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Impact of classroom environment on student wellbeing in higher education: Review and future directions

Nastaran Makaremi [a,*], Serra Yildirim [a], Garrett T. Morgan [b], Marianne F. Touchie [a,c], J. Alstan Jakubiec [d], John B. Robinson [e]

[a] Department of Civil & Mineral Engineering, University of Toronto, Canada
[b] Department of Geography and Planning, University of Toronto, Canada
[c] Department of Mechanical & Industrial Engineering, University of Toronto, Canada
[d] John H. Daniels Faculty of Architecture, Landscape and Design, University of Toronto, Canada
[e] Munk School of Global Affairs and Public Policy, University of Toronto, Canada

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ABSTRACT

Given the emerging concern for student wellbeing in public health discourse, a question arises: What role do campus buildings play in shaping the overall wellbeing of students? Following the PRISMA guideline, this study reviews the current building science literature that explores the relationship between higher education learning environments, specifically classroom spaces, and the wellbeing of students. Our investigation reveals that the existing literature primarily frames student wellbeing in terms of individual comfort and health. While acknowledging the importance of these aspects, we emphasize the desirability of embracing wider social and collective dimensions from an interdisciplinary perspective. We also advocate for a departure from the traditional approach that focuses primarily on mitigating adverse environmental effects to one focused on net positive environmental and human benefits. Encompassing these two perspectives, this paper presents a holistic approach to better understand the wellbeing of both individuals and the communities within educational settings. This comprehensive perspective aims to highlight the diverse and collective dimensions influencing campus wellbeing, contributing to a regenerative pathway toward achieving net-positive design and sustainability in both human and environmental terms.

1. Introduction

Within higher education settings, student wellbeing has emerged as a key public health concern, drawing significant attention from students, faculty, and university administrators at an international scale [1–3]. Amidst urgent calls to address what has been described as a student health and wellbeing crisis [4–6], a significant component of these settings remains underutilized: the campus built environment itself.

Universities and colleges have typically responded to this emerging wellbeing crisis by expanding access to on- and off-campus mental health and academic support services [7,8], implementing campus-wide initiatives to encourage students to make ‘healthy choices’ [9,10], and/or by attempting to integrate wellbeing into curricula [11]. While these programs have positively impacted individual students [12], another area where higher education institutions often hold the power and capacity to act lies in the design, utilization, and management of campus buildings, especially learning spaces, which can also influence the wellbeing of students [13]. This article aims to investigate the potential connections between the physical learning environment in higher education and student wellbeing further, with a specific focus on classroom spaces. In the absence of a universally accepted definition of wellbeing within the built environment domain [14], this paper first examines how the classroom environment influences student wellbeing through a review of the building science literature. Following the examination of wellbeing indicators in buildings, the insights derived from this review led us to identify additional dimensions that warrant consideration, emphasizing the need for a more comprehensive approach bridging between multiple disciplines.

2. Background

Prior studies have identified clear links between physical campus

* Corresponding author.
E-mail address: nastaran.makaremi@utoronto.ca (N. Makaremi).

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characteristics and different dimensions of student wellbeing, encompassing quality of campus life, academic performance, as well as physical, social, and mental health [15–18]. This association is demonstrated in various studies conducted across diverse cultural and climatic contexts, bolstering the credibility of these findings.

In the built environment literature, exploration of the quality of the campus environment has predominantly revolved around two design perspectives: the macro-scale, which encompasses outdoor spaces and campus planning, and the micro-scale, which focuses on campus buildings and the quality of indoor environments. From the macro-scale perspective, studies often aim to investigate how various elements such as campus design, infrastructure, accessibility, green spaces, and other physical attributes impact students' experience including their satisfaction, comfort, engagement, the feeling of belonging and safety, and the sense of inclusion within the campus environment [19–23]. From the building perspective, research often explores the indoor ambience or environmental features and design elements of individual buildings. These studies were conducted in various indoor environments, such as learning spaces, libraries, and laboratories [24–30]. These investigations have mainly examined different aspects of the indoor environment including thermal, visual, acoustic, and air quality aspects, collectively known as indoor environmental quality (IEQ), frequently integrating interior design and spatial elements such as space layout, furnishings, and maintenance as well. The primary objective of these prior studies on campus buildings was to investigate the impact of indoor environments on various dimensions of the student experience during their exposure to such settings. These efforts focused on dimensions like health outcomes, academic and cognitive performance, satisfaction and comfort levels, and the overall perception of the indoor environment. Muhammad et al. [18] conducted a qualitative study to investigate students' perceptions of how academic buildings affect their wellbeing. The authors identified six key themes that emerged from their analysis: "comfort, health and safety, access and quality of facilities, space provision and adequacy, participation and inclusiveness, and interaction". Notably, the research underscored specific factors that students emphasized as crucial for meeting their needs within academic buildings, such as thermal conditions, internet access, furniture quality, duration of access, the availability of refreshment facilities, access to discussion rooms, and the availability of personal workstations.

Given the range of theoretical and operational definitions of wellbeing in the built environment, developing a universal and comprehensive approach to its assessment remains a challenge for scholars and practitioners alike.

2.1. Framing wellbeing in the built environment

The topic of wellbeing in the built environment has gained prominence in both scholarly research and industry practices over the past few years [31,32]. Traditionally, there are two main approaches to understanding wellbeing: hedonic and eudaimonic. Hedonic wellbeing focuses on pleasure and happiness, and more immediate gratification, while eudaimonic wellbeing emphasizes personal growth, meaning, and self-actualization, contributing to a deeper sense of fulfillment and purpose in life. Both perspectives are essential in achieving a comprehensive and enriched experience of wellbeing [33–36].

In the context of the built environment literature, however, wellbeing is often framed as and used interchangeably with terms like comfort and health or is characterized as the result of combining both comfort and health indicators [37,38]. Regarding IEQ assessments, Rohde et al. [37] emphasize the importance of hedonic wellbeing, specifically focusing on individuals' moods and daily experiences of happiness, sadness, stress, etc., as opposed to the broader scope associated with eudaimonia. The authors suggests that emotional states exhibit a stronger connection with environmental stimuli, particularly concerning short-term emotions, feelings, and affect, compared to more enduring moods and temperaments [37].

More recent work by wellbeing scholars proposes moving beyond the hedonic/eudaimonic binary, towards a more nuanced approach that includes both elements. These evolving perspectives address the diverse influences of various philosophical traditions on both individual and collective wellbeing in the building context, with broader impacts of social factors related to cultural interpretations of wellbeing that shape occupants' experiences within buildings [39–41].

Despite its conceptual diversity, wellbeing is often measured exclusively through so-called subjective or objective methods. Subjective measurement of wellbeing involves the determination of the self-reported wellbeing of individuals as defined by the individuals themselves [36,42,43]. Subjective wellbeing is assessed through surveys that ask participants to describe how they 'feel' about their lives, including their mental health. Objective measurement of wellbeing, conversely, is concerned with the "non-feeling features" [42] of an individual's life, such as socio-demographic information, health state, and lifestyle choices [40]. Objective wellbeing indicators are often linked to wellbeing outcomes at a broader scale, such as access to strong social networks healthy lifestyle choices. The possibility of an applied approach for wellbeing in buildings that incorporates both subjective and objective wellbeing measures and concepts is demonstrated by the International WELL Building Institute's (IWBI) Global Research Agenda [44] and marks a significant step toward a comprehensive evaluation of occupant wellbeing. Building health and performance, according to the IWBI Global Research Agenda, are interactive, changing, adaptable, and occurring at various scales and, in their conceptual model, come together as a result of three types of "outputs": cognitive/psychological, behavioral, and physiological. As a result of such work, our understanding of how environmental and spatial qualities of indoor spaces may affect wellbeing has evolved within the built environment domain, incorporating a cumulative consideration of internal and external environmental conditions, organizational inputs, as well as individual and collective norms and values. Given these changing perspectives, it is essential to undertake investigations that shed light on the interplay of factors influencing student wellbeing within the higher education context.

In campus environments, educational buildings play a key role in shaping the student experience as they are, by their nature, the places where students learn, study, work, and/or socialize [18]. Spending numerous hours in classroom settings, in particular, exposes students to a range of environmental stimuli and stressors that may positively and/or negatively affect their on-campus experience. In classrooms, the quality of the indoor environment has various impacts not only affecting the comfort and health of students, but also potentially impacting their emotional status, engagement, cognitive performance and quality of learning [28,45]. Although the physical environment alone is not the sole factor that can influence wellbeing, research suggests that it is a correlated element worth considering and assessing [40,46].

2.2. Outline and scope of the review

Considering the dynamic nature of wellbeing in buildings, encompassing both individual and collective elements, the questions we aim to explore here are: How does the classroom space influence student wellbeing? And what additional dimensions that contribute to wellbeing outcomes for users, specifically students, should be considered in educational buildings?

The literature on classrooms design and indoor environment encompasses a wide spectrum of educational stages, ranging from K-12 to higher education settings. Researchers have explored various aspects of classroom space and student experiences across these diverse educational contexts, contributing valuable insights to the fields of education, and building engineering and design. This literature aids in understanding the evolving needs and challenges associated with different educational levels and informs effective design practice.

