant over a prolonged period. To investigate the effect of design studios, the participants were surveyed about any illnesses and associated symptoms they had encountered in the previous year and the preceding three months. Based on the statistics depicted in Figure 6, it can be observed that around 27.6% of the student population reported having encountered allergies in the past. Nevertheless, a noticeable escalation in disease symptoms was documented over the preceding year, with most students, explicitly, exceeding 74%, experiencing the onset of an infection. The prevalence rate of eczema was found to be the greatest, exceeding 81%, with hay fever following closely at 79% and asthmatic disorders at a rate of 62.5%.

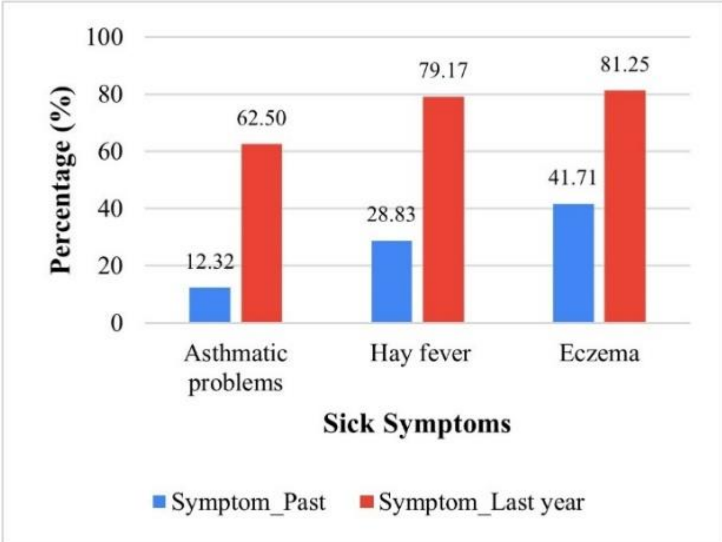

Figure 6. Comparison of symptoms among students.

The students were asked about their present experience of symptoms that may have arisen from unfavorable indoor environmental conditions. According to the data presented in Figure 7, almost 40% of the student population experienced various symptoms within the preceding three-month period. The weekly occurrence of these symptoms was experienced by over 9% of students. According to the survey, 47% of the students identified DS4 as exhibiting the highest prevalence of symptoms compared with the other options. Overall, 44% of the students chose DS1, while 32% of the students selected DS2 and DS3. In the context of DS4, it was observed that approximately 15% of the student population experienced weekly episodes of suffering. The prevalent symptoms experienced by most students over the past three months included headache (75%), difficulties with concentration (70%), weariness (60%), dry facial skin (55%), itchy, stuffy, or runny nose (53%), and a sensation of heaviness in the head (50%). Additional documented symptoms encompassed hoarseness, parched throat, and feelings of nausea or dizziness in around 40% of cases, accompanied by coughing in 35% of instances. Furthermore, approximately 22% of individuals experienced itching, burning, or irritation of the eyes, while 17% reported dryness, itching, and reddening of the hands. Additionally, approximately 14% of individuals encountered scaling and itching of the scalp or ears. Approximately 25% of the student population experienced weekly challenges with concentration, while 16.5% reported dryness of the facial skin, and 14.5% encountered nausea or dizziness symptoms. The weekly occurrence of symptoms was experienced by over 10% of the student population. Symptoms may include nasal irritation characterized by congestion, stuffiness, excessive nasal discharge, and a hoarse and dry throat. Additionally, individuals may have a headache and irritation of the eyes. Overall, a majority of 63.5% of the student population believes that the symptoms experienced can be attributed to the classroom environment. A significant majority, exceeding 70%, established a correlation between various symptoms such as headaches, impaired concentration, nasal congestion or rhinorrhea, dry skin, and the substandard quality of the interior atmosphere within the design studios.

