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Impacts of school environment quality on autistic pupil's behaviours – A systematic review

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ABSTRACT

The school environment plays a critical role in the early years of a child's learning journey. This is especially true for autistic children, whose ability response to school environments significantly differs from that of their non-autistic peers. Autism is a complex developmental condition characterized by social and communication differences, repetitive behaviours, sensory reactivity differences, and need for consistency and routines. The impact of indoor environmental quality (IEQ) parameters of school environment on the behaviour of autistic pupils represents a nascent area of research. The review represents a leap forward by providing comprehensive framework that explain the interaction between IEQ, autistic sensory processing and behaviours. Also, through a systematic review, this paper aims to synthesize and critically assess the existing studies on how IEQ parameters affect autistic behaviours within classroom settings. A total of Eleven relevant studies were identified, indicating a nascent correlation between IEQ parameters—primarily lighting and acoustics—and various autistic behaviours. Other parameters impact such thermal has less attention while the air quality is not studied. Furthermore, there is a significant lack in quantitative research that could support architectural design practices for classrooms catering to autistic pupils. The notable differences in educational outcomes and classroom designs for autistic pupils as compared to those in mainstream schools highlight the insistent need for further research into the impact of IEQ. Such investigations are essential not only to bridge current knowledge gaps but also to guide the development of educational spaces that meet the unique needs of autistic pupils, enhancing their learning and development.

1. Introduction

The relationship between indoor environmental quality and human well-being has been a subject of extensive scholarly investigation, informing the healthy building design for all [1]. This relationship is of particular importance in educational settings, where school-age children spend a substantial portion of their time. The design and conditions of these indoor learning environments are crucial, influencing not only the comfort and well-being of pupils but also their cognitive functions and academic performance [2,3]. Therefore, optimizing the indoor environment to meet the diverse needs of all pupils, including those with unique sensory reactivity differences and cognitive requirements, is essential.

In the research related to mainstream schools, the significance of the indoor environment on pupils' learning and behaviour is well-established [4–8]. However, the specific needs of autistic pupils in school environments and how it could be impacted by school indoor environment have received limited attention. Autism is defined by the Diagnostic and Statistical Manual of Mental Disorders (DSM-5), as a neurodevelopmental condition characterized by challenges in social communication and repetitive behaviours, with many individuals also experiencing differences in sensory reactivity [9–12]. These sensory reactivity differences can significantly influence how autistic pupils perceive and interact with their exposed environment [13,14],

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necessitating adapted approaches to the design of indoor spaces to support their unique needs.

Sensory reactivity in autism is a complex phenomenon, encompassing hyperreactivity (intense responses to stimuli), hypo-reactivity (under-responses), and sensory-seeking behaviour (a desire for specific sensory experiences) [15–18]. These sensory responses can significantly affect autistic individuals' engagement with their environment, potentially leading to discomfort or distress in unsuitable settings [19]. For example, hyperreactivity can make school environments characterized by loud sounds and visual stimuli, overwhelming or even unbearable for some autistic pupils [20–22]. Conversely, hypo-reactive individuals have an under response or dampened reaction to sensory input, such as not noticing sounds or being less aware of temperature changes [23,24]. These individuals may not respond to environmental stimuli in the same way as the hyper-reactive ones, and those with sensory-seeking behaviours may find certain textures or sounds particularly appealing or calming [25]. The relationship between sensory reactivity and human behaviour is a critical area of study, as sensory sensitivities can significantly impact educational progress and behaviour. Externalising behaviours, causing disruptions in class, can be influenced by poor acoustic conditions. Additionally, modifications to the environment, such as improved lighting and sound absorption, may enhance engagement and academic performance [26,27]. Furthermore, sensory reactivity is also linked to internalising behaviours, including anxiety and depression, highlighting the significant impact of the indoor environment on autistic pupils' emotional well-being and educational experiences [17,21,28–30].

Despite the recognized importance of suitable learning environments, research on the specific needs of autistic pupils within these settings is limited. The existing architectural and environmental design practices for schools often draw upon a fragmented knowledge base, with recommendations that may not be fully informed by the latest scientific insights [26,27,31–37]. While some studies offer guidance to specific cases for designing autism-friendly classrooms, the evidence supporting the implementation and effectiveness of these designs is limited [14,38], highlighting a critical gap in the literature. Several review studies have examined the recommendations for the built environment catering to autistic individuals, highlighting the influence of architectural design on sensory sensitivity, comprehension, and predictability of environmental changes [38–42]. However, while these reviews have established the general impact of the built environment on autistic individuals, there is a gap in literature specifically addressing the classroom indoor environment and its effect on educational performance. Furthermore, existing design criteria, often the focus of architectural research, are called to be evidence-based to develop effective building standards that cater to the needs of autistic individuals [14].

The most relevant review on the relationship between indoor environment and autistic children's performance in school settings has been conducted by Dargue et al. [39], but it primarily focuses on lighting and acoustics. Their insight is valuable, yet it also highlights the necessity to investigate other indoor environmental quality (IEQ) parameters, such as air quality and temperature, which could be potentially equally influential. For example, autistic children may exhibit distinct behavioural responses to temperature variations, differing from those of neurotypical children, as research indicates a significant relationship between thermal conditions and behavioural reactions [43]. Such findings emphasize the need for a broader exploration of IEQ parameters and their impacts on autistic pupils' behaviours in classroom settings.