This paper explores the impact of physical classroom environments on students' overall experience in order to gain a deeper understanding of how higher education classrooms can influence student wellbeing. The overall purpose of this paper is to provide a broad perspective with which to facilitate the assessment of student wellbeing within the campus environment. Aspects directly related to teaching styles and pedagogy fall outside the scope of this study. Our primary focus is on higher education classrooms, occasionally referencing other educational levels for comparison.

To achieve this, following the methodology outlined in Section 3, we conducted a review of the building science literature, as presented in Section 4. We conclude this section by highlighting the usage of the term wellbeing in the reviewed papers and recent changes in building science literature. In Section 5, we highlight the overlooked aspects within the building science-related literature and an emerging paradigm shift occurring in the built environment domain regarding wellbeing. Subsequently, we suggest the need for the consideration of additional dimensions for a more holistic approach to wellbeing that responds to these gaps. We also introduce our perspective on the necessity of considering student wellbeing collectively and propose the potential for a social practice approach to investigate campus wellbeing. This paper concludes by outlining potential areas for future research and emphasizing the need for broader, more inclusive conceptual approaches to exploring wellbeing in campus environments. It should be noted that the primary focus of this manuscript is not to conduct an exhaustive meta-review, but to examine the degree to which previous studies in the building science literature have considered wellbeing, its definition, and the indicators used for its evaluation.

3. Literature review methodology

A literature review using the PRISMA guideline [47] was performed to examine the extent to which the effects of the physical classroom environment on student experience and wellbeing have been investigated, considering two domains: environmental and spatial qualities. To identify potentially relevant papers, the Scopus multidisciplinary citation database was used as a search engine. Prior to initiating the search process, we explored multiple preliminary search strategies to build a comprehensive approach to the review. We then utilized a combination of keywords related to the indoor environment, along with different aspects of wellbeing in the building science domain, in either the title, abstract, or keywords (Fig. 1). The selection was limited to articles and review papers written in English, with no restrictions imposed on time or geographical considerations. In addition, the terms 'classroom' and 'student' were added to the query to enhance the relevance of records, and the terms 'higher education,' 'university,' 'college, ' 'campus,' and 'lecture' were included to specifically target studies that explored classrooms within higher education settings. The search excluded publications that addressed virtual or remote classrooms. Appendix 1 in the supplemental data presents the search strings that were used.

The titles and abstracts of each article were screened to determine their relevance to the impact of various indoor conditions on students' experiences within classroom spaces and teaching buildings. This was followed by a comprehensive review of the full papers, and where appropriate and necessary, additional sources suggested by the authorship team were incorporated into the review pool. For the inclusion criteria, we selected only journals ranked in Q1 and Q2 based on the SCImago Journal Rank (SJR) [48]. In total, 56 articles related to IEQ and 31 articles on classroom interior space attributes were selected for analysis. Additionally, studies on educational spaces such as K-12 classrooms or campus student offices were included to support the statements where relevant. During the review process, efforts were made to ensure that as many aspects of classroom environments as possible were captured, rather than focusing on specific elements. The quality of each study was not assessed before their inclusion in the review, however, authors provided evaluative remarks on certain studies, particularly concerning their methodology, as deemed necessary.

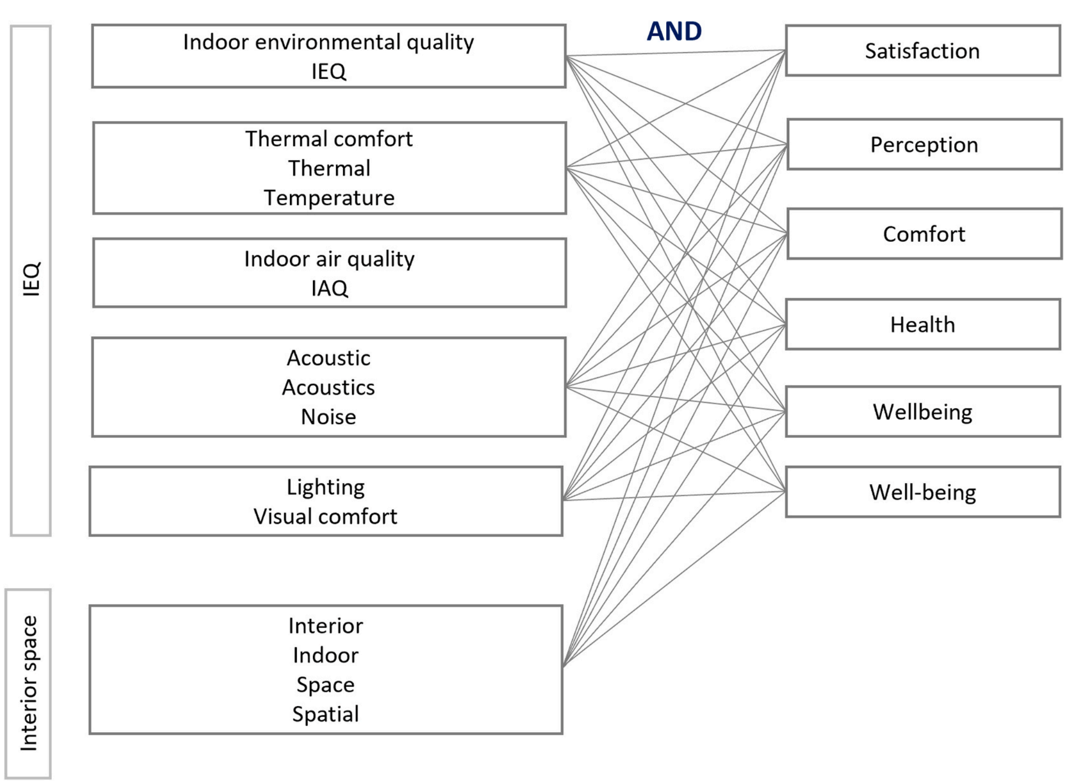

Fig. 1. Search strategy.

4. Results

This section provides an overview of building science studies that investigated different attributes of physical classroom environments and how they influence different dimensions of student wellbeing in higher education. Section 4.1 focuses on IEQ and Section 4.2 concentrates on space quality and classroom design. Both sections discuss the underlying factors and assessment approaches. Furthermore, in the review process, we checked for the inclusion of socio-demographic analysis in the papers regarding students' experiences and perceptions of the environment. This analysis is presented in Section 4.3. In Section 4.4., we concluded with a summary summarizing the key considerations and outlining the areas requiring further exploration. Finally, Section 4.5 explores how the term wellbeing was utilized in the reviewed papers.

4.1. Impact of indoor environmental quality on wellbeing

From our literature review on the relationships between IEQ and wellbeing, we anticipated gaining insights into how various aspects of the built environment impact health, comfort, and satisfaction of students. A limited number of papers discussed wellbeing itself, but where wellbeing was included, it often took the form of building-related symptoms, self-rated health, comfort or satisfaction.

IEQ consists of four key parameters: thermal comfort, indoor air quality (IAQ), acoustic and lighting conditions [49] and encompasses all the sensory stimuli that can be detected by humans, including perceptions of temperature, smells, sounds and visuals. Ensuring good IEQ conditions in campus buildings is important—as students spend approximately 15 total hours per week in university classrooms in North America [50], exposing them to classroom IEQ which can affect their wellbeing through their physical health, cognitive performance, comfort, satisfaction and mental health. In addition, due to the health and wellbeing concerns caused by COVID-19, ventilation strategies and their effect on IEQ in classrooms are becoming more popular topics [51–55]. Similarly, the impacts of pandemic safety measures like wearing masks [56] and increased natural ventilation [57] on student comfort are also gaining more attention.

Typically, IEQ assessments rely on subjective responses through questionnaires, but in many cases, objective measurements are also incorporated [58]. Some studies use these subjective and objective IEQ measurement methods to compare performance differences and students' satisfaction in classrooms located within different types of green, conventional and retrofitted university buildings [59,60]. Preferences and comfort in classrooms are frequently discussed to find which individual parameter causes the most dissatisfaction with overall IEQ in university classrooms [61], or to predict the overall comfort from individual IEQ parameters [59,62].

The existing literature establishes a connection between IEQ in elementary schools and its impact on students' health [63]. However, the connection between IEQ and student wellbeing is usually not evaluated directly. Instead, it is often assumed through comfort ratings or the prevalence of sick building syndrome (SBS) symptoms [64]. While the effect of IEQ on student wellbeing is rarely reported, studies use a variety of quantitative methods to characterize IEQ impacts. For example, a cost-benefit analysis method uses both measured IEQ data and self-reported data on the prevalence of SBS symptoms (e.g. headaches, fatigue) to calculate sick leave days, with the benefit of avoided sick leave defined by the authors of the study as an indicator for student wellbeing in classroom environments [65]. A more direct method to evaluate wellbeing could involve a comprehensive and standardized wellbeing survey, such as the Multicultural Quality of Life Index (MCQLI), that encompasses emotional, physical, social, and environmental aspects of wellbeing [66]. Additionally, combining this survey with a question on the effect of IEQ on wellbeing and comparing these wellbeing survey responses with physical IEQ measurement may provide a more personal and direct assessment of the effect of IEQ, rather than relying on proxies for wellbeing such as SBS symptoms.

