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University library indoor environment quality and student achievement: mediating role of learning engagement

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ABSTRACT

This current study investigates how university library indoor environment quality (IEQ) influences academic achievement (AA) through learning engagement (LE), drawing on environmental psychology and learning space theory. Although IEQ has been widely studied in classroom contexts, little empirical evidence exists regarding its academic influence in university libraries, which represent critical yet understudied learning environments. Using survey data from 383 Chinese college students, the study demonstrates that IEQ positively predicts both LE and AA, and that engagement serves as a significant mediating mechanism. These findings highlight the academic value of improving acoustic comfort (AC), visual comfort (VC), thermal comfort (TC), and indoor air quality (IAQ) in library spaces, offering actionable guidance for educational planners seeking to enhance student performance through spatial design. The study contributes novel evidence to the literature on learning environments and suggests future research should incorporate multi-campus samples, broader achievement metrics, and contextual factors to deepen understanding of how environmental conditions shape student learning.

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1. INTRODUCTION

The indoor environment quality (IEQ), conventionally encompassing acoustic comfort (AC), thermal comfort (TC), visual comfort (VC), and indoor air quality (IAQ), constitutes a pivotal research domain due to its profound influence on human well-being and performance [1]. Its significance has intensified in recent years, particularly in educational architecture, prompting scholars to advocate for greater attention to user satisfaction and expressiveness in school buildings [2]. Drawing on principles from environmental psychology and learning space theory, which underscore the dynamic interplay between individuals and their physical surroundings, it is evident that students' extensive time spent in these academic settings renders IEQ parameters critical [3], [4]. These diverse parameters are understood to profoundly shape student health and learning outcomes by engaging cognitive functions through various sensory channels (e.g., sight, hearing, and touch) [5]. This mechanism, further elucidated by cognitive ergonomics, highlights how ambient conditions directly affect mental processes vital to effective learning, thereby demonstrably contributing to academic achievement (AA) [6], [7].

AA refers to what students aim to achieve in their education, including test scores, engagement, and overall understanding of what they are learning [8]. It plays a vital role in the future development and social evaluation of college students [9], [10]. Scholars in various countries have confirmed through research that

the IEQ of the learning environment can affect students' cognitive responses, learning ability, and other aspects, which, in turn, impact students' learning efficiency and AA [11], [12].

However, the pathways through which IEQ ultimately translates into improved AA are complex and often mediated by students' active engagement with their learning process. Rooted in educational psychology, learning engagement (LE) is conceptualized as students' conscious and active involvement in learning tasks [13]. LE is a lasting, positive psychological state characterized by three key components: dedication, vigor, and absorption. Dedication represents a strong commitment to education, marked by enthusiasm and a sense of purpose. Vigor reflects mental energy and persistence in learning, helping students overcome challenges. Absorption involves deep concentration, in which learners become fully immersed in academic tasks, often losing track of time [14].

This educational psychology highlights the interaction between energy, emotional connection, and focused attention in the learning process. Research consistently demonstrates that learning space design significantly impacts student behavior and LE, influencing attentiveness, cognitive ability, and motivation [15]. Optimized environments, aligning with learning space theory, can notably enhance students' inclination to invest more energy and focus in their studies [4].

Studies have found that the design of the learning environment significantly affects students' learning behavior and can promote or limit their participation to a certain extent [16], including students' attentiveness, cognitive ability, and motivation [17]. Accordingly, what impact can these changes in learning state ultimately have on students' engagement in learning? To answer this question, researchers have done a series of related studies. For instance, Guo *et al.* [18] examined the relationship between multiple factors, encompassing academic self-concept, perceptions of the learning environment, LE, and learning outcomes. The findings demonstrate that students who learn in more positive environments tend to devote more energy to their studies and are more focused, which can ultimately affect learning outcomes.

During this process, students' autonomous learning ability and self-discipline improve, and the development of these abilities directly affects the degree of engagement in learning [19]. Furthermore, if the learning space provides students with positive incentives and support, their willingness to participate and their learning performance will generally be more positive [20]. Indeed, high-level learning has a profound impact on students' AA, and continuous participation is crucial to academic success.