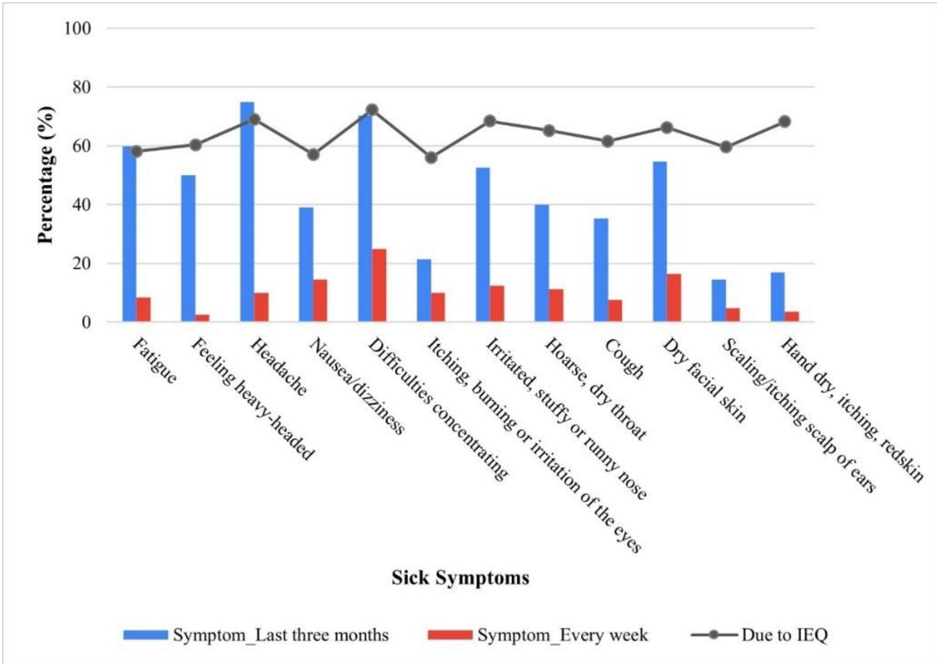

Figure 7. Frequency of symptoms among students in the surveyed design studios.

3.4. Academic Performance

The 77 participants evaluated the study conditions and learning performance. Most students thought architecture design has significant challenges as an academic pursuit. A substantial majority of the students, above 80%, reported that pursuing this academic discipline necessitates considerable exertion and focused attention to address design challenges within the classroom setting effectively. Furthermore, a significant proportion of students, approximately 49%, held the belief that fostering support and collaboration among their peers is crucial for augmenting their academic pursuits. When the students were requested to assess the present design studios, it was found that merely 48% of the students saw the classroom as a stimulating setting for engaging in and dealing with architecture design study. Furthermore, half of the students, precisely, 49%, perceived that they are afforded the chance to improve the learning environment within these educational spaces, as illustrated in Figure 8.

