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Cross-tabulation Analysis of the Impact of University Students on IEQ Factors

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ABSTRACT

This study investigates the impact of indoor environmental quality (IEQ) factors—thermal environment, indoor air quality, lighting, and acoustics—on university students' satisfaction. Conducted at University College London (UCL), the research employs a mixed-method approach, combining subjective assessments through questionnaires with objective measurements of environmental conditions. The findings reveal that students exhibit higher satisfaction with cooler indoor environments during spring, with thermal comfort significantly influencing their overall satisfaction. Indoor air quality, particularly air movement and relative humidity, also plays a crucial role, with students preferring neutral conditions. Acoustic and lighting environments further impact satisfaction, with a notable preference for brighter lighting despite overall contentment with current levels. The study underscores the complex interplay between various IEQ factors and their collective influence on students' well-being, highlighting the need for tailored environmental designs in educational settings to enhance student satisfaction.

1. Introduction

Urban occupants spend approximately 85% to 90% of their time indoors. According to Jiang *et al.,* [1], the majority of contemporary students devote approximately 30–50 percent of their time to educational activities. It is imperative to create and furnish an interior environment that is conducive to their needs [2,3]. The design of educational buildings is frequently approached by architects and engineers in a manner that is similar to that of other public constructions [4]. Research suggests that students in both air-conditioned and free-running classrooms demonstrate substantial dissatisfaction with the current classroom environment [5-7]. This trend is observed in both developed and developing countries [8]. In a steady-state office environment, the reference criteria for evaluating students' comfort were initially established, with the assumption that occupant density, clothing

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insulation level, and activity levels would remain constant [9]. The utilisation of workstations, laptops, and other portable electronic devices is another potential contributor to the elevated temperature in the classroom. The presence of these factors results in a discrepancy between the planned and actual indoor environments and inadequate indoor air quality (IAQ) [10].

Colleges and universities offer an exceptional environment for students to establish connections with individuals from around the world, acquire new knowledge, and advance their careers. The capacity of students to retain and implement new information may be influenced by the character of the tangible environment in which they learn [11]. The quality of classroom facilities has the potential to impact student performance; however, it is uncertain whether this effect is consistent across all student demographics, despite the growing body of evidence linking the physical environment, relevant sociodemographic factors, and educational outcomes [12]. Additionally, there is a wealth of evidence that indicates that students' academic performance and attentiveness are negatively impacted by their thermal dissatisfaction in a classroom [13]. Universities are more susceptible to environmental issues than other category buildings as a result of persistent budget reductions that result in inadequate facility management and maintenance [14]. It would be unwise to disregard the impact of these integrated settings on students' academic performance. The academic performance of students has been individually examined in relation to the thermal environment [15,16], visual environment [17,18], auditory environment [19], and indoor air quality [20]. In the 1990s, it was determined that no single factor dominated the concerns regarding thermal perception and its influencing factors [21]. Research suggests that a favourable interior environment may improve health, despite the complex interactions among numerous IEQ components [22,23]. Clausen *et al.,* [24] conducted a study that demonstrated the significant impact of thermal comfort, indoor air quality, and auditory and visual conditions on the environmental tolerance and work performance of occupants. Many studies have shown that university students' satisfaction with the indoor environment is affected by the thermal environment [25-28], light environment [29,30] and sound environment [31,32], but few studies have focused on the cross-influence of each of these IEQ factors on university students' satisfaction. Therefore, it is necessary to focus on this topic and conduct research.

2. Methodology

2.1 Study Area and Climate Conditions

This research selects University College London (UCL) as the experimental site, located in London. London is the city with the most students in the United Kingdom, as well as the city with the highest degree of internationalisation. London features a temperate oceanic climate, located in the United Kingdom (51°30 N, 0°39 W). This gives the city cool winters, warm summers. In London, the annual highest temperature in the summer was 37.2℃ in 2023, while in the winter it was -5.2℃. Table 1 reports that the hottest month of the year is July, with an average high temperature of 24.7℃ and low of 14.8℃. The coldest month of the year is January, with an average high temperature of 7.3℃ and low of 1.8℃. In addition, there are frequent precipitation and cloudy days all year round due to the characteristics of the temperate oceanic climate. During the months from September to December of investigation in 2023, the average precipitation reached high level, the highest value was 92.8 mm, happened in October, which resulted in the average daily sunlight hours from September to December was lower than other periods all year round.

2.2 Investigation Procedure

Prior to the implementation of experimental measures, agreement from both instructors and students needs to be secured in accordance with the preliminary questionnaire design. The first step is to obtain the lecturers' permission in person. For instance, A is the classroom designated for investigation. One week before, the lecturer will be informed of the experiment's participants, the subjects of investigation, and other relevant details, as per the timetable. The lecturer beforehand alerted the students and confirmed that each participant was told via email about their involvement in the investigation. Ten minutes before the commencement of class, reiterate the objective and methodology of the experiment to the students, ensuring that all participants understand the survey participation. The ensuing data collection is bifurcated into two segments, the initial segment comprising the subjective information gathered from the questionnaire, which encompasses participants' demographic details and subjective assessments of the thermal environment, indoor air quality, lighting conditions, and acoustic environment. The second portion comprises interior objective measurement data, including temperature environment, indoor air quality, lighting conditions, and acoustic environment. Ultimately, the outcomes and data analysis are provided.

2.3 Questionnaire Design

A questionnaire was designed based on the previous studies [33-35] for the subjective assessment of thermal environment, which includes indoor temperature evaluation, relative humidity evaluation. Indoor temperature evaluation includes indoor temperature sensation, indoor temperature preference, and indoor temperature satisfaction of subjects, where indoor temperature sensation employs ASHRAE 7-point scales (-3, -2, -1, 0, 1, 2, 3 indicate cold, cool, slightly cool, neutral, slightly warm, warm, and hot, respectively). Regarding relative humidity, relative humidity preference, relative humidity sensation and relative humidity satisfaction of subjects also based on the same standard. The three factors of indoor air quality, acoustic environment, and lighting environment are also evaluated by the subjects’ sensation, preference and satisfaction based on studies [36-38]. Students’ evaluations of indoor air quality and air movement are the two aspects of indoor air quality factors.

3. Results

3.1 Thermal Perception Cross-analysis for University Students

In order to investigate the relationship among university students’ thermal perception, thermal satisfaction, and thermal preference, this study conducted a cross-tabulation analysis on this factor. Table 1 and Table 2 are cross-tabulation statistics analyses of thermal perception, thermal preference, and thermal satisfaction. Figure 1 depicts a graphical representation of the outflow ratio data from Table 1 and Table 2. According to Figure 1, in the spring, when the thermal perception vote is neutral (TSV=0), the percentages of university students’ thermal satisfaction votes of 4 (dissatisfaction) and 5 (very dissatisfaction) are 5.7% and 0%, and the percentages of university students' thermal preference votes of 1 (cooler) and 3 (warmer) are 8.0% and 6.0%, respectively. When the thermal perception vote is cold (TSV = -1), the percentages of university students’ thermal satisfaction votes of 4 (dissatisfaction) and 5 (very dissatisfaction) are 2.0% and 0%, respectively, and the percentages of university students’ thermal preference votes of 1 (cooler) and 3 (warmer) are 4.1% and 28.6%, respectively, indicating that university students in this survey prefer a cooler thermal neutral temperature.