Nevertheless, despite the established importance of IEQ and its demonstrated impact on academic outcomes, and the critical mediating role of LE, extant research predominantly focuses on classroom environments, leaving other crucial learning spaces, such as university libraries, significantly underexplored [21]. Specifically, while previous studies have conducted in-depth explorations of IEQ in classrooms, research on its impact in libraries—spaces with similarly high usage rates and dense populations, uniquely designed to foster independent learning—remains notably insufficient [22]. However, the campus learning environment significantly affects students' pursuit of knowledge and engagement in education [23].

The university library, as one of the essential buildings in university education, provides a platform for college students to study and conduct independent research [24]. Despite the rapid development of e-libraries, college students' demand for university libraries is not decreasing but increasing [23]. Furthermore, library usage correlates with students' AA [25]. While existing studies have demonstrated that prolonged occupancy and high user density significantly compromise IEQ in classroom settings, there is no research on whether the IEQ of university libraries can reach such a conclusion.

Critically, the intricate correlation mechanism among library IEQ, LE, and AA, which constitutes the precise core issue addressed by this study, has not been systematically explored, particularly the mediating role of LE. Previous work by Zhang [26] in Chinese university libraries, for instance, suggests that IEQ influences student engagement. Yet, its limited sample size necessitates further validation, especially given the typically lower recorded student participation rates in China [23].

To address this critical research gap, this present study clarifies how the quality of the library environment quality influences learning outcomes through LE. As the first comprehensive study to explore the relationship among IEQ, LE, and AA in libraries, this research provides valuable guidance for education policymakers, campus planners, instructional designers, and student support service professionals. It helps school administrators formulate scientific space management strategies, guides architects in constructing a more supportive physical environment for learning, and provides students with a direction for securing better learning resources.

2. METHOD

2.1. Study area

This study focuses on Fuzhou University Library—a Luban Prize-winning facility with 4,936 reading seats—selected due to the institution's status as a top-tier "Double First-Class" university in Fujian Province, serving over 42,000 high-achieving students who demonstrate strong demand for library resources.

As one of China's top 50 universities, Fuzhou University attracts academically outstanding undergraduates (62% of its student body) and receives robust government support, ensuring a representative sample for investigating LE patterns. The library's central five-story building (35,500 m²), operational since 2006, offers diverse study environments ideal for analyzing how spatial and environmental factors influence engagement. Given the institution's academic rigor and the library's infrastructure, this setting provides a strategic context to explore the interplay between library IEQ, LE, and AA within the theoretical frameworks of environmental psychology and learning space theory. Based on these considerations, this study proposes the four hypotheses outlined in Figure 1. The details of the hypotheses delineated in Figure 1 are as:

- H1: the library IEQ has a positive influence on college students' AA.
- H2: the library IEQ has a positive influence on college students' LE.
- H3: LE has a positive influence on college students' AA.
- H4: LE is a mediating role between the library IEQ and college students' AA.