To bridge this gap, the current study aims to advance our understanding of the impact of indoor environment quality on autistic pupils' behaviours in the classroom by conducting a systematic review. A framework is firstly developed that describes how various environmental parameters, such as lighting, acoustics, air quality, and temperature, interact with the sensory sensitivities and behaviours of autistic pupils. Then, we conduct a systematic review to enhance our understanding of the indoor environmental impact on autistic pupils' behaviours in the classroom setting. This research contributes to the fields of psychology, architecture, and inclusive education, offering valuable insights for architects, educators, and policymakers dedicated to creating equitable and effective learning environments.

2. Conceptual framework addressing the interaction between IEQ, ASD sensory processing and behaviours

Theoretical models have been proposed to explain the sensory processing mechanisms in autism, highlighting how sensory inputs can influence autistic behaviours [17,44–46]. However, there is still a lack of specificity in the defining of sensory input and outcome classification. By explaining sensory inputs related to IEQ, such as acoustics, light, thermal and air quality, this paper proposes a comprehensive framework aiming at enhancing educational progress for autistic individuals through optimal IEQ conditions [47].

Our framework starts from the sensory taxonomy by He et al. [46], which provides a level of analysis from perceptual sensory sensitivity to observable behaviours in autistic individuals. Their framework has broad applicability but does not specifically detail the role of sensory inputs and their outcomes in classroom settings. A study by Fernández-Andrés et al. [48] demonstrates the significant impact of classroom environment on autistic sensory reactivity, particularly in auditory and tactile domains compared to the home context. While this study emphasizes the intricate relationship between sensory reactivity and IEQ parameters, other studies focus on the subsequent behaviours of sensory reactivity [49,50]. Consequently, we propose a new framework combining the two studies and broadening the potential autistic behaviours influenced by IEQ parameters in the classroom setting.

Our proposed framework, illustrated in Fig. 1, conceptualizes the pathway from sensory inputs within the classroom environment-such as sound, light, temperature and air quality-through sensory processing, leading to behaviour change that influence educational progress. This sensory process encompasses initial physiological reactivity (hypoarousal versus hyperarousal), to sensory stimuli, followed by sensory reactivity (e.g., feeling overwhelmed or calm towards a sensory stimulus), and turn into observable behaviour (e.g. leaving the room to avoid the sensory stimulus) [45,46]. Sensory reactivity differences may manifest in varied responses to sensory inputs, including hyperreactivity (overwhelm), hypo-reactivity (diminished response), or seeking behaviours (fascination) [46]. These processes give rise to a spectrum of behaviours, both internal and external, that have the potential to affect educational progress. Significantly, these responses can be modulated by personal factors and external mediators, such as the support provided by teachers. The framework highlights the importance of a holistic understanding of these dynamics to develop strategies that enhance indoor environmental quality, thus supporting the educational progress of autistic pupils.

To illustrate, consider the acoustic environment within a classroom as a sensory input that can cause different behavioural responses in autistic pupils, particularly those hypersensitive to auditory stimulation. Various classroom activities may produce fluctuating noise levels, initiating physiological responses like increased heart rate, leading to hyperarousal and hyperreactivity, such as feeling overwhelmed by noise [45,51]. This can result in observable behaviours including ear covering, crying, or self-injury, which could negatively impact educational progress [27,52]. Similarly, other IEQ parameters—lighting, thermal conditions, and air quality—also play crucial roles in influencing the classroom experience for autistic pupils. The following section explores these fundamental concepts, emphasizing the intricate relationship between IEQ parameters and autistic behaviours, and underscoring the necessity for comprehensive strategies to improve classroom environments for autistic pupils' educational benefit.

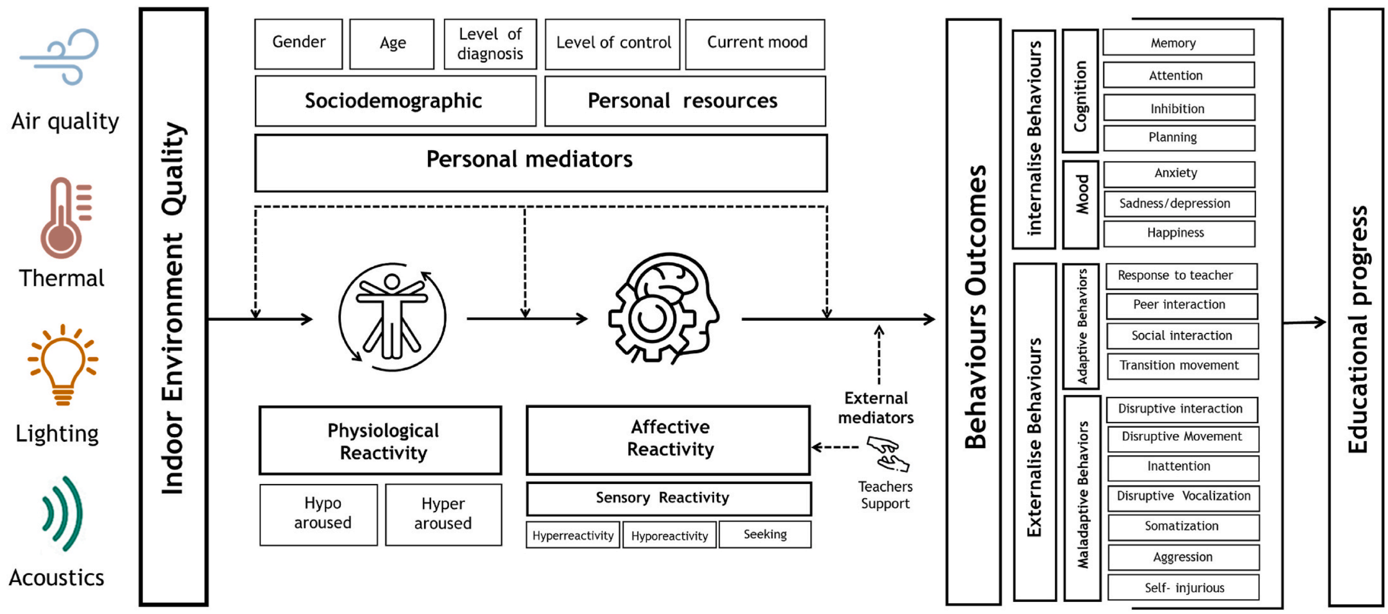

Fig. 1. Conceptual framework addressing the interaction between IEQ, autism sensory processing and behaviours.