In addition to the effect of individual IEQ parameters on wellbeing, assessing multiple indoor environmental conditions simultaneously is important as these parameters have interactions and influences on each other [67]. However, studies looking at all four IEQ parameters and the impact of multiple IEQ parameters on participants in real classrooms with large sample sizes are rare [68].

In both review papers and original studies, the effects of IEQ perception and satisfaction on academic performance have been getting increased attention in recent years [28,68–74], but the connection to student wellbeing remains unexplored. Individual IEQ parameters affect the quality of learning and short-term academic performance of students [70]. The reported impact of IEQ on student experience suggests classrooms with CO_2 levels below 1000 ppm are associated with higher levels of self-rated student experience compared to classrooms with CO_2 concentrations over 2000 ppm. Also, higher air exchange rates (1.65/h compared to 0.78/h) were associated with higher student wellbeing using proxies such as avoided sick leaves and academic performance as measured by behavioral tasks [65]. Overall, creating adequate indoor environments with appropriate temperature, sound, light and maintenance contributes to more favorable academic, community, safety and institutional environments, and consequently, improves student experience in these K12 school climates [75]. While comfort is subjective, and standards may not suit everyone's comfort needs, there are several standards that discuss what environmental conditions are appropriate in classrooms. For instance, ASHRAE 62.1 specifies a minimum ventilation rate of 10 L per second per person for classrooms [76], ASHRAE 55 [77] and ISO 7730 [78] suggest maintaining temperatures between 20 °C and 24 °C in winter and 23 °C–26 °C in summer, with 40%–60 % relative humidity in various types of indoor environments, including classrooms. EN 12464–1 [79] specifies lighting levels of 300–500 lux, and ANSI/ASA S12.60 [80] and ISO 3382–2 [81] recommend background noise levels below 35 dB(A) with reverberation times less than 0.6 s. However, there is still a lack of research on the multidomain assessment of thermal comfort, IAQ, lighting and acoustics in university classrooms [68]. Among the papers focusing on student satisfaction, comfort, perception, wellbeing or health in university classrooms, thermal comfort is the most frequently studied parameter followed by lighting, IAQ and acoustics, and lastly by studies examining more than one IEQ parameter. IEQ preferences, optimal ranges for comfort, student learning and academic performance are described regularly in studies of IEQ in university classrooms, as explained in Sections, 4.1.1 to 4.1.5.

4.1.1. Thermal comfort

Research shows that, in higher education classrooms, the quality of the thermal environment can impact students' comfort, performance and overall wellbeing [82]. Classrooms are densely populated spaces, where this occupant density is an important factor affecting temperature and relative humidity variations [83]. Furthermore, the use of personal laptops in classrooms contributes to the generation of heat, which could result in actual thermal conditions not meeting the designed thermal environments [82]. Inadequate heating or cooling can impact students' wellbeing through its effect on cognitive function [84,85], stress levels [86], productivity [87], health [88] and academic performance [82].

Single dose-response models like predicted mean vote (PMV)/predicted percentage of dissatisfied (PPD) and adaptive comfort models were used historically to assess thermal comfort. The PMV model, developed by Fanger, predicts the average thermal sensation vote of a large group of people on a seven-point scale ranging from −3 (cold) to +3 (hot). This model is based on the heat balance approach, which considers factors like metabolic rate, clothing insulation, air temperature, radiant temperature, air speed, and humidity. The PPD index complements the PMV model by estimating the percentage of people likely to feel thermally dissatisfied at a given PMV value [89].

The PMV model is a commonly employed metric which is integrated into thermal comfort standards [90–92]. However, the establishment of

ASHRAE's Global Thermal Comfort Database II showed that Fanger's PMV model has an accuracy of only 34 % and exhibits inconsistencies by either underestimating or overestimating individuals' thermal sensations [93]. The ASHRAE 55 standard was initially designed based on controlled laboratory conditions, which often don't mirror the diverse conditions found in real-world buildings. Later, the Adaptive Comfort Model was integrated into ASHRAE 55 which was intended to model the thermal response to naturally-ventilated buildings with operable windows [94], where there was a high potential for improving comfort and lowering energy consumption [95]. Literature on the collection of adaptive thermal comfort models in university classrooms looks at model accuracy [96] and the neutral temperatures applicable to these models in different climates [97,98]. In their analysis of adaptive models in Italian classrooms, Buratti and Ricciardi [96] aimed to establish correlations between experimental data and mathematical models using measurements and surveys conducted according to standards EN ISO 7730 [78], EN ISO 10551 [99], and ASHRAE Standard 55/2004 [100]. Their findings indicated that the adaptive model proposed by EN ISO 10551 is a better predictor of thermal comfort than the PMV model due to the adaptive model's consideration of behavioral, physiological, and psychological adaptation mechanisms. In the cold climate of Taiyuan, China, Jing et al. [101] further supported the use of adaptive models and indicated the limitations of the PMV model in classrooms by showing that students' actual thermal comfort differed from PMV predictions. These studies illustrate the importance of context-specific evaluations and the potential deviations in adaptive models when applied in different regions and building types, highlighting the need for localized data to develop more accurate adaptive comfort models.

In classrooms, thermal comfort affects the quality of learning and short-term academic performance of students [70,87] and the effect of thermal comfort on cognitive performance appears to be task dependent.

The Kraepelin arithmetic assessment or K test evaluates the subject's capabilities in terms of both the speed and accuracy of their task performance by a series of arithmetic questions and necessitates the subject's focused effort and attentiveness, making it a valuable tool for evaluating mental stress [102]. Similarly, the Prague distributive attention assessment requires the subject to concentrate on multiple tasks and assess their ability to resist mental fatigue [103]. Sarbu and Pacurar [104] examined 18 university students' performance in a Romanian classroom over 36 days, manipulating temperatures between 22 °C and 29 °C. Both attention tests, the Kraepelin and Prague tests, showed an inverted-U curve pattern, with optimal performance occurring at different temperatures (27–28 °C for Prague and 25–26 °C for Kraepelin), supporting the arousal theory that moderate higher temperatures reduce stress and benefit test scores.

In addition to survey questions on comfort and preference, and temperature, relative humidity and air velocity data, collecting physiological responses from occupants is common in thermal comfort research. When the temperature was increased from 22 °C to 24–26 °C in Italian classrooms, an increased influence of the sympathetic division of the autonomic nervous system on cardiac function, led to increased heart rate and contractility [84]. Barbic et al. [84] also found that at 24–26 °C, cognitive performance as measured by the Cambridge Brain Sciences cognitive evaluation tool decreased and students reported more thermal discomfort compared to 22 °C. Besides experimental studies, there has also been additional numerical research, such as the work conducted by Sarbu and Pacurar [104], aiming to predict students' academic performance in relation to thermal comfort and CO_2 concentration. Although there is a pleathora of studies on the effect of temperature on performance, the data seem to be noisy, so the relationship between temperature and performance, remains uncertain.

4.1.2. Indoor air quality conditions

IAQ is a fundamental aspect of indoor conditions which promote wellbeing through the lens of an integrative health framework with various levels including from molecular, to physiological, behavioral, psychological, and social levels of health [105]. Poor IAQ is characterized by elevated concentrations of particulate matter (PM), gaseous pollutants (e.g. volatile organic compounds (VOCs), carbon monoxide (CO), carbon dioxide (CO_2), ozone (O_3), nitrogen oxides (NOx), allergens, mold and bacteria. These elevated contaminant concentrations can impact student wellbeing through respiratory health, allergies, SBS symptoms, cognitive function, attendance and academic performance [106].

Insufficient IAQ, as indicated by high CO_2 levels and low ventilation rates, resulted in lower cognitive performance and productivity in controlled chambers [107,108] and K-12 environments [109,110]. In K-12 classrooms, high CO_2 levels above 1000 ppm, indicating insufficient ventilation rates and potentially poor IAQ, affected student performance and academic achievement [111,112]. Compared to K-12 schools, the study of IAQ in higher education buildings has been limited [113].

A lack of outdoor air in buildings was found to cause illness-related absences [114,115], and higher ventilation rates significantly reduced illness-related absences in K-12 classrooms [116] When the building envelope is tight and ventilation rates are low, there is a higher prevalence of SBS symptoms such as headaches, difficulty breathing and eye irritation [117], and low ventilation rates were linked to an increased risk of disease transmission [118]. Morawska et al. [119] argued that there is a need for a paradigm shift in combating indoor respiratory infections like COVID-19 and emphasized the importance of addressing airborne pathogens and improving building ventilation systems. COVID-19 exacerbated concerns about infection risk in university classrooms and increased the research interest in natural ventilation strategies and resulting CO_2 concentrations [53,120,121]. Rodríguez-Vidal et al. [122] discussed the implementation of natural ventilation protocols in university classrooms to reduce infection risk. Fantozzi et al. [123] proposed a method to estimate infection probability based on CO_2 concentration monitoring in university classrooms. Tint et al. [124] conducted CO_2 measurements in high school auditoriums and found a correlation between high CO_2 levels and the spread of COVID-19. In addition to field studies, a simulation study on natural ventilation retrofitting techniques proposed a solar chimney to assist a wind tower to increase both thermal comfort hours and decrease CO_2 concentration in university classrooms [125]. Overall, these studies show that improved ventilation in classroom settings plays a critical role in reducing illness-related absences, mitigating disease transmission risks like COVID-19, and enhancing overall indoor air quality and health outcomes such as SBS. Continuous CO_2 monitoring can help assess ventilation system effectiveness and respond to evolving health risks.