Table 1
Crosstabulation of thermal perception vote and thermal preference vote of participants

			Thermal preference vote			Total
			1	2	3	
Thermal perception vote (7 point)	-3	Count	0	1	5	6
		% within thermal perception vote	0.0%	16.7%	83.3%	100.0%
		% within thermal preference vote	0.0%	0.7%	13.2%	2.4%
		% of Total	0.0%	0.4%	2.0%	2.4%
	-2	Count	2	7	13	22
		% within thermal perception vote	9.1%	31.8%	59.1%	100%
		% within thermal preference vote	2.6%	5.1%	34.2%	8.8%
		% of Total	0.8%	2.8%	5.2%	8.8%
	-1	Count	2	33	14	49
		% within thermal perception vote	4.1%	67.3%	28.6%	100%
		% within thermal preference vote	2.6%	24.3%	36.8%	19.5%
		% of Total	0.8%	13.1%	5.6%	19.5%
	0	Count	7	75	6	88
		% within thermal perception vote	8.0%	85.2%	6.8%	100%
		% within thermal preference vote	9.1%	55.1%	15.8%	35.1%
		% of Total	2.8%	29.9%	2.4%	35.1%
	+1	Count	34	15	0	49
		% within thermal perception vote	69.4%	30.6%	0.0%	100%
		% within thermal preference vote	44.2%	11.0%	0.0%	19.5%
		% of Total	13.5%	6.0%	0.0%	19.5%
	+2	Count	22	4	0	26
		% within thermal perception vote	84.6%	15.4%	0.0%	100.0%
		% within thermal preference vote	28.6%	2.9%	0.0%	10.4%
		% of Total	8.8%	1.6%	0.0%	10.4%
	+3	Count	10	1	0	11
		% within thermal perception vote	90.9%	9.1%	0.0%	100.0%
		% within thermal preference vote	13.0%	0.7%	0.0%	4.4%
		% of Total	4.0%	0.4%	0.0%	4.4%

Table 1
Continued

Total	Count	77	136	38	251
	% within thermal perception vote	30.7%	54.2%	15.1%	100.0%
	% within thermal preference vote	100.0%	100.0%	100.0%	100.0%
	% of Total	30.7%	54.2%	15.1%	100.0%

Note. -3-Cold; -2-Cool; -1-Slightly cool; 0-Neutral; +1-Slightly warm; +2-Warm; +3-Hot; 1-Cooler; 2-No change; 3-Warmer.

Table 2
Crosstabulation of thermal perception vote and thermal satisfaction vote of participants

			Thermal satisfaction vote					Total
			1	2	3	4	5	
Thermal perception vote (7 point)	-3	Count	0	2	1	3	0	6
		% within thermal perception vote	0.0%	33.3%	16.7%	50.0%	0.0%	100.0%
		% within thermal satisfaction vote	0.0%	1.9%	1.3%	8.8%	0.0%	2.4%
		% of Total	0.0%	0.8%	0.4%	1.2%	0.0%	2.4%
	-2	Count	2	8	9	3	0	22
		% within thermal perception vote	9.1%	36.4%	40.9%	13.6%	0.0%	100.0%
		% within thermal satisfaction vote	5.9%	7.8%	12.0%	8.8%	0.0%	8.8%
		% of Total	0.8%	3.2%	3.6%	1.2%	0.0%	8.8%
	-1	Count	12	21	15	1	0	49
		% within thermal perception vote	24.5%	42.9%	30.6%	2.0%	0.0%	100.0%
		% within thermal satisfaction vote	35.3%	20.4%	20.0%	2.9%	0.0%	19.5%
		% of Total	4.8%	8.4%	6.0%	0.4%	0.0%	19.5%
	0	Count	11	54	18	5	0	88
		% within thermal perception vote	12.5%	61.4%	20.5%	5.7%	0.0%	100.0%
		% within thermal satisfaction vote	32.4%	52.4%	24.0%	14.7%	0.0%	35.1%
		% of Total	4.4%	21.5%	7.2%	2.0%	0.0%	35.1%
	+1	Count	7	13	22	7	0	49
		% within thermal perception vote	14.3%	26.5%	44.9%	14.3%	0.0%	100.0%
		% within thermal satisfaction vote	20.6%	12.6%	29.3%	20.6%	0.0%	19.5%
		% of Total	2.8%	5.2%	8.8%	2.8%	0.0%	19.5%
	+2	Count	1	5	7	11	2	26
		% within thermal perception vote	3.8%	19.2%	26.9%	42.3%	7.7%	100.0%
		% within thermal satisfaction vote	2.9%	4.9%	9.3%	32.4%	40.0%	10.4%
		% of Total	0.4%	2.0%	2.8%	4.4%	0.8%	10.4%
	+3	Count	1	0	3	4	3	11
		% within thermal perception vote	9.1%	0.0%	27.3%	36.4%	27.3%	100.0%
		% within thermal satisfaction vote	2.9%	0.0%	4.0%	11.8%	60.0%	4.4%
		% of Total	0.4%	0.0%	1.2%	1.6%	1.2%	4.4%

Table 2
Continued

Total	Count	34	103	75	34	5	251
	% within thermal perception vote	13.5%	41.0%	29.9%	13.5%	2.0%	100.0%
	% within thermal satisfaction vote	100.0 %	100.0 %	100.0 %	100.0 %	100. 0%	100.0%
	% of Total	13.5%	41.0%	29.9%	13.5%	2.0%	100.0%

Note. -3-Cold; -2-Cool; -1-Slightly cool; 0-Neutral; +1-Slightly warm; +2-Warm; +3-Hot; 1-Very satisfaction; 2-Satisfaction; 3-Neutral; 4-Dissatisfaction; 5-Very dissatisfaction.

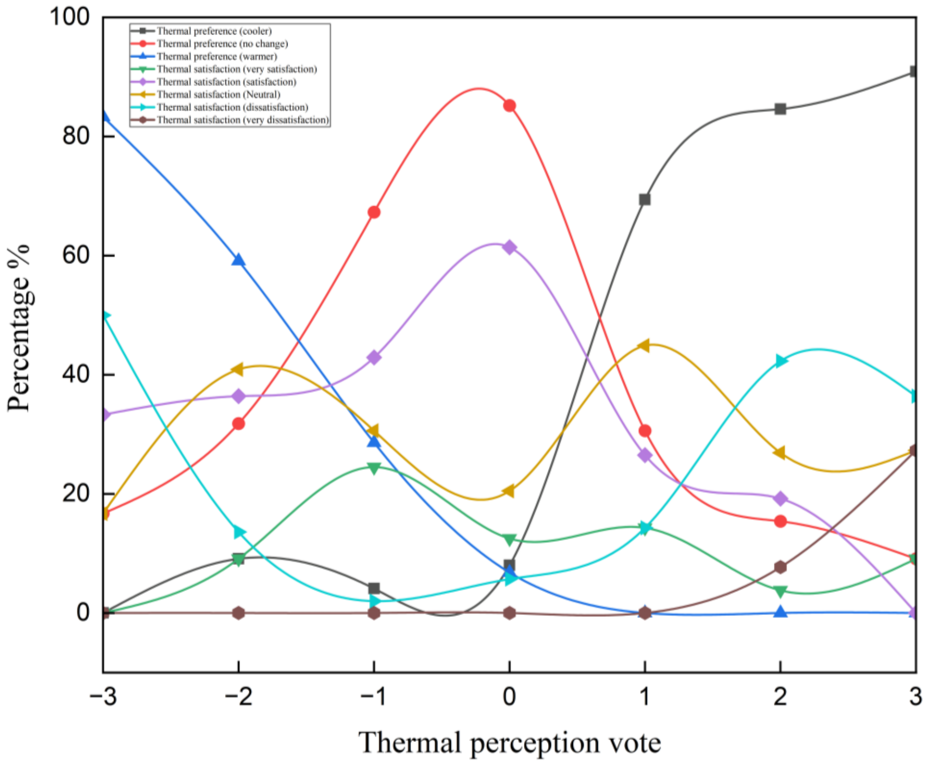

Fig. 1. The relationship between university students' thermal perception, thermal satisfaction, and thermal preference