2.1. Indoor environment quality (IEQ)

The concept of Indoor Environment Quality includes various indoor environmental variables, which define the quality of the environment of spaces and its acceptability to users: thermal comfort, indoor air quality, visual, and acoustic comfort [53,54]. IEQ presents as a sensory stimulus input, produced from external factors such as noise, odours, lighting, and temperature, and is perceived through the senses, including sight, touch, hearing, smell, taste, and proprioception[55].

2.2. Sensory processing

Sensory processing is defined as a complex process whereby the brain detects and receives sensory inputs from the external environment and consequently produces a response based on the detected inputs [56]. Autism research reveals distinct sensory processing patterns, characterized by psychological and physiological approaches. Psychological studies focus on observable behaviours stemming from sensory reactivity, whereas physiological research delves into the underlying neural mechanisms [45]. Dunn [57] proposed a taxonomy that integrates neuroscience with behavioural science to delineate sensory processing, highlighting that neurological thresholds influence stimulus perception, and behavioural responses reflect reactions to these stimuli. This model presents four sensory processing taxonomy: poor registration, sensitivity to stimuli, sensation seeking, and sensation avoiding. Furthermore, He et al. [46] propose a hierarchical model of sensory differences in autism, spanning neural excitability activity, sensory perception, affective reactivity and behavioural responsivity. This integrated model emphasizes the significant influence of sensory processing variations on autistic individuals' experiences within indoor environments. A comprehensive understanding of sensory processing in autism is critical for adjusting indoor environments to adapt educational progress for autistic individuals.

2.3. Behaviours

Despite the lack of studies directly linking IEQ parameters with autistic behaviours in classroom settings, developing research underlines a significant correlation between sensory reactivity in autistic individuals and their behaviours within school environments [19,49,50,58–61]. These studies find that autistic pupils' behaviours can manifest as either externalising or internalising, with external behaviours ranging from adaptive engagements, such as participating in lessons or interacting with teachers, to maladaptive responses including inattention or self-injurious actions.

The proposed framework suggests that IEQ parameters affect these behavioural dimensions, offering a holistic view of the impact of environmental parameters on the educational progress of autistic pupils.

3. Method

We apply the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines ensuring a rigorous and structured analysis process [62]. A comprehensive literature search was conducted across three major electronic databases: Web of Science, Scopus, and PubMed, covering the period from June 2021 to June 2023. In addition to this, manual search of references and citations was performed to capture any additional relevant studies.

The search strategy included terms related to autism and the physical environment: (Autis* OR ASD) AND ("physical space" OR "building design" OR "sensory environment" OR "learning environment" OR "indoor environment" OR "classroom*" OR "physical environment" OR "ambient environment" OR "school design") AND (sound* OR noise* OR acoustic* OR lighting OR smell* OR olfact* OR vibrat* OR temperature* OR visual* OR "airflow" OR "ventilation" OR "humidity" OR "daylight" OR "air quality" OR "thermal comfort" OR "*stimul*"). This included a broad array of keywords to encompass various aspects of the physical environments within educational settings, ensuring a wide-reaching review of the literature in this field.

The inclusion criteria were carefully defined to focus on studies involving autistic participants within specific classroom contexts, excluding those in mixed or non-autistic settings. Selected studies were required to examine the effects of physical environmental parameters (e.g., noise level, lighting) on autistic behaviours, with a particular interest in both externalising (e.g., disruptive behaviour, aggression, social interaction) and internalising behaviours (e.g., cognition, attention, mood). Studies utilizing the physical environment as an intervention tool (e.g., black light, music background) or those focused on multisensory or virtual environments were excluded to maintain a clear focus on natural educational settings. Additionally, post-occupancy evaluations were also included to gather insights into effective design practices for autistic classrooms, excluding those developing measurement tools for such environments.

The literature search identified 11 papers that met the inclusion criteria, with some studies examining multiple IEQ parameters. These studies, published between 2007 and 2021, reflect the evolving criteria for autism diagnosis introduced in 2007. Among the included studies, nine focused on acoustical parameters, two on lighting and one on thermal comfort, highlighting the diverse impacts of IEQ on autistic behaviours within educational settings, see Fig. 2.

4. Results

The results are presented within a developed framework that systematically evaluates how each identified IEQ parameter influences behaviours in autistic pupils, using data derived from both field and laboratory studies to illustrate these relationships. Table 1 provides a comprehensive overview of the key findings, highlighting the specific IEQ parameters investigated and their observed effects on autistic pupils.

The evaluation matrix is utilized as a structured tool to categorize and compare the IEQ parameters across the reviewed studies, enabling a systematic analysis of how each parameter impacts autistic behaviours. It quantifies elements like sound levels, lighting conditions, and air quality, and correlates them with observed behavioural outcomes, providing a comprehensive and comparative overview.