The impact of air purifiers on measured and perceived IAQ in university classrooms has become prominent in student wellbeing research in recent years. In a refurbished classroom with minimal infiltration where students are the main source of air pollutants and outdoor air pollutant levels are low, air purifiers could decrease PM concentrations but not TVOC and CO_2 concentrations [126]. Presumably this is because the air purifiers did not include photocatalytic or charcoal filters, though the authors did not specify the filter type. Without an external ventilation system, air purifiers were not effective at reducing CO_2 levels, and average $PM_{2.5}$ concentrations still exceeded 35 $\mu g/m^3$ despite the filtration [127]. In terms of microbiological concentration, there was no clear difference found before and after air purifier use in a classroom [128].

In recent years, there has also been increasing interest in the use of plants to purify air and improve perceived IAQ. While indoor plants have limited impact on IAQ when plant density is low, they may affect psychological wellbeing when situated within the line of sight [129]. High density potted plants (15 % of floor area) had positive effects on perceived IAQ, SBS symptoms and learning efficiency of university students [130]. Overall, integrating IAQ into discussions about how to enhance student health, comfort, and academic performance in university classrooms is important, but the direct impact of IAQ on wellbeing remains to be fully explored.

4.1.3. Acoustic conditions

Noise pollution is a public health issue with consequences for physical health, overall wellbeing, and mortality [131,132]. Soundscapes can impact both physical and psychological aspects of wellbeing [133]. Continuous exposure to high noise levels can lead to increased stress, decreased attention spans, and impaired communication [134]. Furthermore, excessive noise from both indoor and outdoor sources creates discomfort and can be distracting in a learning environment as the perception of listening ease in study environments plays a significant role in students' experience in universities [135].

Ventilation strategies critically affect the indoor acoustical conditions of classrooms, through window opening for natural ventilation or mechanical ventilation equipment itself creating loud and distracting sounds. Opening windows may introduce sounds such as traffic, aircraft, construction or human noise, as well as natural sounds to the indoor environment. In their systematic review, Pellegatti et al. [136] found that fan noise generated by mechanical ventilation affects the performance and comfort of students. Similarly, in the presence of background noise, lecturers were found to adapt their speech delivery by reducing the pauses and used vowel-articulatory strategies [137], and increased background noise exacerbated vocal health risks of teachers [138].

Acoustic comfort may also affect the quality of learning and short-term academic performance of students [139,140]. Ensuring good speech intelligibility is critical for teaching and learning environments [141] and if the acoustic design of classrooms is inadequate, it hinders speech reception, forcing students to allocate additional cognitive resources to comprehend the class material clearly [142,143]. This sustained high level of concentration can lead to student fatigue, affecting both acoustic comfort [29,69] and perceived learning performance [30]. Alternatively, in certain contexts some sounds can be used to improve indoor acoustic environment by masking unpleasant sounds, and possibly, to improve affect the performance and cognition of students [144,145].

4.1.4. Lighting conditions

The existing literature has explored the visual and non-visual biological effects of light, encompassing both natural daylight and artificial light, on students' performance, overall classroom experience, and various dimensions of their wellbeing as detailed below. Insufficient lighting can cause eye strain, fatigue, and difficulty in reading or focusing; whereas appropriate levels of natural and artificial light in university classrooms can enhance student wellbeing through improved mood, concentration, cognitive performance and mental alertness via visual and non-visual effects [146]. In university classrooms, various teaching methods and educational technologies such as text-based or image-based learning on student's desks using papers or computers, as well as the use of white/blackboards and projectors which can suffer from excessive daylight. Consequently, it is necessary to adjust the classroom's luminous environments according to the nature of the tasks and different lighting setups are required for tasks such as writing-reading, reflecting-discussing, and paying attention [147]. For classrooms, the recommended lighting level on the work plane is between 300 and 500 lux [148,149]. A comparison between subjective ratings and objective measurements by Ricciardi and Buratti [29] showed that the average measured illuminance value is highly correlated with the perceived visual comfort in university classrooms and that higher illuminance values lead to higher comfort, although there is likely an upper threshold where too much light could lead to glare [150]. Whereas one particular classroom in their study, which experienced the most unfavorable comfort conditions, was characterized by bothersome glares and reflections caused by natural light and this issue is likely attributed to an excessively high mean illuminance levels [29].

Virtual reality (VR) based experiments are commonly used to study the effects of lighting on student memory, attention and cognition. VR studies demonstrated that classroom illuminance influenced students' memories at psychological and neurophysiological levels, and as the level of illuminance increased, students' performance in memory tests declined, and neurophysiological activation decreased [151]. With its correlated color temperature (CCT) and illuminance, lighting had significant effects on male students' memories, females' attention and all students' level of agreement with the statement "in general, I like this classroom" [152]. However, it should be noted that despite VR becoming an important tool in lighting research and participatory approaches across diverse settings, concerns about generalizing findings and the validity of results may arise due to factors such as limitations associated with the lighting environment, personal, and contextual conditions [153].

In a real classroom, psychophysical tests were conducted to investigate the impact of tubular LED and panel LED sources on students' visual perception and cognitive performance: changes in indoor lighting impacted participants' perception, but no measurable effects of lighting were observed on the participants' alertness and attention levels [154]. Blue-enriched LED light was found as an effective potential countermeasure for morning drowsiness and falling asleep in real classrooms, particularly in schools with insufficient daylight [155]. Similarly in high school classrooms, blue-enriched white lighting in the morning influenced very basic information processing of students: increased cognitive processing speed and improved concentration [156]. In moderately ambient indoor lighting, choosing an optimal CCT was more beneficial than increasing illuminance, as it provides better lighting comfort in real classrooms [157]. With an intervention study done in real classrooms, Yuen et al. [158] examined the emotional impact of the lighting conditions, and showed that filtered fluorescent classroom lights yield more positive emotions and fewer headaches.

4.1.5. Combined influence of two or more IEQ parameters (multi-domain effect)

While standards-driven approaches require that each IEQ parameter individually meets comfort criteria, attaining an acceptable indoor environment necessitates the simultaneous consideration of air quality and thermal, acoustic, and visual conditions. Cao et al. [159] highlighted that the discomfort experienced by individuals is not solely attributable to a single factor; rather, it arises from a combined influence of multiple factors in campus buildings. With growing interest in evaluating the impact that buildings have on wellbeing, it is important to be able to capture the effects of multi-domain IEQ on wellbeing yet there are current no universally accepted methodologies for conducting multi-domain IEQ assessments. In campus environments, like university classrooms, the cause-effect relationships in IEQ investigations are missing.

The current research in multi-domain effects of IEQ parameters in classrooms focuses on weighting schemes to determine the most important parameters [160] and the combined effect of all IEQ parameters [28,74]. Several studies look at multiple IEQ parameters at the same time and discuss the relationships, most favorable conditions and combined effects of thermal comfort and IAQ [161], thermal comfort and acoustics [162], lighting and acoustics [163], IAQ and acoustics [55,136]; and thermal comfort, acoustics and lighting [164]. The multi-domain effect research is promising for satisfaction, comfort and possibly for wellbeing assessments, as this approach is closer to how we actually experience real spaces, rather than isolated single factor studies.

Most research in multi-domain IEQ looks at the impact of the indoor physical environment on learning performance and uses a case study approach. According to Ref. [161], the combined impact of air temperature and CO_2 concentration appears to intensify with the rise in both air temperature and CO_2 levels. For maximizing learning efficiency, Xiong et al. [164] determined the most favorable environmental conditions through various environmental interactions. For perception-oriented tasks, they observed that the highest level of learning efficiency was in environments that were perceived as thermoneutral, relatively quiet, and well-lit. In mockup classrooms, Kabanshi et al. [162] indicated that logic-based tasks and writing abilities are negatively impacted by heat and background noise, while implementing cooling measures helped to maintain performance in these tasks. In addition to measuring satisfaction with IEQ parameters using surveys in real classrooms, multivariate regression models are created to estimate overall satisfaction from IEQ measurements [159]. Previous research on the multi-domain effect of IEQ factors reveals the complex interactions between different environmental factors and how they collectively impact the overall comfort and learning performance of students, but not yet on student wellbeing. The multi-domain effect research is especially promising for understanding wellbeing, as it reflects how people actually experience real spaces, rather than just focusing on one factor at a time. Overall, there is a need to quantify the effect of environment on wellbeing through direct measures like wellbeing surveys in real spaces and for more widely accepted weighting of different domains to truly capture what makes campus learning environments comfortable, effective for learning and conducive to student wellbeing.