Table 3 shows the cross-tabulation inflow ratios of the tested university students' thermal sensation votes, thermal satisfaction votes, and thermal preference votes. The value of the operating temperature t_{op} in the table is the average value, that is, the average value of the operating temperature of the indoor environment where the university student samples are located when voting for each scale of -3 ~ +3. It can be seen from Table 4 that when TSV = -1, in the spring, the proportion of university students' thermal satisfaction votes is 1 (Very satisfaction), 24.5%, 2 (Satisfaction), 42.9%, 3 (Neutral), 30.6, Thus, when TSV = -1, the proportion of the thermal satisfaction vote of university students is 98%, and the proportion of the thermal preference vote is 2 (No change) is 67.3. When TSV = 0, the percentages of thermal satisfaction votes (1, 2, 3) and thermal preference votes (2) are 94.3% and 85.2%, respectively. When TSV = +1, the proportions of thermal satisfaction votes (1,2,3) and thermal preference votes (2) are 85.7% and 30.6% respectively, which means that in the thermal comfort range (-1≤ TSV ≤ +1), university students in spring overall have higher satisfaction with indoor cold environment than with an indoor hot environment. In the colder range (-2 ≤ TSV ≤ -3), 13.6% and 50% voted for dissatisfaction with their thermal environment, respectively, and in the thermal preference vote, when TSV = -3, 83.3% of the students voted for a warmer environment. In the warmer range (+2 ≤ TSV ≤ +3), 50% and 63.7% of the votes were dissatisfied with the thermal environment, which shows that the students in this survey are more satisfied with the colder environment than the hotter environment. Generally speaking, university students are more satisfied with the cold indoor environment than the hot indoor environment in the spring.

Table 3
Crosstabulation of thermal perception, thermal satisfaction, and thermal preference votes of spring participants

Thermal perception	Spring								
	t_o (℃)	Thermal satisfaction (%)					Thermal preference (%)		
		1	2	3	4	5	1	2	3
-3	21.4	0.0	33.3	16.7	50.0	0.0	0.0	16.7	83.3
-2	21.7	9.1	36.4	40.9	13.6	0.0	9.1	31.8	59.1
-1	22.1	24.5	42.9	30.6	2.0	0.0	4.1	67.3	28.6
0	22.9	12.5	61.4	20.5	5.7	0.0	8.0	85.2	6.8
+1	23.3	14.3	26.5	44.9	14.3	0.0	69.4	30.6	0.0
+2	24.9	3.8	19.2	26.9	42.3	7.7	84.6	15.4	0.0
+3	26.9	9.1	0.0	27.3	36.4	27.3	90.9	9.1	0.0

Note. -3-Cold; -2-Cool; -1-Slightly cool; 0-Neutral; +1-Slightly warm; +2-Warm; +3-Hot; 1-Very satisfaction; 2-Satisfaction; 3-Neutral; 4-Dissatisfaction; 5-Very dissatisfaction; 1-Cooler; 2-No change; 3-Warmer; t_o - Operative temperature

Numerous studies have demonstrated that thermal perception, thermal preference, and thermal satisfaction are not synchronised. Comparing the results of numerous field studies, Su *et al.,* [39] discovered that individuals living in hot regions prefer an environment that is slightly colder than neutral, while those living in frigid regions prefer an environment that is slightly warmer than neutral. The same research results also found by Damiati *et al.,* [40] and Rijal *et al.,* [41]. In this investigation, university students preferred the cold indoor environment during the spring. This is primarily due to London's relatively high latitude, but due to its temperate maritime climate, the temperature difference between the four seasons is not large, the outdoor temperature difference in spring is also relatively small, and the humidity of the climate has an effect on the thermal sensitivity of university students who have lived in London for an extended period of time. The thermal comfort zone determined by this investigation is therefore colder than the neutral environment.

3.2 The Perception of Indoor Air of University Students

3.2.1 The perception of indoor air quality

Table 4 displays the results of a cross-tabulation analysis of the perception, satisfaction, and preference of university students regarding the indoor air quality in the spring. The data in the table is plotted by stacked histograms in Figures 2 and 3. In the evaluation of the relationship between indoor air quality perception and air quality satisfaction, in satisfaction vote level 1 (Very satisfied), 25% and 12.5% of participants consider the indoor air quality to be "Fresh" and "Very fresh", respectively. However, in level 2 (Satisfied), nobody voted "Fresh", 71.6% of level 2 (Satisfied) respondents thought their indoor air quality was "Neutral". In addition, 100% of those who voted level 5 (Very dissatisfaction) believed the indoor air to be "Very stuffy". Regarding the relationship between indoor air quality perception and preference, at voting level 1 (stuffier of indoor air quality preference), 100% of people think that indoor air quality is "Neutral". In voting level 2 (No change of indoor air quality preference), 65% of people voted for "Neutral", which is also the highest indoor air quality perception option in this voting level; 3.6% and 23.8% respectively, voted for “Very fresh” and “Fresh”. However, 6.0% and 1.2% of the votes for “Stuffy” and “Very stuffy”, respectively. At voting level 3 (Fresher of indoor air quality preference), the option with the most votes was “Stuffy” at 45.8%, followed by “Neutral” at 43.4%, “Fresh” at 7.2% and “Very stuffy” at 3.6%.

Table 4
Crosstabulation of indoor air quality perception, indoor air satisfaction, and indoor air preference votes of spring participants

Indoor air quality perception	Spring							
	Indoor air quality satisfaction (%)					Indoor air quality preference (%)		
	1	2	3	4	5	1	2	3
1	8.3	0.0	0.0	14.7	0.0	0.0	1.2	3.6
2	4.2	6.9	51.1	76.5	100	0.0	6.0	45.8
3	50.0	71.6	45.6	5.9	0.0	100	65.5	43.4
4	25.0	21.6	3.3	2.9	0.0	0.0	23.8	7.2
5	12.5	0.0	0.0	0.0	0.0	0.0	3.6	0.0
Total	100	100	100	100	100	100	100	100

Note. 1-Very stuffy; 2-Stuffy; 3-Neutral; 4-Fresh; 5-Very fresh; 1-Very satisfaction; 2-Satisfaction; 3-Neutral; 4-Dissatisfaction; 5-Very dissatisfaction; 1-Stuffier; 2-No change; 3-Fresher.