Studies within the acoustics domain investigate the effects of noise levels and echo on both internalising and externalising behaviours, identifying significant effects on autistic pupils' comfort and engagement in learning environments. Research on lighting examines the influence of light source characteristics, luminance, intensity, and flickering rates, primarily focusing on their impact on externalising behaviours. Thermal conditions have been much less explored compared to the prior two, with only a singular study addressing the effect of temperature on facial expressions and the potential influence of airflow on externalising behaviours.

4.1. Acoustic

4.1.1. Acoustic evaluation matrix

In the domain of acoustics, nine studies have been identified, primarily focusing on the implications of noise levels on internal and external behaviours exhibited by autistic individuals [26,27,31,51,58,63–66].These studies focus on a critical examination of noise exceeding 45 dB and its potential disruption to autistic individuals, due to differences in auditory filtering [68]. However, other acoustic parameters such as speech clarity (C50 and D50) and lower noise levels remain underexplored, despite their potential significance [69–71]. Furthermore, similar research on non-autistic pupils underlines the impact of reverberation time (RT) and speech clarity on concentration and speech perception within classroom settings [72], suggesting these acoustic parameters need further exploration in autistic pupils.

4.1.2. The relationship between acoustic matrix and autistic behaviours

The nine studies observe autistic behaviours including internalising and externalising behaviours. Six of nine studies identify externalising behaviours associated with acoustics environments, including repetitive behaviours, ear covering, and repetitive movements [26,27,31,63–66]. Specifically, Kanakri et al. [63] documented a significant correlation between elevated noise levels and increased instances of repetitive behaviours and pupils produce noise, with a correlation coefficient of 0.31 ($p < .001$). Moreover, three studies identify a relationship between noise level and internalising behaviours [31,51,58], with two among them identifying a negative impact of noise level on cognitive performance due to increasing arousal levels in autistic pupils [51,58]. Nevertheless, none of studies differentiate autistic behaviours based on sensory reactivity profiles (hypo- or hyper-reactivity) as different sensory reactivity types may response differently to the same acoustic stimuli [64], indicating a need for incorporating this variability to fully comprehend the sensory experiences of autistic individuals and their behavioural responses.

4.2. Lighting

4.2.1. Lighting evaluation matrix

In the dominion of lighting, two studies have been conducted. Gaines et al. [67] and Kinnealey et al. [26] explored the effects of classroom lighting levels (illuminance) and flickering rates on autistic behaviours, respectively. Gaines et al. [67] found that sources of light and luminance can cause stereotypical behaviours. Kinnealey et al. [26] observed a

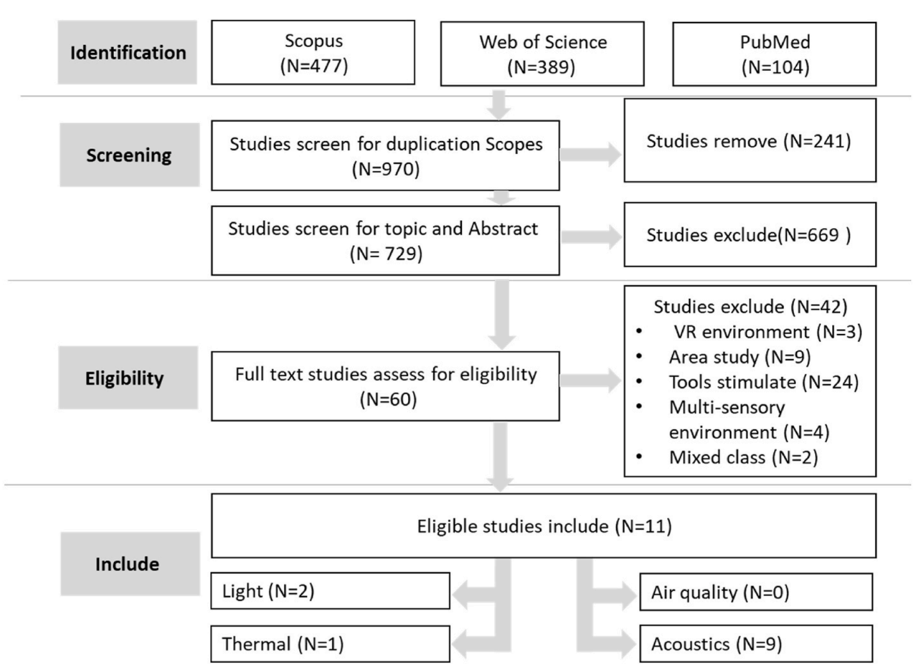

Fig. 2. PRISMA flowchart of the screening process for article selection.

Table 1
Summary of key studies and findings from the 11 reviewed papers.