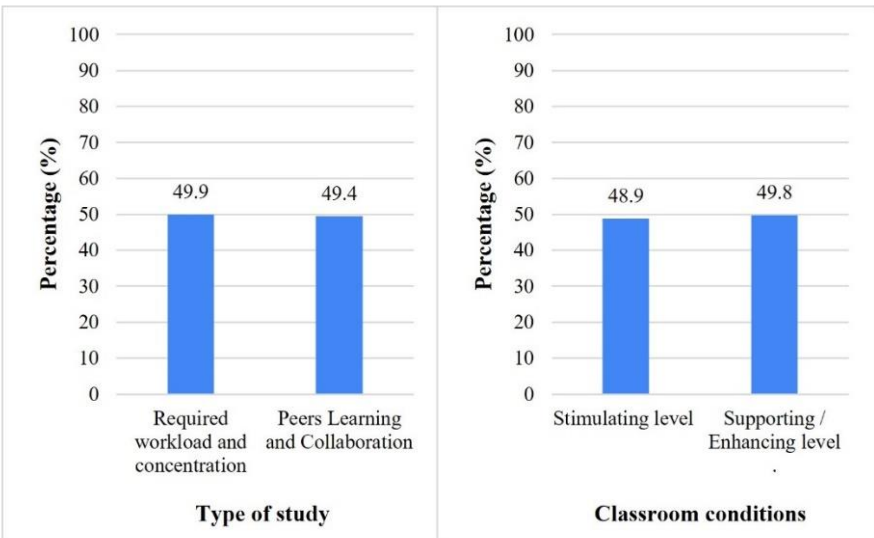

Figure 8. Students' self-assessment of study (architecture) conditions in the surveyed design studios.

The students were tasked with assessing the influence of IEQ in classes on learning productivity and performance within the architecture domain. The impact of IEQ in design studios on learning productivity is believed to be significant by students. However, it is worth noting that a mere 5% of the student population perceives a beneficial impact on their learning productivity due to the prevailing indoor environmental conditions within the building (Figure 9). The participants were queried regarding the measures that could be implemented to enhance the IEQ of the design studios. Most students, precisely, 77%, concur that implementing specific measures would improve the learning process. Furthermore, the students perceive that these methods influence the teachers, with approximately 65% agreeing that they will enhance the instructors' performance. Nevertheless, the students' responses to the effects of the enhancements in classroom environments differ among the various design studios. The data indicate that DS4 achieved a score of 90%, DS1 received a score of 80%, DS3 obtained a score of 76%, and DS2 attained 72%.

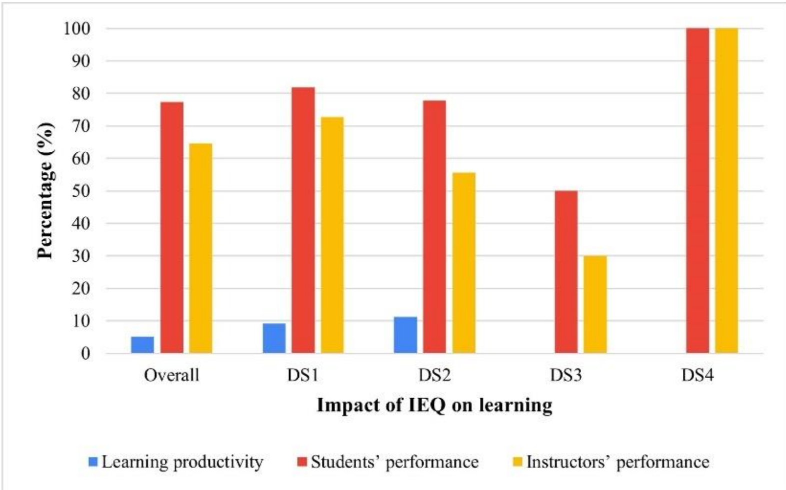

Figure 9. Students' self-assessment of learning quality (productivity and performance) due to IEQ in the surveyed design studios.

In other respects, a significant association exists between students' learning productivity and gender. Furthermore, based on the correlations obtained using the Chi-Square statistical test, as shown in Table 7, it can be concluded that dust within the classroom has the most significant impact on students' productivity.

On the other hand, this study evaluated academic performance using a combination of objective and subjective grading measures. The analysis primarily centered on the comprehensive evaluation of students' performance in the design studios encompassed in the survey. On a scale of 100%, all participants in the course with the same design received an average score of 72.38%. The average scores for DS1, DS2, DS3, and DS4 were 68%, 72.6%, 75.7%, and 73.2%, respectively. Based on the survey findings, a significant majority of students (77.4%) expressed their belief that enhancing the IEQ will improve their academic performance. The students enrolled in DS3 had the greatest concentration level and achieved the highest final grades. The students in DS1 had the lowest concentration level, resulting in the lowest final grades. A positive correlation was shown when examining the self-reported concentration assessment about the average grading outcome for the design studios assessed. This indicates that when the degree of concentration grows, there is a corresponding increase in the course grading (Figure 10).