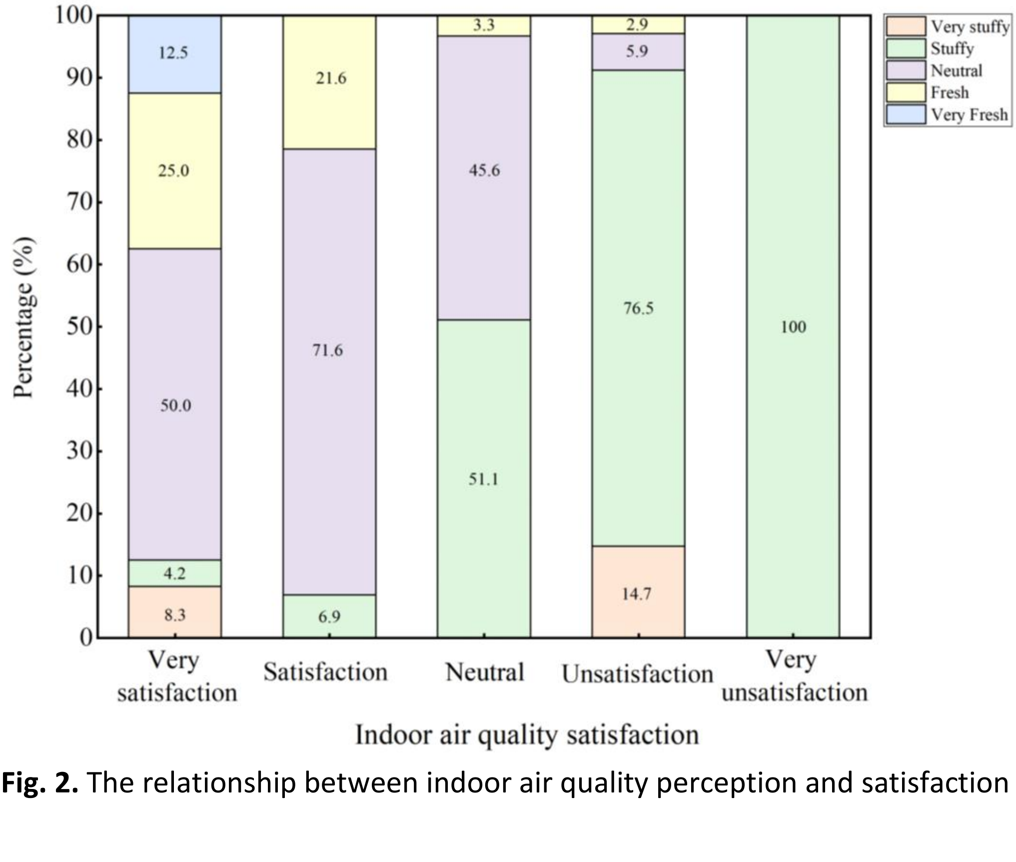

Fig. 2. The relationship between indoor air quality perception and satisfaction

Fig. 3. The relationship between indoor air quality perception and preference

3.2.2 The perception of indoor air movement

The crosstabulation result of university students' perception, satisfaction, and preference for indoor air movement could be identified in Table 5. The cross-analysis histograms of indoor air movement perception and satisfaction, as well as perception and preference, are shown in Figures 4 and 5, respectively. Figure 6 is a cross-analysis stacked histogram of university students' indoor air movement perception, satisfaction, and preference in spring. The wind speed refers to the mean value, specifically the mean value of the indoor wind speed reported by university students across several levels of perceived draughtiness, namely "Very draughty", "Draughty", "Neutral", "Still", and "Very still". Based on the data presented in Figure 6, it can be observed that the cumulative percentages of voting for "Very satisfaction" and "Satisfaction" indicate that the highest percentage of votes is attributed to the level "No change", which amounts to a cumulative percentage of 73.4% (21.0% + 52.4%). Furthermore, within this voting category, the majority of respondents, specifically 58.1%, expressed a preference for the indoor wind speed being "Neutral". Consequently, during the spring season, university students indicate a greater inclination towards the indoor wind speed environment they experienced at that time (equivalent to "No change" of voting level), specifically favouring an average wind speed of 0.05m/s.

Table 5
Crosstabulation of indoor air movement perception, indoor air movement satisfaction, and indoor air movement preference votes of spring participants

Indoor air movement perception	Spring							
	Indoor air movement satisfaction (%)					Indoor air movement preference (%)		
	1	2	3	4	5	1	2	3
1	0.0	0.0	0.0	2.4	0.0	0.0	0.0	0.8
2	17.9	10.0	15.3	4.9	0.0	40.0	13.7	9.0
3	42.9	58.8	38.8	7.3	0.0	20.0	58.1	22.1
4	32.1	30.0	36.7	56.1	0.0	40.0	24.2	49.2
5	7.1	1.3	9.2	29.3	100	0.0	4.0	18.9
Total	100	100	100	100	100	100	100	100

Note. 1-Very draughty; 2-Draughty; 3-Neutral; 4-Still; 5-Very still; 1-Very satisfaction; 2-Satisfaction; 3-Neutral; 4-Dissatisfaction; 5-Very dissatisfaction; 1-Less air movement; 2-No change; 3-More air movement.