Reference	Research design	Environment measures	Instrument	Number of Schools	Sample size	Age	Behaviours		Analysis	Correlation
[27]	Survey	Sound level, echo	Develop survey	4	74 teachers	Preschool to high school	Externalising behaviours	maladaptive Behaviours (Disruptive behaviours)	Descriptive	Significant (subjective evaluation)
[63]	Physical measurement	Sound level	Logitech-C920 Pro Webcam—Black. 1800 Precision Integrating Sound Level Meter Noldus Observer XT (behaviours track)	2	42 autistics (M = 37, F = 5)	Second and third grades	Externalising behaviours	Repetitive behaviours	Pearson correlation coefficients	Positive correlation
[26]	Intervention (mixed method)	Sound level + Flicking rate	Decibel meter Video recording (attending behaviours) Interview Sensory Profile		M = 4	13–20	Externalising behaviours	Adaptive and maladaptive Behaviours	Descriptive	Improve performance
[58]	Survey	Sound level	SSP (McIntoshetal.,1999)	NA	28 (M = 24, F = 4)	6–10	Internalising behaviours	Cognitive: attention		Negative correlations
[51]	Physical measurement	Sound level	Cognitive Task(The MathWorks, Inc. 2013) Quest Model 1900 sound level meter Sympathetic responses were collected using electrocardiogram (ECG) and electrodermal activity (EDA)	NA	M = 23	12–17	Internalising behaviours	Cognitive: memory	A series of 2 × 2 × 2 mixed-model analyses of variance (ANOVA)	Autonomic Arousal is significant and worse performance
[64]	Physical measurement	Sound level	Skin Conductance Measures SNS (Dawson et al., 2007) SPM manual (Parham et al., 2007) Auditory stimuli	Lab	25 (M = 21, F = 4)	5–12	Externalising behaviours	maladaptive Behaviours	Pearson's correlation	Significant
[31]	Survey, intervention	Sound level, echo	Friedman of attention span and response time Wilcoxon Signed Rank Testing was used for readings of behavioural temperament.	1	12 (M = 9, F = 3)	6–10	Internalising behaviours and Externalising behaviours	attention span, response time maladaptive Behaviours (repetitive behaviours)	NA	Significant
[65]	Survey	Sound level	Develop questions	NA	96 teacher	NA	Externalising behaviours	maladaptive Behaviours (Repetitive Behaviour)	Descriptive	Significant
[66]	Survey Physical measurement	Noise level and RT	Questionnaire Sound level meter (RION NA-28) and extension measurement system (RION NX-BA)	3 classrooms	NA	NA	Externalising behaviours	maladaptive Behaviours (Self-injury)	Descriptive	Significant
[67]	Survey	source of light, luminance, and intensity of light	Focus group Questioner	NA	NA	NA	Externalising behaviours	Repetitive Behaviours	Descriptive	NA
[43]	Physical measurement	Temperature	Tactile stimulation Video recorder Behaviour was coded (reactivity score of 1 or 0)	Lab	30 (M = 28, F = 2)	7	Externalising behaviours	facial expression	NA	Significant
		Airflow						behaviour patterns of seeking		Significant

reduction in the frequency of maladaptive behaviours in autistic when the lighting fixtures were switched from fluorescent to halogen. However, these studies did not assess the accuracy of light level measurements, leaving a gap in the evaluation of lighting levels' impact. Moreover, other critical lighting parameters such as daylight, colour temperature, and reflection remain unexplored with their effects on autistic behaviours. Research in non-autistic populations, such as Mirrahimi et al. [73], suggests that natural light significantly enhances mood, attitude, and performance and high correlated colour temperature (CCT) of lighting fixtures can improve on-task behaviours [74] and attention [75], while short-wavelength radiation positively affects oral reading fluency [76]. These findings indicate the potential impact of other lighting parameters on autistic pupils, given their increased sensory sensitivity.

4.2.2. The relationship between autistic behaviours and lighting matrix

The influence of lighting on behaviours, especially externalising behaviours, was investigated in two studies. Gaines et al. [67] and Kinnealey et al. [26] observed externalising behaviours, including both adaptive and maladaptive responses. Kinnealey et al. [26] specifically examined behaviours such as ear covering, vocalizing, and responsiveness to teachers, with interventions including modification of classroom lighting from fluorescent to halogen fixtures. This change was found to enhance sensory comfort, thereby improving attention, engagement, and academic performance among autistic pupils with hyperactivity. Additionally, Gaines et al. [67] identified that the intensity of light had a significant effect on repetitive behaviours, more so than other IEQ parameters, across various contexts in the USA and UK. These findings highlight the critical role of lighting parameters in influencing autistic behaviours, though they also underscore the need for further research to comprehensively understand these influences.

4.3. Thermal comfort

In the domain of thermal comfort and its impact on autistic behaviours, Pernon et al. [43] stand out as the only study measuring the effects of thermal stimuli—specifically temperature and airflow—on autistic children in a laboratory setting. The experiment explored tactile temperature stimulation through direct contact with (50 °C–45 °C), and cold (−5 °C to− 10 °C) objects, alongside controlled ambient conditions and direct airflow to the face, to observe externalising behaviours. Temperature changes prompted neutral facial expressions, while airflow caused seeking behaviours, such as moving closer to and engaging with the airflow source. These findings, however, are conducted in a controlled laboratory environment, which may not accurately reflect classroom settings where factors like occupant density can significantly affect thermal comfort and behaviours [77]. Moreover, while the impact of thermal comfort on learning and well-being has been established in non-autistic populations [77,78], the challenge of assessing thermal comfort in autistic pupils—particularly those with limited verbal communication abilities [12] -highlights a gap in research. This focuses the necessity of further investigation into how thermal comfort influences autistic pupils in classroom environments.

4.4. Air quality

No study has specifically assessed the impact of indoor air quality on the behaviours of autistic pupils in classroom settings. Existing research concerning autism behaviours and air quality primarily investigates potential etiological links between autism and environmental air quality factors [79,80]. Larsson et al. [79] suggested that factors such as material pollution, ventilation, and humidity could influence autism's prevalence. The impacts of classroom air pollutants, such as $PM_{2.5}$, PM_{10}, and CO_2, on learning performance and health risks are well-documented in non-autistic pupils [81–83], with children particularly vulnerable due to their developing respiratory systems [84]. This vulnerability may be heightened in autistic individuals due to their increased sensory sensitivities. Despite these insights, evaluations of indoor air quality conditions in schools specifically for autistic individuals remain notably absent, highlighting a crucial gap and underscoring the need for future research to understand how indoor air quality parameters impact autistic behaviours.