Table 7. Correlations between students' learning productivity and the internal environment within the surveyed design studios.

Dependent Variable	Independent Variables	Significant Value (According to SPSS Chi-Square Tests)	Association between the Two Variables	
			Yes	No
Learning productivity	Gender	0.033 (<0.05)	√	
	Time spent in the classroom	0.255 (≥0.05)		x
	Classroom air temperature	0.308 (≥0.05)		x
	Air quality	0.261 (≥0.05)		x
	Odors inside the classroom	0.775 (≥0.05)		x
	Dust/dirt conditions	0.012 (<0.05)	√	
	Air movement	0.119 (≥0.05)		x
	Noise levels	0.743 (≥0.05)		x
	Quality of natural daylighting	0.599 (≥0.05)		x
	Quality of artificial lighting	0.094 (≥0.05)		x

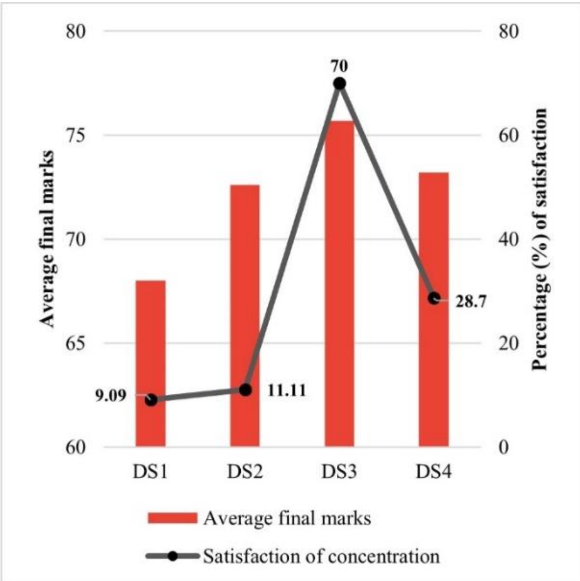

Figure 10. Correlation between level of concentration and grading marks.

3.5. Improvements in IEQ Conditions in Classrooms

From the students' standpoint, multiple factors contribute to improving IEQ within architecture design studios. A sizable majority of students (74.4%) who agreed on this issue indicated that improving air quality is a top priority. The second component pertained to improving visual comfort, with a reported agreement proportion of 74%. Most students, namely, 73.3%, agreed on the need to enhance temperature conditions within the educational environment. This was closely followed by concerns regarding sound comfort and the ventilation system, with agreement rates of 71.6% and 69.6%, respectively (Figure 11).

The results of this study support the idea that classroom environment improvements should be customized to suit the specific circumstances of each classroom. A modest 83% of the student sample indicated a need for air conditioning in the design studios in the evaluation by students, which used a five-point Likert scale ranging from strongly disagree to strongly agree. This resulted in an average score of 4.14 out of 5. Additional significant concerns involved the implementation of window filters as a preventive measure against dust infiltration, with an average rating of 3.97, as well as the regulation of cleaning standards, with an average rating of 3.92. Table 8 illustrates the different dimensions of enhancements observed in the design studios.