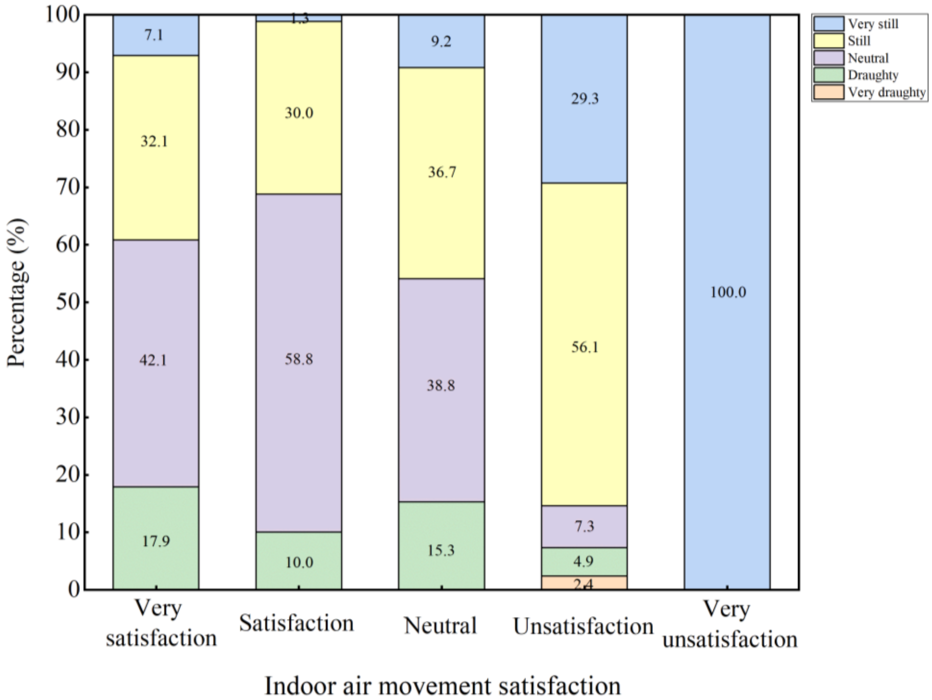

Fig. 4. The relationship between indoor air movement satisfaction and perception

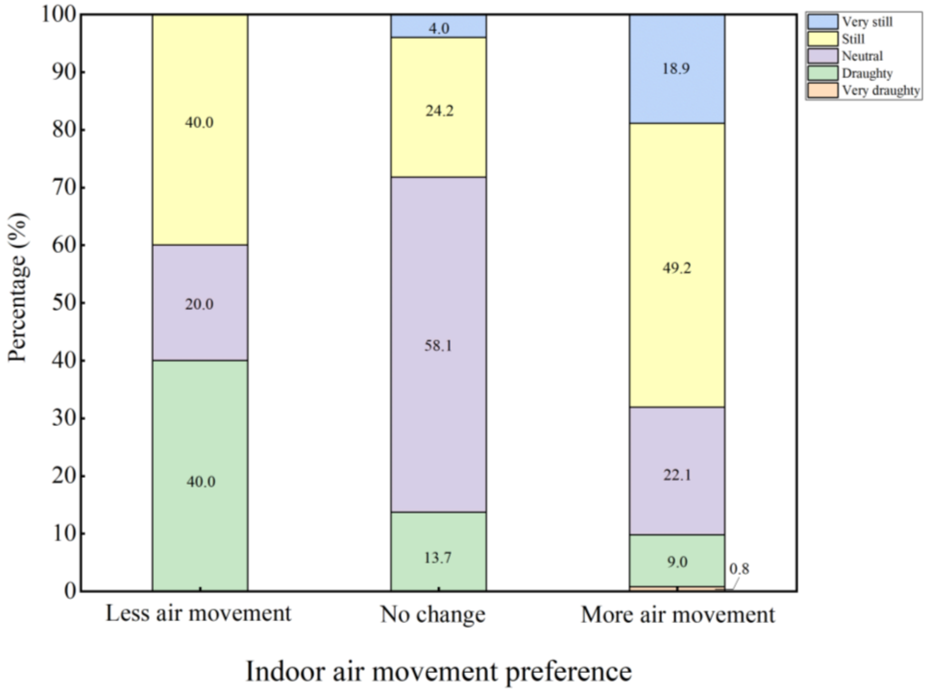

Fig. 5. The relationship between indoor air movement preference and perception

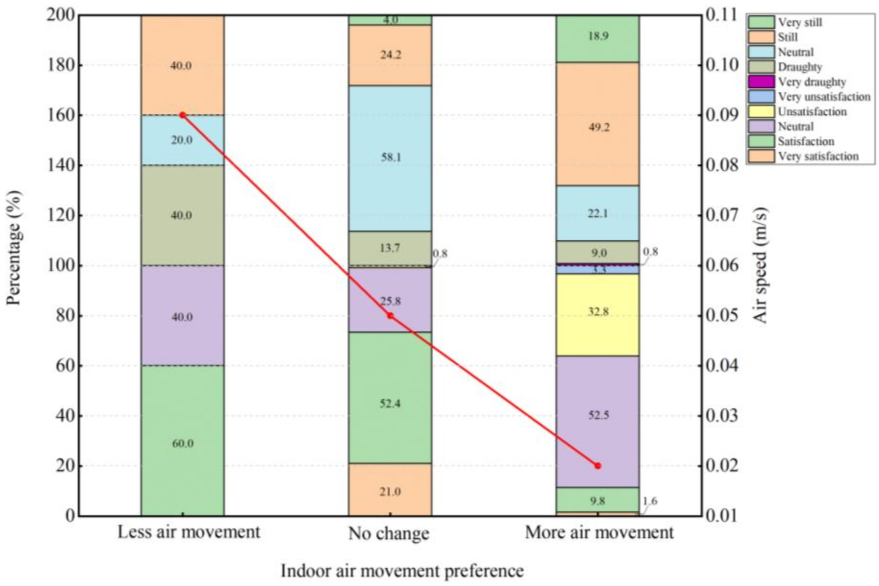

Fig. 6. Cross-analysis of indoor air movement perception, satisfaction and preference

3.3 The Perception of Relative Humidity of University Students

The crosstabulation result of university students' perception, satisfaction, and preference for indoor relative humidity could be identified in Table 6. The cross-analysis histograms of indoor relative humidity perception and satisfaction, as well as perception and preference, are shown in Figures 7 and 8, respectively. Figure 9 is a cross-analysis stacked histogram of university students' indoor relative humidity perception, satisfaction, and preference in spring. The relative humidity is the average value, that is, the average value of the relative humidity of the corresponding university student samples when voting for each level of "Very dry", "Slightly dry", "Neutral", "Slightly moist", and "Very moist". Based on the data presented in Figure 9, it can be observed that the cumulative percentages of voting for "Very satisfaction" and "Satisfaction" indicate that the highest percentage of votes is attributed to the level "No change", which amounts to a cumulative percentage of 66.4% (16.1% + 50.3%). Furthermore, within this voting level, the majority of respondents, specifically 73.1%, expressed a preference for the indoor relative humidity being "Neutral". Consequently, during the spring season, university students indicate a greater inclination towards the indoor relative humidity environment they experienced at that time (equivalent to "No change" of voting level), specifically favouring an average relative humidity of 50.3%.

Table 6
Crosstabulation of indoor relative humidity perception, indoor relative humidity satisfaction, and indoor relative humidity preference votes of spring participants

Relative humidity perception	Spring							
	Relative humidity satisfaction (%)					Relative humidity preference (%)		
	1	2	3	4	5	1	2	3
1	0.0%	1.8%	3.3%	6.7%	2.4%	8.7%	0.5%	8.6%
2	9.4%	14.9%	27.8%	20.0%	19.1%	8.7%	15.0%	48.6%
3	78.1%	70.2%	54.4%	20.0%	62.5%	26.1%	73.1%	28.6%
4	12.5%	12.3%	12.2%	53.3%	14.7%	52.2%	10.4%	14.3%
5	0.0%	0.9%	2.2%	0.0%	1.2%	4.3%	1.0%	0.0%
Total	100	100	100	100	100	100	100	100

Note. 1-Very dry; 2-Slightly dry; 3-Neutral; 4-Slightly moist; 5-Very moist; 1-Very satisfaction; 2-Satisfaction; 3-Neutral; 4-Dissatisfaction; 5-Very dissatisfaction; 1-Drier; 2-No change; 3-Moister.