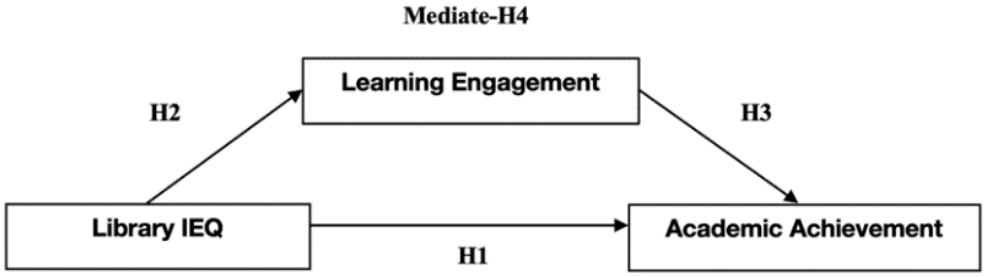

Figure 1. Conceptual model

2.2. Instrument

To evaluate college students' perceived university library IEQ in China, this study used the IEQ questionnaire developed by Hou *et al.* [27]. Research by Hou *et al.* [27] showed that Cronbach's alpha coefficient scores for the IEQ questionnaire are 0.864, indicating a high level of reliability. Moreover, the four dimensions of the IEQ questionnaire also demonstrate good to excellent reliability: TC (0.702), VC (0.891), AC (0.741), IAQ (0.841), the model fits indices are as: χ^2/df =1.939, IFI=0.787, CFI=0.774, GFI=0.939, AGFI=0.913, and RMSEA 0.048, indicating a high level of validity.

To assess LE among college students in China. This study used the Utrecht Work Engagement Scale, Student Version (UWES-S), developed by Schaufeli *et al.* [28]. The three dimensions of the UWES-S demonstrate good to excellent reliability: vigor (0.78), dedication (0.84), and absorption (0.73). This scale consists of 17 items, each scored on a 7-point Likert scale. To assess AA among college students in China. cumulative grade point average (CGPA) is the most commonly used to indicate college students' AA. Therefore, in this study, AA is operationally defined and measured by students' CGPA.

2.3. Sampling

The 383 college students were randomly recruited from Fuzhou University in Fujian Province, China, in March 2025 through a quantitative survey. Among the sample, 210 male students (54.8%) and 173 female students (45.2%) were included. As for week of frequency, there were 87 students (22.7%) do not go to the library often, 217 students (56.7%) go to the library twice a week, 71 students (18.5%) go to the library three to four times a week, and 8 students (2.1%) go to the library more than five times a week. Regarding library tasks, 66 students (17.2%) went to the library to do professional-related homework, 245 students (64%) went to the library to prepare for exams, and 72 students (18.8%) went to the library to do academic research. For each library, 58 students (15.1%) spent less than one hour, 190 students (49.6%) spent 1-3 hours, 132 students (34.5%) spent 3-5 hours, and 3 students (0.8%) spent 5-8 hours. As for grades, 48 students (12.5%) are freshmen, 108 students (28.2%) are sophomores, 126 students (32.9%) are juniors, and 101 students (26.4%) are seniors. Table 1 presents the demographic information of the samples.

2.4. Data analysis

Statistical data analysis was performed by means of SPSS 27.0 version. In the current study, university library IEQ is the independent variable, AA is the dependent variable, and LE is the mediating variable. To account for potential confounding effects, library usage frequency (as captured by visits per week and hours per day) was considered in interpretation of the relationships. A Pearson correlation analysis

was conducted to assess the strength of relationships among university library IEQ, AA, and LE. Additionally, the SPSS process macro was employed to test the path coefficients among university library IEQ, AA, and LE, and to verify the mediating role of LE in the relationship between university library IEQ and college students' AA.

Table 1. Demographic characteristics of the sample (N=383)

Demographic variable	Description	Frequency	Percentage (%)
Gender	Male	210	54.8
	Female	173	45.2
Grade	Freshman	48	12.5
	Sophomore year	108	28.2
	Junior year	126	32.9
	Senior year	101	26.4
Visiting days per week	No often	87	22.7
	1-2 days	217	56.7
	3-4 days	71	18.5
	5 days and above	8	2.1
Hours per day	<1 hour	58	15.1
	1-3 hours	190	49.6
	3-5 hours	132	34.5
	5-8 hours	3	0.8
Duty	Complete professional assignments	66	17.2
	Prepare for examinations	245	64.0
	Academic research	72	18.8

3. RESULTS AND DISCUSSION

3.1. Results

3.1.1. Description and correlation analysis

Table 2 provides the descriptive statistics and correlations of the library IEQ, LE, and college students' AA. Specifically, library IEQ (M=4.020, SD=0.475), college students scored on TC (M=4.069, SD=0.689), VC (M=4.060, SD=0.565), AC (M=3.988, SD=0.587), and IAQ (M=3.964, SD=0.630). In terms of LE (M=3.860, SD=0.689), college students scored on vigor (M=3.910, SD=0.728), dedication (M=3.874, SD=0.779), and absorption (M=3.796, SD=0.680). Furthermore, for college students' AA, measured by their CGPA, they scored on (M=3.798, SD=0.691).