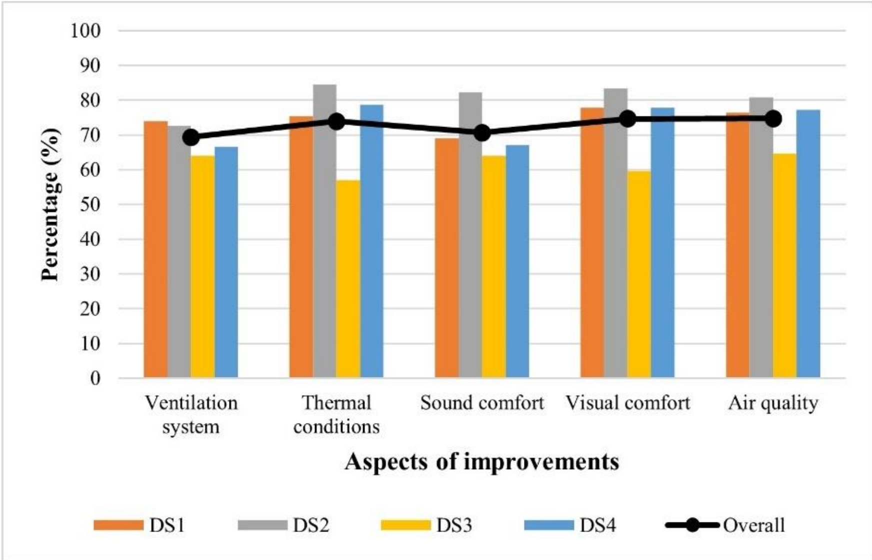

Figure 11. Students' agreement to improve IEQ in the surveyed design studios.

Table 8. Aspects of improvements to IEQ according to students' perspectives.

Aspects of Improvements	Improvements to IEQ	Mean (Out of 5)	SD	% of Agreement	Overall Agreement Mean	Overall Agreement %
Ventilation system	Using air fans	2.89	1.07	57.8	3.48	69.6
	Using air conditioning	4.14	0.82	82.8		
	Keeping the hall windows and door open to enhance air movement	3.41	1.12	68.2		
Thermal conditions	Adding interior curtains for windows	3.65	0.98	73.0	3.67	73.3
	Adding exterior sun breakers for windows	3.68	1.03	73.6		
Sound comfort	Keeping the hall windows and doors closed to enhance sound insulation	3.35	1.18	67.0	3.58	71.6
	Enhancing the quality of air fans	3.81	0.88	76.2		
Visual comfort	Changing the paint color	3.59	1.17	71.8	3.70	74.0
	Accurate illuminance level of artificial lighting	3.88	0.99	77.6		
	Adding exterior sun breakers for windows	3.68	1.03	73.6		
	Adding interior curtains for windows	3.65	0.98	73.0		
Air quality	Adding filters for windows to prevent the entry of dust	3.97	0.76	79.4	3.72	74.4
	Limitation on classroom capacity	3.27	0.99	65.4		
	Control the cleanliness	3.92	0.83	78.4		

4. Discussion

In terms of students' satisfaction with IEQ, our findings are consistent with the research conducted by Haverinen-Shaughnessy and Shaughnessy [42], as well as Ranjbar [41], which suggest that students may experience adverse effects due to the thermal conditions within indoor spaces, thereby impacting their overall satisfaction with the indoor environment. This discrepancy can be attributed to the recorded air temperature in the classroom, which exhibited a mean value of 19.35 °C. This measurement falls below the comfort range (19.4 °C–27.7 °C) stipulated by ASHRAE. Furthermore, the findings corroborated prior research, indicating that ventilation and air circulation have a beneficial effect on the satisfaction of students. This is because elevated levels of carbon dioxide and unpleasant odors tend to arise in inadequately ventilated spaces [43,44,46–48].

The recorded average lighting intensity levels in the surveyed classrooms, measured at 240 lux, do not meet the established standards outlined by ASHRAE (500–1000 lux). These findings, which indicate no significant correlations, are consistent with the research conducted by Ja'en et al. [49], as their research suggests that the presence of flickering at levels below 100 lux can have negative impacts on students.

Regarding health and well-being symptoms, our findings corroborated the outcomes of prior research. According to Takaoka et al. [29], various risk factors are linked to asthma and respiratory symptoms in educational buildings, including elevated carbon dioxide levels and uncomfortable air temperature and humidity levels. Furthermore, our survey results agreed with the findings of Cedeño-Laurent et al. [37], indicating a positive link between the quality of light and the prevalence of eye irritation problems. In their study, Wålinder et al. [62] establish a correlation between noise exposure and headache and fatigue symptoms in a sample of students. According to Bluyssen et al. [30], there is a correlation between dry skin and low relative humidity. Furthermore, the findings of Daisey et al. [63] demonstrate that poor indoor air quality (IAQ) can cause symptoms like headaches and fatigue.