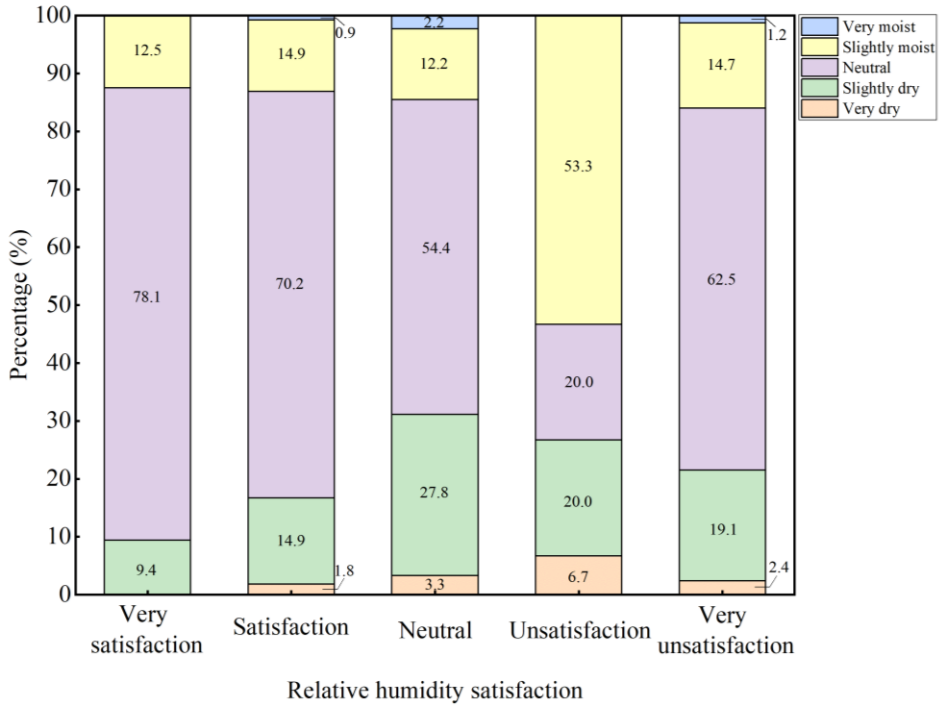

Fig. 7. The relationship between relative humidity satisfaction and perception

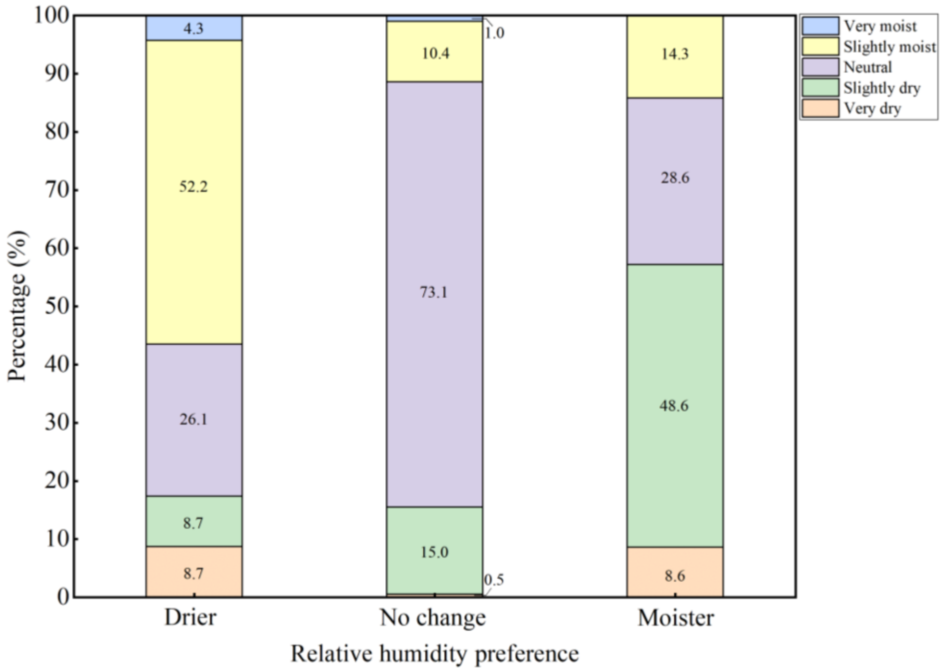

Fig. 8. The relationship between relative humidity preference and perception

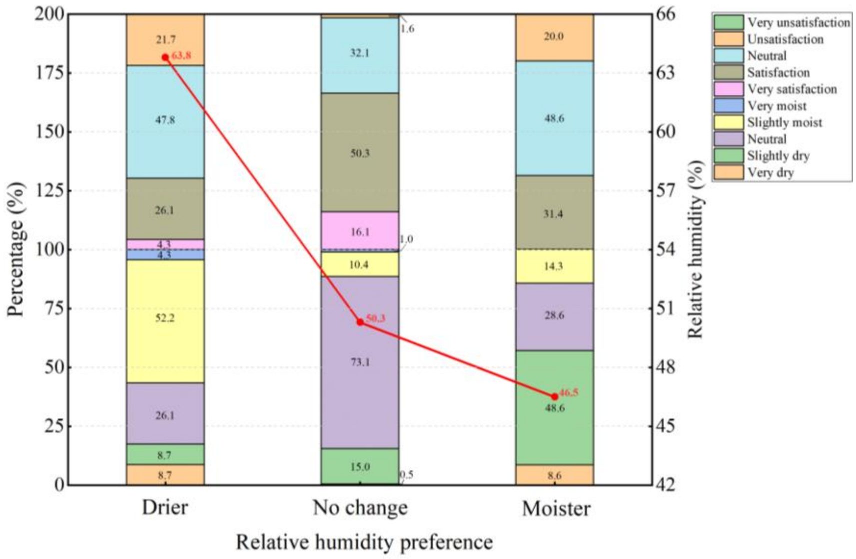

Fig. 9. Cross-analysis of indoor relative humidity perception, satisfaction and preference

3.4 The Perception of Acoustics of University Students

The crosstabulation result of university students' perception, satisfaction, and preference for indoor acoustics could be identified in Table 7. The cross-analysis histograms of indoor acoustics perception and satisfaction, as well as perception and preference, are shown in Figures 10 and 11, respectively. Figure 12 is a cross-analysis stacked histogram of university students' indoor acoustics perception, satisfaction, and preference in spring. The acoustics level is the average value, that is, the average value of the acoustics of the corresponding university student samples when voting for each level of "Very quiet", "Quiet", "Neutral", "Noisy", and "Very noisy". Based on the data presented in Figure 12, it can be observed that the cumulative percentages of voting for "Very satisfaction" and "Satisfaction" indicate that the highest percentage of votes is attributed to the level "No change", which amounts to a cumulative percentage of 81.2 % (17.5 % + 63.7 %). Furthermore, within this voting category, the majority of respondents, specifically 66.9%, expressed a preference for the indoor acoustics being "Neutral". Consequently, during the spring season, university students indicate a greater inclination towards the indoor acoustics environment they experienced at that time (equivalent to "No change" of voting level), specifically favouring an average acoustic level of 57.6dB.

Table 7
Crosstabulation of indoor acoustics perception, acoustics satisfaction, and indoor acoustics preference votes of spring participants

Indoor acoustics perception	Spring							
	Indoor acoustics satisfaction (%)					Indoor acoustics preference (%)		
	1	2	3	4	5	1	2	3
1	3.4	0.8	1.2	0	0.0	8.3	1.2	0.0
2	13.8	26.2	18.5	18.2	0.0	33.3	26.9	10.1
3	75.9	62.3	43.2	18.2	0.0	50.0	66.9	34.2
4	6.9	10.8	37.0	63.6	0.0	8.4	5.0	55.7
5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Total	100	100	100	100	0	100	100	100

Note. 1-Very quiet; 2-Quiet; 3-Neutral; 4-Noisy; 5-Very noisy; 1-Very satisfaction; 2-Satisfaction; 3-Neutral; 4-Dissatisfaction; 5-Very dissatisfaction; 1-Noisier; 2-No change; 3-Quieter.