Table 2. Means, standard deviations, and correlations

Variables/statistics	1	2	3
1. IEQ			
2. LE	0.414***		
3. AA	0.396***	0.710***	
Mean	4.020	3.860	3.768
SD	0.475	0.689	0.691
Cronbach's alpha	0.841	0.955	

***p<0.001

Table 2 shows the means, standard deviations, and correlations. There was a significant positive correlation between library IEQ and LE (r=0.414, p<0.001) and a statistically significant positive correlation with AA (r=0.396, p<0.001). Instrumental support also had a significant positive correlation between LE and AA (r=0.710, p<0.001).

3.1.2. Mediation test

To assess the mediating effect of LE, the bias-corrected nonparametric percentile Bootstrapping method was utilized. Table 3 illustrates that the direct effect of library IEQ on college students' AA was significant (β=0.179, Z>1.96, 95% CI=[0.067, 0.291]). The total effect of library IEQ on college students' AA was significant (β=0.576, Z>1.96, 95% CI=[0.441, 0.711]), while the mediation of LE (β=0.397, Z>1.96, 95% CI=[0.295, 0.511]) reached a statistical significance level. The mediation of LE was calculated to be 68.9% of the total effect. Thus, the effect of library IEQ on college students' AA was partially mediated by LE.

Table 3. Path coefficient test

Mediation effect test	Point estimate	Bootstrap SE	Z	Bootstrapping 95% CI		Mediation effect proportion
				Lower	Upper	
Total effect	0.576	0.069	9.763	0.441	0.711	-
Direct effect	0.179	0.057	3.140	0.067	0.291	-
Indirect effect (LE)	0.397	0.054	7.352	0.295	0.511	68.9%

3.2. Discussion

Within the overarching frameworks of environmental psychology and learning space theory, this study explored the university library IEQ among college students in China. It examined the positive effects of university library IEQ, college students' AA, and LE. Additionally, the mediating roles of LE between the university library IEQ and college students' AA were tested. The present findings provided several important insights.

First, this study's results showed that university library IEQ had a significant positive effect on college students' AA. Hence, the hypothesis was accepted. This finding is linked to previous studies [29], [30]. This finding provides institutions with a clear framework to use IEQ metrics to support academic success. Institutions can track key IEQ metrics tied to long-term AA (TC, AC, air quality) and set minimum standards based on our study's findings. For example, if TC metrics fall outside a focus-supporting range, institutions can adjust heating, ventilation, and air conditioning (HVAC) systems to restore conditions that boost students' information retention and academic performance.

For instance, Fan *et al.* [29] stated that students' use of libraries as a consumption behavior, and a study using the ABC attitudinal theory model found that the library's indoor environment has a significant influence on students' academic performance. Likewise, Brink *et al.* [30] adopted a quantitative approach combining subjective and objective research methods to conclude that the quality of the indoor environment has a significant impact on students' academic outcomes, with students' perceptions of the indoor thermal environment being critical. Nonetheless, the academic performance in his study refers to short-term academic performance. Hence, the results of the present study, which demonstrate students' long-term AA, further improve this aspect of the research.

However, this result is inconsistent with Zhang [26], which argues that library IEQ has no direct effect on students' AA and that satisfaction fully mediates the association between library IEQ and AA. Possible reasons for this different result include that, in his research questionnaire, TC and AC were measured by only two factors, "comfortable temperature" and "background noise"; the measurement of indoor environments in buildings should be more detailed [2]. The scale in this study was subdivided into three questions for TC: "humidity", "temperature", and "comfort"; and two questions for AC measurements were carried out.