4.2. Impact of classroom interior space quality on wellbeing

Compared to IEQ, interior design and spatial attributes are subject to less standardization through industry codes. There has also been less research dedicated to examining how classroom interior design affects student satisfaction, comfort and performance, although some consensus has been reached [30]. However, there has been a limited focus on investigating the impact of classroom design on the overall wellbeing of students. Through an examination of literature regarding the interior design elements of classrooms, we aim to address aspects that may impact various dimensions of student wellbeing within the learning environment throughout the learning experience. In general, the literature related to classroom design, encompassing both K-12 and higher education settings, is extensive and includes discussions on classroom architecture in relation to educational theory and contemporary trends [27]. A parallel imperative, however, may be to investigate students' perspectives on classroom space and the impacts it has on their experience. This involves examining the connection between the interior space of the classroom and students' experiences, specifically exploring whether students attribute their wellbeing to the spatial characteristics of the classroom or not. Understanding how students perceive their classroom environments and how the physical characteristics of these spaces influence their satisfaction, behavior, academic performance and self-reported wellbeing holds significant importance both in the academic study of learning environments and in the practical application of design principles.

When exploring the quality of classroom interior space, several key aspects should be considered, such as functionality, flexibility and aesthetics. In addition to IEQ conditions, the spatial layout and functionality (the degree to which classroom spatial qualities and equipment meet students' needs) of a classroom can influence cognitive and affective/emotional evaluations of student satisfaction with the course [165].

Based on our literature search, the elements that have been most frequently investigated in higher education classrooms can be grouped as: layout and furniture, wall color, window views and the integration of nature in the classroom space.

From a methodological perspective, the reviewed papers mostly explored students' subjective evaluations, using assessments that capture their perceptions, satisfaction, feelings, and personal experiences, as reported by the students themselves. A few studies addressed objective evaluations (such as behavioral observations) and external measures (like academic outcome and learning process). Additionally, research related to ergonomic design often utilized anthropometric measurements and body data. The predominant approach to understanding students' perceptions in the reviewed studies involves using questionnaires to gather responses from students. These questionnaires generally incorporate pre-defined assessment scales, which are established by researchers or other experts in the field. In some cases, interviews with students and/or experts are also employed either in the design phase of the questionnaire or for gaining supplementary insights post-questionnaire construction to facilitate a more comprehensive analysis. In general, given that the subjective assessment of classroom settings primarily relies on quantitative research, many studies suggested the addition of qualitative methodologies, such as focused group discussion, interviews and observations, to conduct more comprehensive research on students' perceptions. Adopting this mixed-approach could enable a deeper understanding of the factors influencing students' experiences in the classroom [166]. Furthermore, while most studies primarily emphasized subjective assessments, some also incorporated objective evaluations, especially in cases where they examined IEQ attributes. Yet it is worth noting that most of the discussed work primarily focuses on students' satisfaction and experience, rather than their wellbeing. While there is a connection between these aspects, wellbeing is not clearly addressed in the majority of the reviewed papers.

4.2.1. Layout and furniture

In general, studies addressing students' perception of classroom spatial environments typically examined classroom layout (arrangement and boundaries), size, form, visibility (the distance and line of sight between students and an instructor or visual aids such as a projector or black/whiteboard), furniture (type, size, level of comfort and adjustability), and decoration [18,27,30,73,165,167]. Classroom layout and seating arrangement not only influence students' perception of the physical environment but could also play a crucial role in shaping their learning experience, academic performance, academic satisfaction and in their evaluation of the course and instructors' teaching [73,166,168].

In general, classroom environments in higher education are continuously evolving, influenced by learning theories and shaped by information technology. Traditional lecture classrooms are characterized by fixed rows of desks facing one direction, focusing on an instructor-centered approach and cost-effective space layouts, while new and modern learning environments emphasize formats that foster active learning psychology and providing adaptive spatial layouts [166]. These new classrooms are typically designed to facilitate teaching and learning activities, student-centered instruction, group work, and peer interaction, and they appear to have a positive impact on student engagement, collaboration, and overall learning outcomes. Interactive learning spaces mostly include flexible furniture, movable chairs and large (round or hexagonal) tables for group work, and technology to support collaborative learning [25]. Research shows that many students preferred furniture layouts with groupings of students for active learning and collaboration versus rows [168]. The flexible seating setup encourages students to naturally form groups, providing a platform for diverse types of instructional interactions. It also promotes a welcoming and comfortable atmosphere, which may facilitate peer connections before and after class. This setup ultimately enhances the effectiveness of group-based learning activities for both students and instructors [169,170].

To facilitate academic performance, learning environments should align with and support students' preferences and needs. Certain studies have explored the positive outcomes linked to active learning classrooms, revealing higher levels of satisfaction within the instructional interaction dimension compared to traditional lecture-based classrooms. These studies suggest that these innovative learning spaces have the potential to enhance students' perceptions of their learning experiences, fostering innovation, creativity, and critical thinking across various disciplines [166,171]. However, traditional classrooms, known for their serious and quiet atmosphere, are more conducive to sensing learners who prioritize perception over intuition [172]. While it is worth noting that these studies exhibited certain methodological limitations, such as issues with sample size, the absence of control groups, and insufficient study variables, their findings remain valuable, highlighting the diversity in student perceptions and preferences. These results underscore the necessity for a variety of learning spaces to be flexible enough to meet the varying requirements associated with different instructional formats and student learning styles.

Several studies have focused on the ergonomic aspects of classroom desks and chairs, assessing their influence on students' comfort levels [173,174] and their ability to support students' health while investigating musculoskeletal issues related to the classroom [175,176]. Benzo et al. [177] discussed the acceptability and feasibility of introducing standing desks into college classrooms, which many students expressed their support for, and many students believed it could improve physical health, attention, and restlessness. This research suggests the need for additional exploration to assess the cost-effectiveness and efficacy of implementing standing desks, and to influence institutional policies regarding classroom design for public health.

4.2.2. *Window view and integration of nature*

Window views, connection to the outdoor environment, and integration of nature in classrooms are other design elements that have been studied for their impacts on students' classroom experience.

These aspects have been examined not only for their impact on perceived environmental quality but also for their potential to influence students' moods, their learning experience and cognitive function, and their overall wellbeing.

Despite the tradition of windowless classroom design aimed at minimizing distractions, Benfield et al. [178] illustrated that classrooms with nature views received more positive course evaluations, and students achieved higher end-of-semester grades compared to those with concrete wall views. Coronado et al. [54] have also argued that having visual access to the outdoors through classroom windows can positively impact students' perception of healthy learning spaces. Additionally, the incorporation of nature views and plants in classrooms has been reported to enhance visual creativity [179], and the presence of interior plants has demonstrated a positive impact on overall course evaluation, especially in classrooms lacking windows or other natural elements [180]. van den Bogerd et al. [181] found that students rate classrooms with indoor nature (e.g. potted plants and green walls) as more attractive and perceive them to have a higher environmental quality than those without. However, the study also revealed that short-term exposure to indoor nature in higher education classrooms did not have immediate positive effects on student wellbeing or attention, although secondary education students reported greater attention and better evaluations of lectures and teachers in classrooms with indoor nature.

Moreover, the vital role of daylight, as a natural element accessible through windows, underscores the importance of incorporating windows into a classroom environment. The importance of daylight as an aspect of IEQ assessments that have both visual and non-visual effects has been mentioned earlier in 4.1.4, and incorporating daylight and outdoor views can seamlessly bring the benefits of the natural environment indoors. The spatial distribution of comfort and mood in classrooms has been shown to vary depending on perceived sky conditions and distance from windows [182]. It is worth noting that research has demonstrated that high-quality views can influence both visual aspects, such as glare, and non-visual elements, such as thermal comfort [183]. These studies mostly exist outside the realm of classroom literature, however, and their characterization of what constitutes high view quality and view preferences continue to evolve.

The human affinity toward the natural world, or biophilia, has been extensively explored across disciplines, but primarily within the field of environmental psychology. A review paper by Peters & D'Penna [184] explored the integration of biophilic design elements (such as nature views, daylight access, lighting variability, natural materials, and nature-inspired patterns) within university classroom settings and comprehensively discussed their potential links to students' experiences, such as reduced stress, improved attention, enhanced mood, creativity, academic performance, and classroom assessments, along with fostering a sense of place and belonging. While many studies have explored the integration of biophilic elements in diverse settings, such as working environments, there has been limited investigation into the role of biophilic design in higher education classrooms.

4.2.3. *Color*

Evidence suggests that the colors used in classroom environments can influence students' environmental satisfaction and perception, potentially resulting in physiological, emotional, and cognitive effects on students' performance [185–187]. Nevertheless, discrepancies between these dimensions occasionally emerge. AL-Ayash et al. [188] discussed that emotional responses do not always correlate with cognitive efficiency. For instance, although the authors' study environment was perceived as relaxed, calm, and pleasant in pale color conditions, reading scores were significantly higher in vivid color conditions.