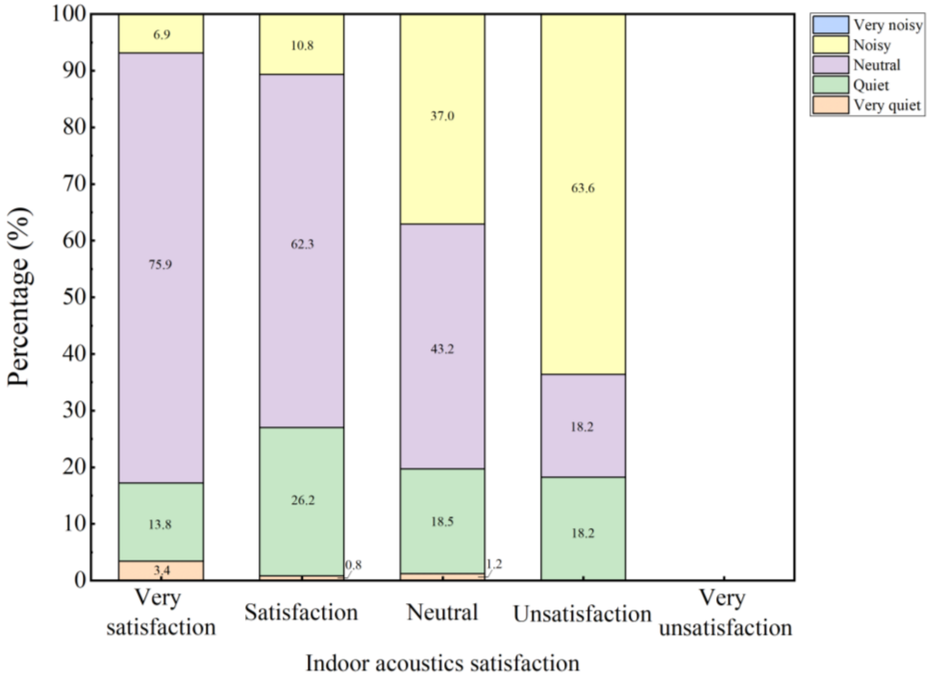

Fig. 10. The relationship between indoor acoustics satisfaction and perception

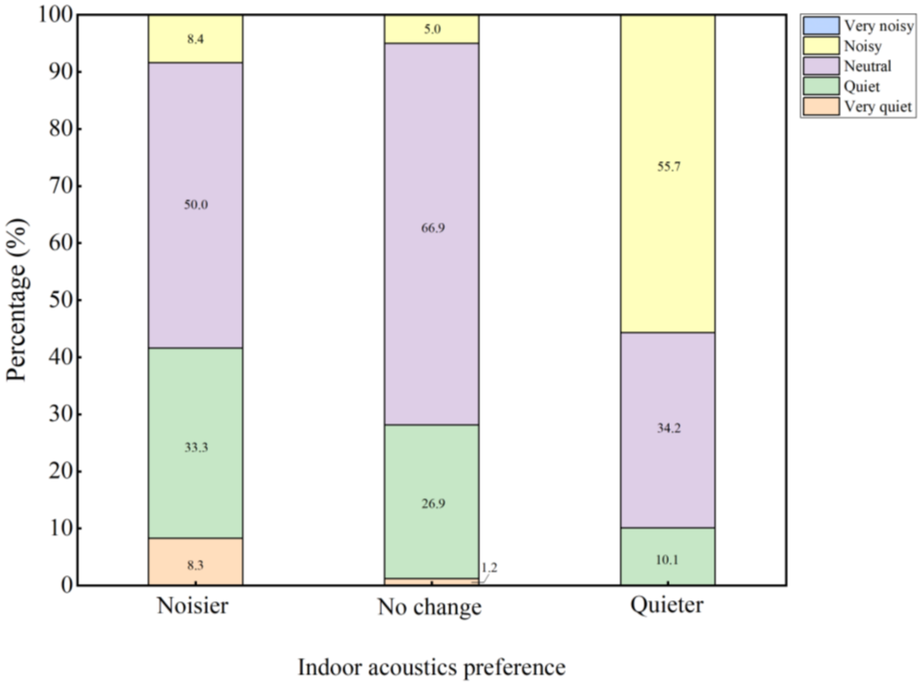

Fig. 11. The relationship between indoor acoustics preference and perception

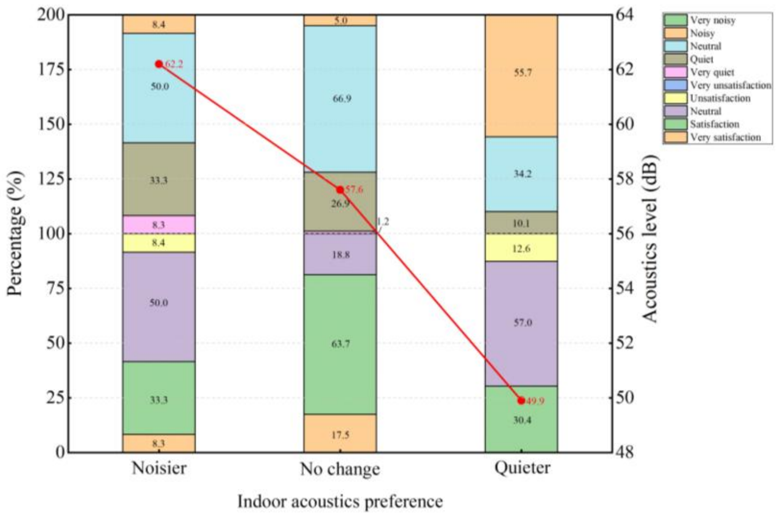

Fig. 12. Cross-analysis of indoor acoustics perception, satisfaction and preference

3.5 The Perception of Lighting of University Students

The crosstabulation result of university students' perception, satisfaction, and preference for indoor lighting could be identified in Table 8. The cross-analysis histograms of indoor lighting perception and satisfaction, as well as perception and preference, are shown in Figures 13 and 14, respectively. Figure 15 is a cross-analysis stacked histogram of university students' indoor lighting perception, satisfaction, and preference in spring. The lighting level is the average value, that is, the average value of the lighting of the corresponding university student samples when voting for each level of "Very dim", "Dim", "Neutral", "Bright", and "Very bright". Based on the data presented in Figure 15, it can be observed that the cumulative percentages of voting for "Very satisfaction" and "Satisfaction" indicate that the highest percentage of votes is attributed to the level "No change", which amounts to a cumulative percentage of 85 % (31.4 % + 53.6 %). However, within voting category "Brighter" instead of "No change", the majority of respondents, specifically 52.4%, expressed a preference for the indoor lighting being "Neutral". Consequently, during the spring season, university students indicate a greater inclination towards the indoor lighting environment they experienced at that time (equivalent to "Brighter" of voting level), specifically favouring an average lighting level of 751.9lux. Therefore, while the majority of university students in the investigation expressed overall satisfaction with the level of illumination in their surroundings, there was a preference for a "Brighter" environment.

Table 8
Crosstabulation of indoor lighting perception, indoor lighting satisfaction, and indoor lighting preference votes of spring participants

Indoor lighting perception	Spring							
	Indoor lighting satisfaction (%)					Indoor lighting preference (%)		
	1	2	3	4	5	1	2	3
1	0.0	0.0	0.0	0.0	50.0	0.0	0.0	4.8
2	1.5	7.0	8.0	33.3	0.0	13.0	3.9	23.8
3	37.9	45.7	42.0	50.0	50.0	21.8	44.4	52.4
4	59.1	45.7	44.0	16.7	0.0	47.8	50.7	19.0
5	1.5	1.6	6.0	0.0	0.0	17.4	1.0	0.0
Total	100	100	100	100	100	100	100	100

Note. 1-Very dim; 2-Dim; 3-Neutral; 4-Bright; 5-Very bright; 1-Very satisfaction; 2-Satisfaction; 3-Neutral; 4-Dissatisfaction; 5-Very dissatisfaction; 1-Dimmer; 2-No change; 3-Brighter.