The outcomes of academic performance showed a positive link when analyzing the self-reported concentration assessment in relation to the average grade outcome for the examined design studios. This suggests that when the level of focus intensifies with a satisfied IEQ, there is a concomitant augmentation in the grading of the course. These results are consistent with the discoveries of previous studies. Pulimeno et al. [20] observed a strong positive association between concentration levels and academic achievement. Hutter et al. [64] examined students in Austria and observed decreased cognitive function in classrooms with high carbon dioxide concentration levels. Gaihre et al. [65] established a positive association between carbon dioxide concentrations in educational institutions in Scotland and decreased average yearly attendance rates and diminished individual academic achievement. Moreover, a study conducted by Twardella et al. [66] in Germany revealed that elevated carbon dioxide levels were linked to a decline in students' short-term attention performance inside classroom environments. It is noteworthy to emphasize that the present investigation identified variations in the prevalence of illnesses based on gender. This discovery is consistent with the findings reported by Fouladi-Fard [67]. Yet, enhancements to the classroom environment must be tailored to accommodate the unique circumstances of individual classrooms.

No link was found after examining the relationship between the final total grading and the self-reported level of stimulation and support in the surveyed classroom setting (see Figure 12). Acknowledging that stimulating environments within design studios can significantly influence the degree of creativity and originality in architectural design is essential. The criteria in question were outside the scope of this study. Thus, additional research is warranted to explore the potential association between critical design criteria, such as creativity and innovation, the stimulating environment, and IEQ within design studios. Additionally, this research investigation indicated a modestly comparable influence of ambient temperature on academic achievement within the design studios. However, numerous studies have established a correlation between IEQ characteristics and both health symptoms and learning performance within the classroom setting. Norbäck and Nordström [68] discovered a positive correlation between elevated temperatures and throat and ocular symptoms. According to a study by Wargocki and Wyon [69], there is a correlation between temperature and academic performance. The researchers discovered that a decrease in classroom temperature resulted in a considerable improvement in students' performance.