This review investigates evidence on the impact of IEQ parameters on autistic behaviours in classrooms, focusing on acoustics, lighting, thermal comfort, and air quality. Acoustic studies show that noise levels above 45 dB exacerbate externalising behaviours like repetitive movements and negatively affect cognitive performance related to internalising behaviours. Lighting studies reveal that halogen lighting reduces maladaptive behaviours compared to fluorescent lighting, although other lighting parameters remain underexplored. A thermal comfort study indicates that temperature and airflow stimuli influence externalising behaviours, but its relevance to real classrooms is uncertain. No specific studies address the impact of air quality on autistic behaviours, highlighting a significant research gap. This review emphasizes the importance of providing optimal IEQ conditions in designing classrooms for autistic pupils to enhance their educational progress.

5. Discussion

This systematic review critically investigates the relationship between IEQ in autism classrooms and the subsequent behaviours, drawing on a mix of laboratory and field studies. Despite IEQ being a well-established research area in the context of mainstream classrooms, its focus on special needs, particularly autistic pupils, only began gaining traction in 2007, with a modest but growing body of work emerging over the last decade. The review reveals a research gap, with only eleven studies meeting the inclusion criteria set forth.

5.1. Participant characteristics

The findings of this systematic review underscore critical methodological issues that can affect the generalizability and validity of research outcomes. The small sample sizes observed across the majority of studies limit the statistical power and robustness of the findings, raising concerns about the reliability and reproducibility of the results [85]. With the largest study involving only 42 participants, it is challenging to draw conclusions that can be applied to a broader population. This is particularly problematic in experimental studies, where larger and more diverse samples are essential to validate the efficacy and applicability of understanding the impact of IEQ on autistic behaviours.

Moreover, the substantial gender imbalance, with males representing 91 % of the sample, highlights a significant gap in the research. This underrepresentation of female participants not only limits the ability to generalize findings across genders but also perpetuates a bias that can affect the interpretation of results. Gender differences in physiological, psychological, and social factors can influence study outcomes [86,87], and without adequate representation, the research fails to account for these variations [88]. The finding by Chang et al. [64], which indicate that females may exhibit more pronounced responses in skin conduction measurements, further underscore the importance of including female participants in research to account for potential physiological differences. This highlights the necessity for further research into the impact of IEQ on females with autism to comprehensively understand their sensory reactivity patterns.

The demographic limitations highlighted the need for a re-evaluation of research designs and sampling strategies. Ensuring diverse and adequately sized samples is fundamental to producing robust and generalizable findings, contributing more effectively to the body of knowledge.

5.2. Assessment criteria

In the context of review studies focused on IEQ in classrooms and its impact on autistic sensory reactivity and behaviours, the methodologies for assessment play a fundamental role in determining the reliability and applicability of findings. Table 2 summarizes the methods used for data collection in review studies, categorizing them as quantitative or qualitative. The assessment of IEQ parameters and their effects on autistic individuals is complex, requiring a clear and accurate methodology to capture the interactions between IEQ, sensory reactivity and behaviour effectively.

5.2.1. IEQ parameters

The methodologies for monitoring IEQ parameters reported in the reviewed studies were predominantly subjective, particularly in assessing lighting conditions. This reliance on subjective methodologies is evident in 7 out of 11 reviewed studies, indicating a potential gap in the use of objective, quantitative measures in IEQ research. For example, the subjective assessment of lighting conditions in Gaines et al. [67] was measured as high or low, which can vary greatly between individuals, introducing significant variability and potential bias into the research findings. Conversely, a study conducted on non-autistic pupils found that varying light levels (380 lux and 750 lux) affected children's cognitive performance [94]. This suggests that different lux levels can produce measurable differences in responses. Additionally, many autistic individuals experience light intensity as brighter than non-autistic individuals due to visual sensitivity [17].

Recent work by Ref. [95] found IEQ parameters show similar sensitivity trends in autistic individuals. However, their survey is subjective hence the impact of air quality on autistic pupils remains underexplored. Many studies have shown the impact of CO_2 and PM levels on the cognitive performance of non-autistic pupils [81–83]. One study found that a slight increase in CO_2 levels from 600 to 1000 ppm negatively influenced cognitive performance [96]. For some autistic individuals, intense odours and stale air may be perceived as stressors [42], suggesting that poor indoor air quality could theoretically impact their behaviour and wellbeing.

The relatively unexplored nature of this area within IEQ research may be due to the lack of standardized, objective measurement protocols. Establishing and widely adopting these protocols is essential to advance our understanding of how IEQ parameters affect autistic behaviours and to develop evidence-based design recommendations for school environments.

5.2.2. Sensory reactivity

The methodologies employed to assess autistic sensory reactivity typically involve standardized tests and surveys, necessitating third-party evaluations that may not fully capture the experiences of autistic individuals [97]. Challenges such as test anxiety and difficulty in maintaining focus can significantly hinder the effectiveness of these assessments for autistic pupils [98]. Furthermore, reliance on sensory profiles to determine sensory sensitivities—without addressing seeking behaviours—highlights the limitations of current evaluation tools [9, 16]. Dependence on reports from parents and teachers introduces additional biases, emphasizing the need for direct, interactive assessment methods [99]. These reports reflect the perceptions of teachers and parents, not the experiences of the children.