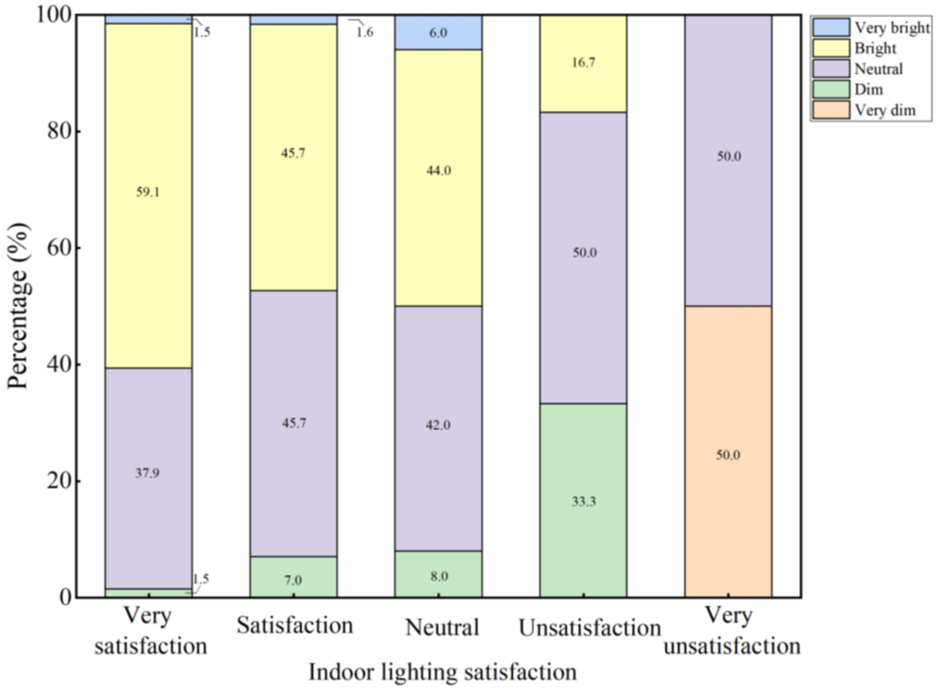

Fig. 13. The relationship between indoor lighting satisfaction and perception

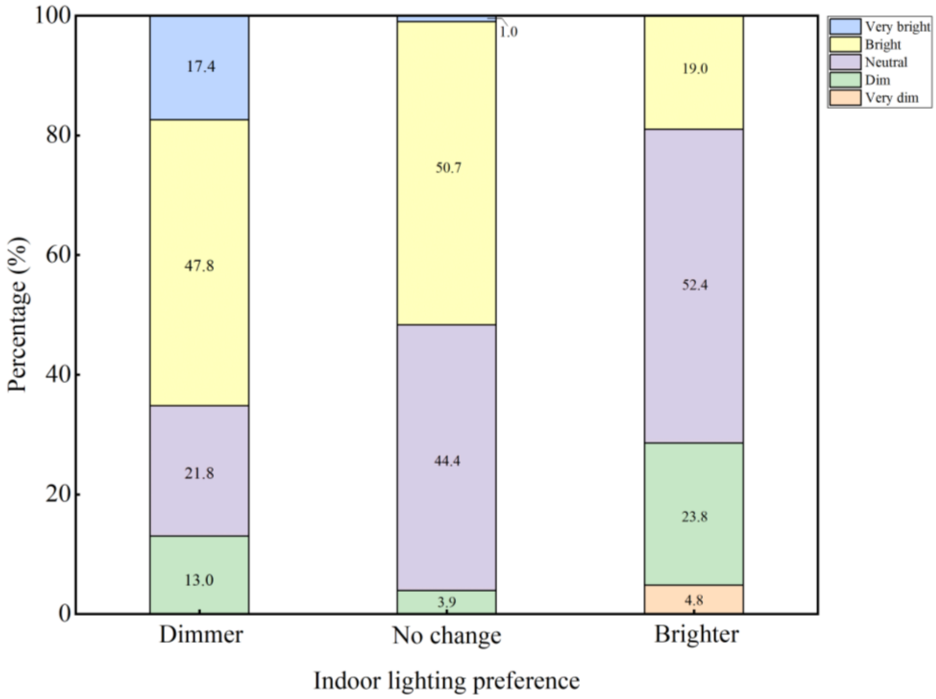

Fig. 14. The relationship between indoor lighting preference and perception

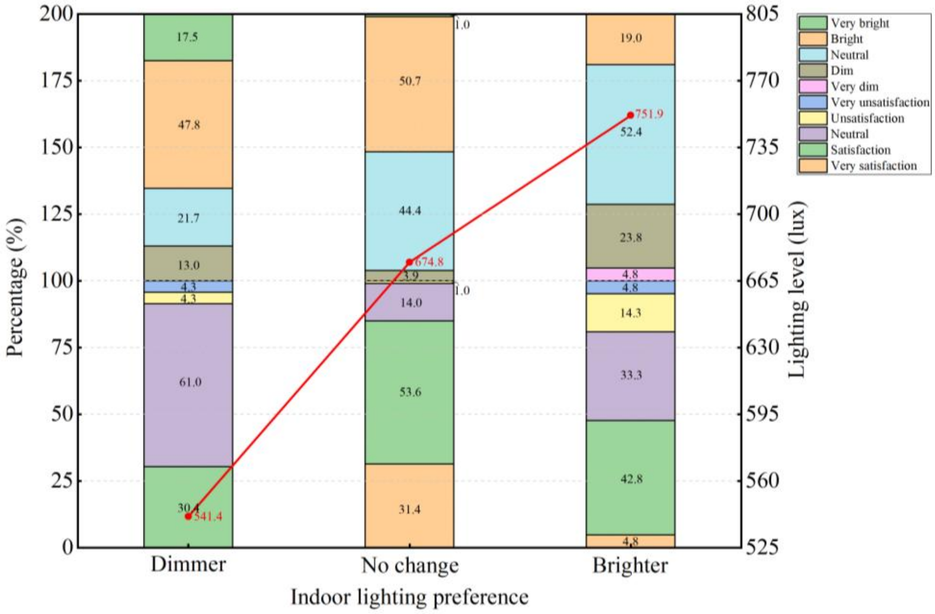

Fig. 15. Cross-analysis of indoor lighting perception, satisfaction and preference

4. Conclusion

The research conducted at UCL highlights the significant influence of IEQ factors on university students' satisfaction. Key findings indicate that students prefer cooler indoor environments during spring, with thermal comfort being a critical determinant of their overall satisfaction. Regarding other indoor IEQ factors, university students prefer an indoor environment with an average indoor wind speed of 0.05 m/s, relative humidity environment with an average level of 50.3%, acoustic environment with an average level of 57.6 dB, and light environment with an average level of 751.9 lux. The study emphasises the intricate relationships among various IEQ factors and their collective impact on students' perception, satisfaction and preference. These insights advocate for the development of tailored environmental designs for educational buildings to optimise student satisfaction and enhance academic outcomes. Future research should explore the cross-influence of these factors in different climatic and cultural contexts to provide a more comprehensive understanding of their effects on student performance and well-being.

Conflicts of Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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