Due to practical and methodological constraints, however, studies comparing the effects of colors in learning environments have predominantly used pictorial questionnaires or virtual reality settings, or they have been conducted in individual experimental environments, rather than real-life learning spaces. Therefore, the findings of these studies may not be representative of the conditions the current study expects when discussing student classroom experience.

It is also worth noting that, surface finishes have been shown to influence acoustic and lighting conditions, visual experience, as well as IAQ within the environment, with the potential to impact student comfort and health [189–191]. Therefore, a thorough understanding of the color environment and material used is important in classroom design, as these elements could influence students' experiences and wellbeing.

4.3. *Impact of socio-demographic factors on student classroom experience*

Overall, individual characteristics significantly contribute to shaping individual perception of the physical environment, impacting how the environment is perceived as healthy or comfortable. When students enter a campus environment, they bring with them a multitude of personal perspectives and beliefs that shape, and are shaped by, their experiences, sometimes exemplifying circular logic. These experiences significantly influence how students perceive and engage with their environment. In research related to educational settings, several studies have explored the impact of students' personal characteristics on their comfort levels and perceptions of their surroundings in addition to environmental and space-related parameters. In their search on student perceptions of classroom attributes, Yang et al. [30] introduced "non-classroom" factors (personal and contextual) like gender, college year, cumulative GPA, and seating locations. They recommended that evaluating physical learning environments requires assessing both their attributes and how students perceive them. The reviewed papers mainly explored the relationship between these personal factors and classroom experience, revealing correlations in the literature, though occasionally with some uncertainty in the results. While the literature emphasizes the significance of socio-demographic considerations regarding environmental satisfaction and comfort, yet there remains an insufficient examination of their relationship to occupant wellbeing.

Gender (and/or biological sex) can potentially serve as one contributing demographic factor that influences how people experience classroom spaces. For some studies that have interchangeably used the terms 'gender' and 'sex' when discussing individual parameters, it is presumed that they are referring to an individual's biological sex as a factor influencing occupants' perception and comfort but the terms in the original studies are presented here (e.g. gender when this may actually refer to sex). Although in these contexts, gender does not necessarily refer to 'gender identity' as it is currently understood. Hu et al. [64] examined the relationships between gender and thermal comfort, work performance, and SBS prevalence and found that, in colder environments, male students experienced enhanced comfort, higher work performance, and a lower prevalence of SBS compared to female students. Similarly, a statistically significant difference was observed between female and male students' thermal sensations and the neutral temperature was one degree higher for female students compared to males [192]. In their experimental study in free-running classroom conditions, Nico et al. [193] revealed that gender had a significant impact on thermal perceptions of students and women felt colder than men when the outdoor conditions are cold. Moreover, Yang et al. [30] demonstrated that perceptions of temperature, acoustics, visibility, and technological attributes in higher education classrooms vary significantly based on gender. The study indicated that, in comparison of perception scores, female students generally rated temperature and visibility more positively but evaluated acoustics more negatively compared to male students.

In addition, individuals typically report higher levels of satisfaction when they have some degree of control over their surroundings. Prior research also indicates that controllability (perceived and actual control) over environmental conditions can significantly influence the satisfaction of building users, playing an important role in mitigating stress-related issues and enhancing experiences of comfort and wellbeing [37]. In academic settings, however, students often do not have control over their indoor environments, and when they do, there is a potential for conflict due to varying preferences of individuals using a shared space. Despite this general lack of control, analysts have shown that students who do have this control report higher levels of satisfaction [18,166,193,194]. Cultural context is another factor that could have an impact on environmental perception and behaviours. Socio-cultural and contextual aspects, such as habits and dress codes, can influence students' thermal comfort and preferences within the classroom environment. Zomorodian et al. [195] discussed this as a significant issue in countries where there are restrictions for females. Although socio-cultural elements could significantly impact students' experiences in the learning environment and campus life, this aspect has received less attention in classrooms than other settings.

Overall, while previous studies have examined demographic factors as moderators influencing individual experiences within their environment, a gap persists in considering the interactions among socio-cultural, organizational, and environmental elements. To fill this gap, there is a need for more comprehensive approaches that consider both individual and broader collective spectrum of elements of wellbeing, including the role of the campus environment.

4.4. Summary of review results

This literature review has examined various factors affecting students' experiences and wellbeing in classroom settings. The following section summarizes the key findings and overarching trends identified within the building science literature in the university classroom context. Poor IEQ in on-campus classroom environments can affect student physical and mental health, comfort, and satisfaction. IEQ has historically been measured to inform physical interventions in classroom spaces to promote student satisfaction and performance. Yet the experience of the COVID-19 pandemic has led to increased attention on ventilation strategies and their impact on IEQ, along with the influence of safety measures like mask-wearing and increased natural ventilation on student comfort. In recent years, the comfort with campus spaces considering interactions between multiple IEQ parameters and individual characteristics of students is also explored, but the connection to student wellbeing is still missing. To a lesser extent than IEQ-focused studies, the building-science literature is replete with examinations of the comfort, health, and academic performance consequences of classroom space design, primarily centered on layout, furniture and connections to the outdoor environment. Moreover, in addition to architectural design and environmental quality, factors such as the length of time spent in classrooms, the nature of in-class activities, the time of day, and personal characteristics can significantly impact an individual's subjective perceptions, comfort level, and performance within the same indoor environment [30,68]. However, what is missing from this expansive body of evidence, however, are studies that address students' overall wellbeing as well as their specific experiences of learning spaces.

As previously mentioned, socio-cultural factors could significantly shape students' experiences in learning environments and campus life; however, in the building science literature related to the classroom environment, they have been less explored. For example, Roetzel et al. [196] investigated the ways in which students' personal and cultural backgrounds may or may not determine the types of spaces where they prefer to study in while on campus. To account for these variables, the authors collected data through open-ended questionnaires and interviews, the result of which they in turn compared to the indoor environmental conditions in these spaces. In soundscape research, for example, the diversity of soundscapes in different cultural settings cannot be fully understood solely through physical measurements alone; contextual experience should also be considered. To account for these contextual factors, building sciences may turn towards those in the humanities and social sciences to better understand how people actually, rather than theoretically, experience these acoustic environments [197]. Other analysis has proposed a similar approach, clustering student profiles, to better understand how students' backgrounds impact their on-campus experience and perceptions of the environment. This approach involves studying different profiles of university students according to their IEQ and psychosocial preferences in study spaces (not classrooms) [198], and health and IEQ preferences in student housing [199]. These studies tend to emphasize the importance of demographic and identity factors such as gender, age, lifestyle, and personality in influencing environmental satisfaction, comfort, and preference. As this stream of work is in its early stages, further research is needed on the ways in which these factors interact and collectively impact student wellbeing within the campus environment, particularly within classrooms.

In general, existing studies on classroom environments have predominantly focused on comfort, physical health, and academic performance, while neglecting the psychological and social dimensions of student wellbeing. Consequently, there is a need for a more comprehensive analysis that considers these overlooked aspects and promotes positive impacts to enhance students' overall wellbeing, rather than solely focusing on the prevention of negative issues. Despite significant research efforts aimed at identifying the causes and informing interventions to enhance student experiences of classroom environments, the narrow understanding of wellbeing undermines much of this work and may be the primary reason why this work has not reached its potential. There is a pressing need to develop a broader perspective that encompasses a wider array of considerations, potentially leading to a change in focus and how we go about studying the impact of the campus built environment on student wellbeing. Investigating socio-demographic aspects is likewise an essential step toward embracing a more comprehensive approach to wellbeing within the built environment.

4.5. Wellbeing terminology in the reviewed papers

During the paper review process, we noticed anecdotally that wellbeing was frequently used in the introductory content of the paper but then not meaningfully addressed in the main body of the papers. To examine this more quantitatively, we conducted a term search in each of the papers that mentioned wellbeing to identify where in the paper this was discussed. Among the analyzed papers, we found 23 related to IEQ (approximately 41 % of the 56 papers) and seven related to interior space quality (approximately 23 % of the 31 papers) that used the term 'wellbeing/well-being' in their papers. Fig. 2 shows where the term 'wellbeing' or 'well-being' was used throughout the body of the reviewed papers.

For the IEQ-related papers in particular, wellbeing is often used as an umbrella term for satisfaction, comfort and health. This is reflected in the frequent use of the term wellbeing in the IEQ paper introductions, but then it is replaced by language about comfort and health in the methods, results and conclusions of the papers suggesting that perhaps wellbeing was not actually the focus of these studies. Overall, only three papers provided definitions of 'wellbeing/well-being' specifically for their research purposes [18,65,181], included a thorough discussion of the term in multiple sections of their papers and explored how various indoor environmental factors and interior space quality impact the wellbeing of students in university classrooms. In these papers, the concept of wellbeing was addressed in two ways: 1) approaches where authors explicitly link variables, such as health-related factors or mood, to wellbeing and subsequently use these variables as proxies for well-being, and 2) approaches that directly evaluate wellbeing using self-reported wellbeing measures and then identify the variables and aspects that are linked to wellbeing.