Additionally, sensory reactivity assessments predominantly measure hyperreactivity, with hypo- and seeking-reactivity types mostly overlooked. This oversight may stem from the limitations of the sensory reactivity assessment tools employed, such as the Sensory Profile [9]. Addressing this gap by incorporating a broader range of sensory reactivity and expanding the sample size is crucial for improving our understanding of autistic sensory experiences and enhancing the generalizability of research findings. The Sensory Assessment for Neurodevelopmental Disorders (SAND) is an evidence-based tool designed to assess sensory reactivity in autism by directly examining sensory hyperreactivity, hyporeactivity, and seeking behaviours across visual, tactile, and auditory sensitivities [100]. This tool has been shown to be effective in autism classroom studies, demonstrating a correlation between classroom behaviours and various autistic sensory reactivity patterns [101]. A comprehensive exploration of the sensory dimensions of autism necessitates using inclusive assessment tools that encompass all sensory reactivity patterns and appropriate tasks, alongside direct assessments, to improve understanding and create supportive environments for varied needs.

Table 2
Methods used to collect the data for reviewed studies.

Reference	IEQ matrix	IEQ assessment	Sensory assessment	Behaviours assessment
[63]	Sound level	✓	–	o
[27]	Sound level + eco	o	–	o
[26]	Sound level	✓	✓	o
[58]	Sound level	–	✓	✓
[51]	Sound level	✓	–	✓
[64]	Sound level	✓	✓	o
[31]	Sound level	✓	–	o
[65]	Sound level	o	–	o
[66]	Sound level and RT	✓	–	o
[67]	Lighting	o	–	o
[43]	Thermal comfort	✓	–	o

✓ observer based on standard, O observed subjectively, - not observed.

5.2.3. Autism behaviours

The terminology related to behaviours was not clearly defined in the reviewed studies, highlighting a significant gap in standardized assessment for classroom settings. This lack of clear definitions presents challenges for researchers and practitioners aiming to draw generalizable and reliable conclusions. Clear definitions in research are essential for maintaining scientific rigour, facilitating effective communication, and ensuring the integrity and usefulness of research findings across various disciplines and contexts [102]. Moreover, most of the reviewed studies predominantly focused on maladaptive behaviours, particularly repetitive behaviours [27,63–67,103]. This narrow focus overlooks the potential insights that could be gained from observing adaptive behaviours, which are equally important for assessing the suitability of indoor environmental conditions.

Incorporating a standardized assessment tool, such as the Behaviour Assessment System for Children (BASC) and the school-age Child Behaviour Checklist (CBCL) [104] is essential. The BASC-3 rating scales have shown sensitivity and accuracy when applied to autistic children's behavioural profiles [105]. These tools offer a comprehensive approach to assessing a wide range of behaviours in the classroom, both adaptive and maladaptive. Utilizing such standardized instruments would enable more consistent data collection and analysis, thereby enhancing the reliability and comparability of findings across studies.

5.2.4. Linking IEQ with sensory reactivity and behaviour

The findings from this systematic review demonstrate that IEQ parameters significantly affect the externalising and internalising behaviours of autistic pupils, with specific IEQ parameters influencing distinct behaviours. Fig. 3 in the review visually represents the methods applied in the studies to categorize sensory processing—specifically affective reactivity and physiological responses—to determine the impact of IEQ on either internal or external behaviours, with each line depicting a different study. The acoustic parameter was the only one measured by both methods [51,64]. However, physiological response measurements were less commonly employed, reflecting the ongoing research in this area. A systematic review by Lydon et al. [106] highlighted

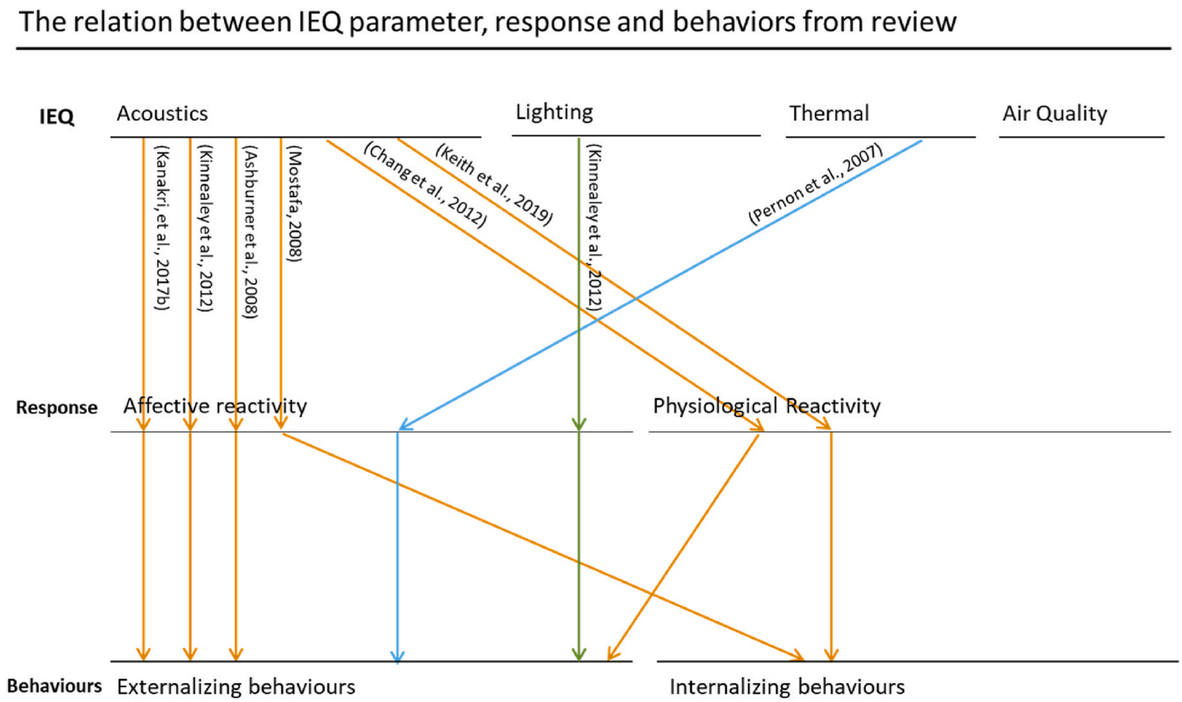

Fig. 3. The number of studies which find a relation between IEQ parameter, response, and autistic behaviours.