This discovery confirms the impact of IEQ dimensions on students' AA and provides empirical support for China's code for design of library buildings (JGJ 38-2015). This core policy establishes mandatory environmental standards for educational buildings. For campus planning, this means designing library spaces with IEQ differentiation: quiet zones (for focused learning) need stricter acoustic control [31]. At the same time, group areas require adjustable thermal/visual parameters to fit collaborative tasks [32]. Poor TC and IAQ distract students and cause health issues; poor lighting reduces alertness, and noise impairs concentration [21]. Thus, optimized IEQ is a policy-compliant, planning-driven foundation for effective learning.

Second, the results showed that university library IEQ had a significant positive impact on LE. Therefore, the hypothesis was accepted. This finding is consistent with several prior studies [23], [32]. Study by Zheng *et al.* [23] found that the library's IEQ positively affects students' LE, and that the direct effect is more significant among liberal arts students than among science students. This aligns with our findings to inform campus design and library renovation. Campus design should place library quiet zones near humanities teaching buildings to support liberal arts students' focused reading, and these zones should be subject to strict acoustic control to reduce distractions. Group study zones for science students' collaborative tasks should be located in low-traffic areas, with adjustable TC to accommodate different group needs. Library renovation should prioritize improving VC and air quality, as these factors directly enhance LE. Therefore, evidence-based design and renovation are the most critical factors to promote students' LE [33].

Meanwhile, Bhandari *et al.* [32] confirmed a positive correlation between AC and students' LE and productivity, and found that noise from electric fans inside the building had a greater impact on students' LE than noise from the street outside. A comfortable learning environment for students presupposes a favorable listening environment [34]. However, previous studies seldom examined the effect of the four IEQ factors on students' learning participation, a finding supported by this study.

Stable TC reduces mental distraction to maintain attention, sufficient VC eases eye strain to keep information processing efficient, and good AC blocks interference to deepen thinking, all of which collectively enhance LE's vigor, dedication, and absorption [33]. LE is an essential indicator of the learning process, and students with a high LE score will have more opportunities for success. It can develop students into better learners [20]. Hence, future research and design must improve IEQ in long-duration study areas (especially libraries) to increase student engagement.

This outcome strongly resonates with learning space theory, which posits that well-designed physical environments inherently encourage active participation. For example, optimized VC, such as soft artificial lighting, significantly enhances learning comfort and engagement [35]. This effect is well understood in cognitive ergonomics: reduced visual strain minimizes cognitive load, thereby facilitating sustained attention and active emotional engagement [36].

Furthermore, this outcome confirms that library IEQ has a significant positive influence on LE, which provides a clear path for universities to use IEQ data to optimize learning environments. Universities can install sensors to monitor key environmental indicators regularly, such as temperature conditions, lighting, noise pollution, and air quality, and connect this data to student behavior records like study zone preferences and task types. This connection helps identify specific environmental issues affecting engagement, such as adjusting noise levels in high-traffic areas if data shows lower engagement there. This finding aligns with previous research and adds practical value by outlining a clear process for turning IEQ data into actionable improvements [11], [17].

Third, this study's results indicated that LE had a significant positive impact on college students' AA. Therefore, the hypothesis was accepted. This finding is consistent with the results of several prior studies [37]–[39] and extends their work by linking LE-AA dynamics to real instructional practices.

For example, Luo *et al.* [37] confirmed this result and indicated that the greater the motivation of students to resist emotional interference, that is, the higher LE, the greater the possibility of AA. According to Qureshi *et al.* [38], a positive correlational relationship exists between LE and academic performance, and students' academic performance can be predicted from their LE. Estévez *et al.* [39] compared AA among students with different levels of LE, and found that students with high LE had higher AA than those with low LE. However, his study was limited to the primary school; the object of this study was college students, and the outside of the classroom (the library) was explored. These results enrich the investigation in this field and further demonstrate that engagement in learning is important for students at every level.