Using the first approach, Shan et al. [65] began by defining self-reported health through SBS symptoms as a means of quantifying student wellbeing in the university context, but the authors did not ask about student wellbeing directly. Instead, they used a subjective questionnaire about SBS symptom prevalence, that was converted to sick leave days and then benefits related to avoided sick leave was treated as a proxy for wellbeing, as described in Section 4.1. The study focused on two nearly identical tutorial rooms, which differed only in their ventilation systems, and explored how IEQ affects students' wellbeing and performance, then translating these parameters into monetary terms. The life cycle costing was calculated based on the number of sick leave days and the weighted average marks for these terms, and different weighting schemes were implemented through a life cycle cost (LCC) perspective. Overall, the study found that consideration of students' wellbeing and performance can lead to significant total net benefits for improved IEQ scenarios. The authors suggested that a more balanced weighting scheme should be adopted for LCC. Instead of the current practice which heavily prioritizes capital and energy, wellbeing and performance should also be integrated. In a study conducted by van den Bogerd et al. [181], the researchers examined the impact of indoor nature on various aspects of students' experiences within a classroom setting. As part of their methodology, they focused on the concept of wellbeing, which they measured using the sub-scales of stress (i.e., tension), fatigue, and vigor from the Dutch Profile of Mood States (POMS) [200]. Data were collected during lectures to assess students' wellbeing using the parameters from POMS, while also investigating perceived environmental quality, health complaints, and teacher evaluations in classrooms with indoor nature compared to control classrooms that lacked such elements.

Considering the second approach which is a more direct evaluation of wellbeing, Muhammad et al. [18] investigated students' perceptions of various aspects of academic buildings and their impact on student wellbeing. Their study examined both interior elements, such as classroom size, furniture, and finishes, and IEQ aspects and controls within different spaces, including classrooms, study areas, offices and libraries. Through semi-structured interviews during focus group discussions, they gathered insights on how academic buildings affect wellbeing, learning, productivity, and the role of building features in students' academic and social interactions. The primary objective was to identify the factors influencing student wellbeing within academic settings, based on key themes highlighted by the participants. By aligning their findings with the Conceptual Model of Quality of College Life [201], they concluded that satisfaction with academic buildings contributes to enhanced overall satisfaction with both academic and social aspects of college life, thereby improving student wellbeing. Their analysis identified six critical themes as essential to student wellbeing in relation to academic buildings including: comfort; health and safety; access and quality of facilities; space provision and adequacy; participation and inclusiveness; and interaction.

Based on this review of the building science literature that cited wellbeing, it appears that indoor environment research based on comfort and health is undergoing a rebranding as wellbeing research. However, this transition does not appear to involve significant changes in the framing of the studies or evaluation methods. The concept of occupant wellbeing in buildings is still commonly understood in the building science literature as the cumulative outcome of the individual interactions between occupants and the diverse array of building features [40]. From this standpoint, the performance of a building is commonly evaluated by examining how well the indoor environment supports the satisfaction of its individual occupants. This evaluation is often primarily focused on assessing the level of satisfaction that occupants have with specific elements of their environment or the overall space [202,203]. This approach overlooks the broader impacts of social

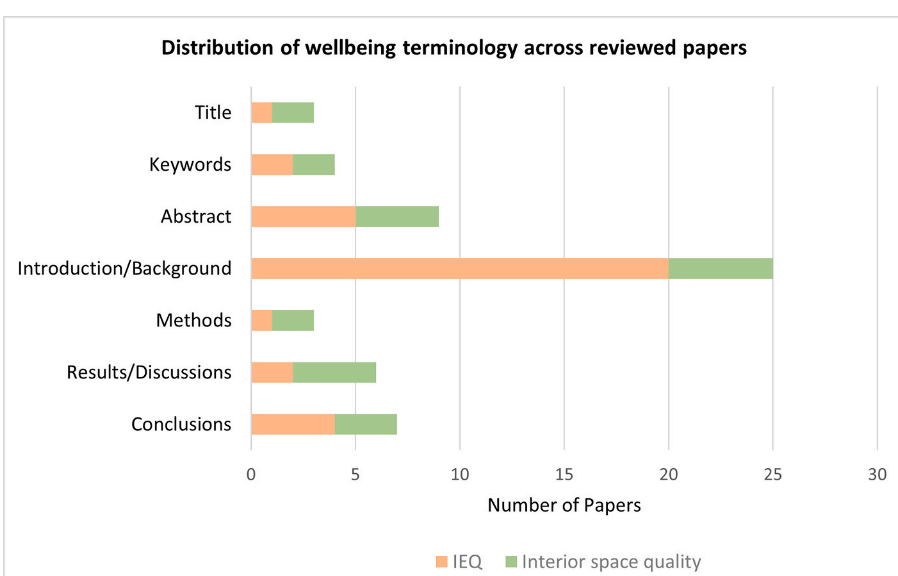

Fig. 2. Distribution of wellbeing/well-being terminology across reviewed papers.

factors, such as the sense of ownership and belonging, as well as symbolic elements related to cultural interpretations of wellbeing which shape occupants' experiences within buildings [40]. These aspects are discussed further in section 5.

5. Towards a broader understanding of wellbeing

Students' experiences and their overall wellbeing are mutually influenced by and influence their interactions with the campus environment. These experiences take place within a physical context that is shaped by diverse cultural norms and administrative policies [204], highlighting the dynamic interplay between students and their educational environment. However, campuses have yet to establish a universally acknowledged definition of wellbeing, and there remains no dominant model for framing and measuring wellbeing initiatives on campus [5,205]. Campus initiatives, with the goal of improving students' overall functioning, should encompass all dimensions of wellbeing and be integrated into every aspect of campus culture, including services, pedagogy, extracurricular programming, and physical spaces [206]. Therefore, as a part of this holistic perspective, the physical, environmental and spatial qualities of the spaces become essential considerations. However, in higher education settings, student wellbeing is often evaluated from individual perspectives and through proxies relating to health and comfort. Rarely are community dimensions taken into account.

In general, student life on campus is shaped within the physical environment, both inside and outside buildings. The physical campus environment comprises diverse elements that have the potential to influence individual and community experience and overall wellbeing of students [17]. For example, the campus walkability, architectural and environmental design aesthetics, and on-campus resources such as a cafes, cafeterias, and study spaces, may be as or less important to student wellbeing as the cost-of-living in the city where the campus is located, the quality and availability of transportation options to and from campus, the position of a campus within a city or region, and the nature of the relationships between the university, students, and their neighbours. If, as suggested above, wellbeing is understood as a multifaceted concept encompassing material, relational, and subjective aspects, it can usefully be regarded as a social process that occurs through various relationships: between individuals and collectives, local and global contexts, and people and the state [207]. Hence, in order to better understand the influences of environmental, personal, and organizational aspects on the wellbeing of individuals and the collective as a whole, a holistic approach to assessment is important.

In addition, explorations of the range of factors and dimensions that shape student wellbeing in educational environments are influenced by how researchers, and students themselves, conceive of what wellbeing is, what it means, and how it can be measured. The ways in which these questions are answered are contingent on the context (i.e. spatial and/or socio-cultural) in which the researchers and students exist and operate. As such, definitions of wellbeing and corresponding approaches to its measurement and evaluation often change over time [208,209] and may differ broadly across cultures [35,210]. For example, researchers and students raised, trained, and operating within the dominant individualistic social system in North America may have very different understandings of wellbeing than those from non-western cultures that often place a higher value on collective, rather than individual achievements [40,211,212]. Accounting for the range of understandings of wellbeing is of particular importance to explorations of student wellbeing in classroom environments at institutions of higher education due to the diversity of the cultural backgrounds and the lived experiences of students, staff, and faculty.

5.1. From reducing risk to promoting wellbeing

The traditional definition of comfort focuses on the absence of annoyance and presence of steady environmental stimuli. The paradigm shift in the built environment domain concerning wellbeing involves introducing positive stimuli to enhance indoor environments, which marks a departure from the traditional emphasis on risk avoidance. This approach recognizes the significance of integrating elements that foster positive experiences, adding value and enhancing the overall wellbeing of individuals within buildings [37,38,46]. In a campus environment, instead of rebranding comfort research as wellbeing research, a new approach which considers the individual and cultural differences of students is needed to understand the contexts in which their wellbeing is assessed. Research on experiential delight (e.g. visual, thermal and acoustic delight) known as alliesthesia, has been focusing on the dynamic exposure to multisensory stimuli and sensory pleasure that extends beyond neutrality [38,213,214]. Using the example of acoustics, historically, "unwanted" sounds are considered as noise regardless of their composition and meaning in the context, but minimizing the sound levels did not always create more comfortable environments. Depending on the performed task, control opportunities, and exposure time; a threshold is proposed for the use of desirable sounds, and if the sound level is above the context-dependent threshold, a switch from the use of desirable sounds to the noise control approaches is recommended [144]. Contextual experience is an important factor in indoor soundscape studies. Perception and experience are evaluated through the combination of objective acoustic measurements and subjective assessments in different space types and cultural contexts, and taking occupant-related indicators into consideration is important, including both physiological and psychological elements [215]. Similarly, thermal comfort is highly context and time dependent, as it varies between people and within the same individual under different circumstances, there is a need for personal comfort models [216]. Nevertheless, in the context of classrooms, further research is necessary to understand the complex interplay of environmental, contextual, individual and community factors that impact students' experiences.