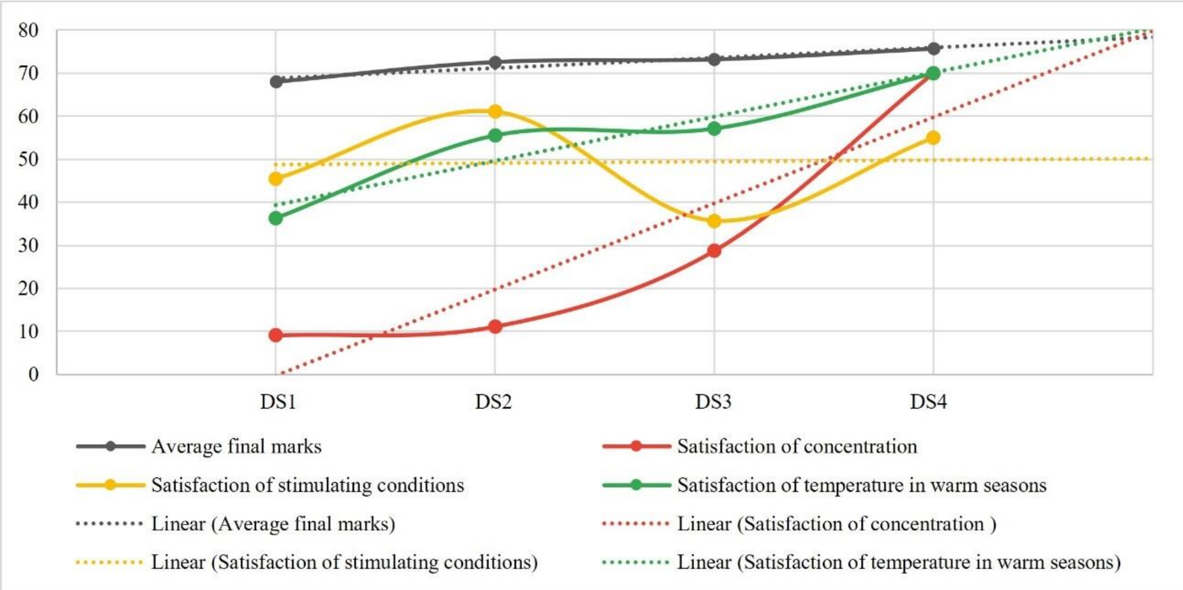

Figure 12. Correlations between average grading final mark, level of concentration, level of stimulating conditions, and temperature in the surveyed design studios.

It is essential to acknowledge that while the ventilation rate and thermal conditions might provide some insight into IEQ [49], a more thorough evaluation may need the use of precise and objective measurements of indoor air pollutants, such as volatile organic compounds (VOCs) and formaldehyde.

5. Conclusions

Architecture is commonly seen as a rigorous academic pursuit among students and a demanding scholarly research area. The design studio environment has unique characteristics that differentiate it from conventional classroom settings. It necessitates a substantial extra workload, focused attention, and proficient abilities. As the estimated duration of students' presence in the design studio is approximately three hours per session, it increases the impact of IEQ on students' overall well-being and academic performance. Poor air quality, extreme temperatures, inadequate lighting, and noise levels contribute to this influence.

This investigation was conducted from October to February in the autumn semester of 2022–2023. The research aims were pursued using three distinct methodologies: instrumental measures, human measurements, and the evaluation of students' academic performance. This study's findings revealed a notable deficiency in the degree of satisfaction with the overall comfort experienced in design studios. The observed values for the five components of IEQ varied between 2.18 and 2.62. A minority of students, specifically, less than 45%, indicated pleasure with the noise level, whereas a majority of 60% expressed contentment with the quality of lighting. Various crucial factors, including air temperature, dust and filth conditions, air circulation, and olfactory conditions, determined the level of comfort experienced by students in the studio environment.

The findings indicated that the most often reported symptoms weekly during the autumn semester in the design studios were low concentration (24.8%), dry skin (16.5%), stuffy nose (12.4%), and headache (10%). A positive correlation was seen when examining the self-reported concentration assessment concerning the average grading outcome for the evaluated design studios. According to the course grades, this discovery suggests a correlation between academic success and level of attention. Several aspects can contribute to these outcomes and should be considered in the educational environment. These factors include the optimization of air quality, the enhancement of visual comfort, and an improvement in temperature conditions.

To optimize the educational experience and improve student performance within architecture design studios, it is strongly advised to:

(a) Increase the lighting intensity;
(b) Enhance ventilation rates, either naturally, which can be achieved by keeping windows open during the summer season, or artificially, which can be used during the winter months;
(c) Allow students a 10-min break every hour while ensuring the doors and windows remain open during this interval.

It is imperative to acknowledge that the measurement assessment conducted in this study was performed during the heating season, notably, in the winter months. Further research should be conducted throughout the warmer months. In addition, it is imperative to acknowledge that while the ventilation rate and thermal conditions may provide some insight into IEQ, a thorough evaluation may necessitate precise and impartial measurements of indoor air pollutants, such as VOCs and formaldehyde. As a result, it is feasible to discern and give precedence to enhancements specific to each classroom in a suitable manner. Furthermore, it is imperative to conduct post-occupancy evaluations to incorporate user viewpoints since they provide invaluable insights that cannot be solely extracted from physical inspections.

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Informed Consent Statement: Informed consent was obtained from all subjects involved in this study.

Data Availability Statement: The data collected in this study are available in this article (results and discussion).

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

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