Finally, this study's results demonstrated that LE partially mediated the relationship between university library IEQ and college students' AA. Hence, the hypothesis was accepted. Previous studies have not examined the role of LE in the relationship between IEQ and AA, but existing studies demonstrate that different dimensions of IEQ positively affect LE [11], [32], [40]. Students studying in a favorable indoor environment will greatly enhance their physical and psychological well-being [30]. Meanwhile, libraries can incorporate IEQ checks into routine support—for example, assessing environmental conditions when students report low engagement before providing academic guidance. This addresses a common gap in current services, where environmental factors are often ignored in favor of academic-only support. The hypothesis is accepted, and this mediation mechanism highlights that optimizing IEQ effectively enhances the value of existing learning support resources.

Effective learning is a prerequisite for the creation of active learning, which in turn improves concentration, cognitive level, memory, and other performances while learning [41], at the same time, reduces negative emotions and insecurities [2], [19]. This process directly explains how IEQ improvements lead to measurable AA gains: our results show that IEQ correlates significantly with AA, and that LE mediates 68.9% of this effect; optimizing IEQ (e.g., improving air quality or lighting) enhances engagement, which then translates into higher CGPA. As a result, students can get into deep learning as quickly as possible. The responding good learning state is consistent with the factors necessary for improving academic performance [42]. Furthermore, it has been shown that LE mediates the relationship between the university environment and intellectual development [43]. The findings of the study confirmed the hypothesis on this basis, and future research should focus on the importance of LE by considering improvements in LE in the relationship between IEQ and students' AA.

This current study, which shows that LE mediates IEQ's effect on AA, offers clear implications for three key stakeholder groups. Facility managers can use IEQ monitoring results to plan preventive maintenance, such as regular ventilation checks, to maintain air quality that supports students' information retention. Educators can assign tasks based on library zones' IEQ characteristics, placing exam preparation or thesis writing in areas with better AC and VC. Policy makers can use our findings to strengthen educational building environmental standards, ensuring they support conditions for higher student grades.

4. CONCLUSION

This study examined how the IEQ of university libraries influences AA through LE, grounded in ecological psychology and learning space theory. The findings show that university library IEQ has a significant impact on college students' AA and LE. LE has a significant effect on college students' AA, and this study confirms that LE partially mediates the relationship between IEQ and college students' AA. By focusing on library environments rather than conventional classroom settings, the study contributes new empirical evidence to an understudied yet increasingly important learning space. The results extend existing IEQ research by demonstrating that environmental factors operate not only as comfort variables but also as behavioral and academic determinants. This work thus enriches the literature on university learning environments and supports ongoing efforts to improve educational quality through evidence-based spatial design.

The practical implications highlight the need for universities to prioritize integrated environmental strategies that strengthen AC, VC, TC, and IAQ within high-use study spaces. Routine monitoring of environmental indicators and incorporating student feedback can help institutions address issues that affect LE and, in turn, academic outcomes. Several limitations should be acknowledged, including the single-institution sample, the reliance on CGPA as the sole performance measure, and the absence of additional behavioral or academic covariates. Future research should draw on a broader range of institutional contexts, use multiple indicators of academic performance, and further examine social and cultural factors that may interact with environmental conditions. Such work will deepen understanding of how learning environments shape student development and inform more comprehensive policies for library design and management.

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AUTHOR CONTRIBUTIONS STATEMENT

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Name of Author	C	M	So	Va	Fo	I	R	D	O	E	Vi	Su	P	Fu
Lingbing Xie	✓	✓	✓	✓	✓	✓		✓	✓	✓			✓	
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C : **C**onceptualization
M : **M**ethodology
So : **So**ftware
Va : **Va**lidation
Fo : **Fo**rmal analysis
I : **I**nvestigation
R : **R**esources
D : **D**ata Curation
O : Writing - **O**riginal Draft
E : Writing - Review & **E**diting
Vi : **Vi**sualization
Su : **Su**pervision
P : **P**roject administration
Fu : **Fu**nding acquisition

CONFLICT OF INTEREST STATEMENT

Authors state no conflict of interest.

DATA AVAILABILITY

The data that support the findings of this study are available from the corresponding author, [SAZ], upon reasonable request.

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