In summary, higher education institutions may aspire to create classroom environments characterized by excellent IEQ and interior design, which are comfortable, health-promoting, and inclusive, effectively incorporating attributes such as sensory environments, biophilia, aesthetics, engagement and safety, with the expectation that these measures will foster opportunities for student wellbeing while supporting their academic performance. Indeed, the idea of moving beyond risk reduction to promoting wellbeing can be interpreted as a shift from net zero to net positive approaches, aligning with regenerative sustainability as a pathway toward achieving net positive design and sustainability in both human and environmental terms [217,218].

5.2. From individual to community wellbeing

Grounded in a sum-of-the-parts perspective, the wellbeing of campus users is typically framed as the cumulative result of the interaction between individual characteristics (such as health and socio-economic status) and environmental features (such as how campus buildings and instructional spaces are designed) [40]. Shared or community-wide elements, such as the lived experience of individuals, academic stress, and/or the effect of geo-political forces such as the climate crisis, are not accounted for in this approach.

To a certain extent, this approach makes sense. For example, if a classroom includes bright windows with views of nature, comfortable seats, adequate charging points, and high-quality audiovisual systems reflective of the style of instruction (all features linked with positive experiences of instructional spaces), a sum-of-the-parts perspective would argue that this space supports student wellbeing. This perspective, however, does not account for the influence of other factors that shape student wellbeing on campus including, but not limited to: the quality of instruction in the classroom [219]; students' lived experience both on and beyond campus [220]; students' sense of belonging within their program of study, department, or university [221]; and broader socio-cultural trends and events such as the accelerating climate crisis [222] or COVID-19 [223] among others. This is not to argue that environmental elements do not play a role in shaping student wellbeing on campus, indeed the studies explored above point to its importance, but rather that environmental factors alone may not be primary determinant in student wellbeing.

Social factors can also dramatically change how users respond to a certain building feature, even if these features were chosen to promote student wellbeing. When a student with the lived experience of racialization attends a lecture on campus, for example, whether or not their experience in a certain lecture hall contributes positively to their wellbeing may have less to do with the design features of the room than with their sense of belonging on campus and/or their anxiety about their performance in their chosen program. In other instances, an instructional or study space that is well-maintained and welcoming to all users may promote student wellbeing even if its environmental features are not often associated with positive wellbeing outcomes. For example, students may gravitate to and do their best work in a space in the basement of an older building that lacks windows or comfortable furniture because they feel safe or welcome there. Yet the extent to which these non-environmental features of the campus-built environment, which we understand to be shared social or community elements, influence and/or mitigate the impacts of environmental features remains largely unexplored in the building science literature.

The absence of community elements in studies of the relationship between the student wellbeing and classroom environments may be attributed in part to the disciplinary backgrounds of researchers. Building science is typically the realm of engineers and architects whose technical expertise may not be accompanied by a familiarity with social-science approaches to wellbeing. In a discipline grounded in a tradition of standardization, benchmarking, replication, and comparability; researchers may be hesitant to explore approaches to understanding wellbeing in building assessment that do not ascribe to these norms. This points to the need for interdisciplinary teams of researchers to explore the influence that the built environment may or may not have on occupant wellbeing from social, technical, and environmental orientations to help identify and account for potential biases and blind spots.

5.3. The potential of a social practice approach

If researchers accept the proposition that student wellbeing on campus environments is shaped in important ways by social or collective elements and environmental and individual factors, they face an immediate theoretical decision during the research design and analysis stages of their work. How these researchers ground their understanding of the influence of collective elements of student wellbeing in social theory(ies) may lead to disparate means of how wellbeing is framed and evaluated.

One theoretical approach that may be well suited for understanding how wellbeing emerges from the dynamic interaction between the collective, individual, and environmental elements of the campus environment is social practice theory. Social practice theory investigates everyday life and how it changes over time by focusing on largely unconscious practices, as the primary unit of social analysis. As advanced in the work of Bourdieu [224] Schatzki [225], Reckwitz [226], and Shove et al. [227] among others, social practice theories explore the ways in which daily routines such as driving, showering, working in an office, and/or, in the case of a campus environment; traveling to, and from campus and attending classes, are culturally produced. The built environment (transportation infrastructure, housing, academic buildings, etc.) plays a key role in shaping these practices carried out by individuals.

The tripartite model of social practice introduced by Ref. [227] in particular, offers a useful framing for exploring student wellbeing in campus environments [40,217]. This model proposes that social practices emerge from the dynamic interaction of three elements over time: material (environmental elements), skills (individual capacities or characteristics), and meanings (shared or collective norms and values). Applying this tripartite social practice perspective to the investigation of student wellbeing on the campus environment presents an opportunity to understand not just how individuals arrive in, interact with, and are shaped by, both the environmental conditions on campus (i.e. building features) but also how collective norms and values that govern their on campus experience (i.e. academic expectations, codes of conduct, their relationships with peers, faculty, and staff) may or may not influence their wellbeing.

6. Areas for future research

In response to the increased awareness of the scale of the wellbeing crisis on university and college campuses in North America, there are early signs that some institutions may be shifting their approaches to promoting student wellbeing from the provision of traditional mental health services towards more systematic interventions that combine health services with "structural, organizational and financial strategies" intended to address the root causes of the crisis [5]. Yet these structural, organizational, and financial strategies may themselves overlook the role(s) that the campus built environment may or may not play in shaping student wellbeing and in turn, how student wellbeing may be influencing how the campus environments are designed, experienced, operated, and/or maintained. Rather than exploring these issues in isolation, there is a need for research on how student wellbeing emerges from the dynamic interaction between the campus environment, student identities and capacities, and collective norms and practices. That type of research will likely challenge disciplinary-specific epistemologies and long-standing practices, but it may also lead to a more holistic understanding of student wellbeing to inform more effective policy and design interventions. This suggests the value of developing new conceptual frameworks that comprehensively address the broader dimensions of wellbeing within the built environment.

7. Conclusion

The growing emphasis on the wellbeing of higher education students has highlighted the significance of indoor environment research within educational buildings. While IEQ research is in the process of rebranding from a comfort and health-oriented perspective to a more wellbeing-centric approach, there is need for a broader, more encompassing perspective that takes into account both individual and collective dimensions of wellbeing to fully understand the specific role that built environments play, in contrast to other organizational, community or individual elements.

In this article, we explored the current understanding of relationship(s) between physical learning environments and student wellbeing outcomes, primarily drawing on literature from the building science domain. By surveying and then deconstructing the mainstream individualistic and sum-of-the-parts perspective of student wellbeing present in the literature, we suggest more holistic and nuanced alternative approaches to understand how student wellbeing emerges in campus contexts, which in turn, may help to identify previously unknown or under-explored components of student wellbeing.

By considering universities to be distinct communities with discrete campus environments, this paper also points to the need to incorporate broader communal or collective elements into assessments of student wellbeing. This calls for the development of a framework that surpasses traditional understandings, facilitating a deeper understanding of the complexities inherent in wellbeing within the campus context. To enrich this framework, we need a multidimensional concept that facilitates the integration of positive elements, feelings, and experiences into indoor environments, moving beyond the current concentration on conventional risk mitigation. Furthermore, it is important to contemplate how the dimensions typically discussed in building science-related literature (i.e. individual and environmental elements) interact with, shape, and are shaped by, broader dimensions (i.e. collective cultural elements) of wellbeing. In our upcoming research, our objective is to operationalize this comprehensive approach by developing a framework that integrates social and community-driven aspects aimed at facilitating the evaluation of how the built environment can improve the sense of wellbeing within campus contexts and beyond. A collaborative effort involving professionals spanning diverse expertise and higher education institutional policymakers becomes imperative in crafting comprehensive guidelines for governing the design and management of educational spaces. This collaborative approach stands as an important factor in ensuring that educational settings prioritize the wellbeing of students.

CRediT authorship contribution statement

Nastaran Makaremi: Writing – original draft, Visualization, Methodology, Investigation, Conceptualization. **Serra Yildirim:** Writing – original draft, Methodology, Investigation, Conceptualization. **Garrett T. Morgan:** Writing – review & editing, Writing – original draft, Methodology, Investigation, Conceptualization. **Marianne F. Touchie:** Writing – review & editing, Supervision, Project administration, Methodology, Funding acquisition, Conceptualization. **J. Alstan Jakubiec:** Writing – review & editing, Supervision, Methodology, Conceptualization. **John B. Robinson:** Writing – review & editing, Supervision, Methodology, Conceptualization.

Declaration of competing 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.

Data availability

Data will be made available on request.

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Appendix A. Supplementary data

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