inconsistencies in results concerning autistic biomarkers, even when studies employed highly similar physiological measures, test stimuli, methodological protocols, and sample characteristics. Furthermore, this review noted that most studies demonstrated a variance in physiological reactivity by measuring electrodermal activity (EDA) in response to stimuli between autistic and non-autistic individuals. These findings propose a reduced dependence on physiological reactivity approaches for measuring the impact of IEQ on the behaviours of autistic individuals, due to the methodological challenges and conflicting results that currently characterize this approach of research.

The sensory reactivity in autistic had an impact on autistic individuals' engagement in classroom activity [11,107]. However, most of the reviewed studies fail to include factors that could influence the interaction between IEQ and behaviours in their analyses. Autistic behaviours can be significantly affected by their sensory reactivity to the same sensory input [29,30]. For example, the same sound level could influence autistic individuals differently. An overloaded sensory environment might lead to avoidance in those with hyperactivity and over-responsiveness [20–22], while individuals with hyperreactivity or under-responsiveness might not be affected [23,24]. Those with seeking reactivity might find it enjoyable or calming [25]. The nature and intensity of sensory reactivity differences can vary greatly among autistic individuals [17,46]. This variability needs to be considered in the analysis, recognizing the diverse nature of autism. Additionally, other mediators such as mood and level of diagnosis can interact with sensory reactivity in complex ways [108,109]. Analysing a sample of autistic individuals without considering their sensory reactivity differences or other influential factors could lead to potentially misleading or incomplete results.

Linking IEQ measurement with behavioural outcomes is crucial for comprehending how environmental conditions affect autistic behaviour during assessments. Thus, only two studies have utilized real-time monitoring systems that continuously track both IEQ parameters and autistic behaviours, providing a dynamic view of how environmental changes influence individuals over time [63,103]. With detailed, real-time data, it becomes possible to create more identified environments that cater to individual preferences and needs, potentially improving overall productivity [110]. This approach enables more accurate adjustments to the indoor environment, specifically adapted to effectively meet the needs of autistic individuals and evidence based.

In conclusion, refining the assessment criteria in review studies on IEQ and its impact on autistic individuals is important. Implementing a more standardized, sensitive, and multidisciplinary approach will significantly enhance our understanding and support the development of learning environments that are conducive to the educational progress of autistic pupils.

5.3. Comparing with mainstream school environment

The educational outcomes measured for autistic pupils differ significantly from those in mainstream schools, highlighting distinct physical environment settings. Classrooms designed for autistic pupils significantly differ from mainstream schools, involving specialized programs such as the TEACCH (Treatment and Education of Autistic and Related Communication-handicapped Children) approach. This methodology tailors the learning experience to align with the cognitive abilities of pupils, rather than exactly following age-based programs [111]. To adapt to the individual needs of autistic pupils, these educational environments are particularly designed, featuring specific classroom layouts and furniture arrangements aimed at enhancing learning effectiveness. Such adaptations result in unique IEQ conditions within autism-focused classrooms, presenting differently to the IEQ settings found in mainstream school environments. Additionally, a study found that different physical classroom designs influence IEQ, which in turn affects the learning performance of pupils in mainstream schools [112]. The difference in classroom design underlines the importance of conducting further investigations into how IEQ parameters specifically impact autistic pupils, necessitating a closer examination to ensure these specialized environments support the optimal development and education of autistic pupils.

5.4. Architecture design practices

Architectural design practices aiming at creating optimal learning environments for autistic children have started to include specific considerations for the physical environment, recognizing their significant impact on this population [38–42]. These considerations, as detailed in Table 3, demonstrate a developing awareness of the importance of environmental conditions to support autistic pupils' needs. However, there exist differences in the development of design guidelines across different IEQ parameters, with thermal comfort and air quality particularly lacking in recommendations for autism-friendly school environments. This highlights a broader gap between current research findings and their application in educational settings for autistic individuals.

The existing guidelines have been formulated based on findings from specific case studies, raising questions about their applicability and effectiveness in diverse autism classroom contexts [38,39]. To address this, there is a critical need for further research that not only explores the intricate relationships between various IEQ parameters and autistic behaviours but also seeks to fill the evidence gap. Further research should adopt a multidisciplinary approach, bringing together insights from architecture, education, psychology, and neuroscience. This comprehensive perspective is essential for developing evidence-based design practices that can be universally applied, ensuring all autistic pupils benefit from environments that facilitate their learning and well-being.

This systematic review highlights significant gaps and methodological issues in research on the impact of IEQ on autistic pupils in classrooms. Despite increased attention since 2007, the field is overly involved by small, non-varied sample sizes and a lack of female participants, limiting the reliability and generalizability of findings. Subjective methodologies and the absence of standardized, objective measures further complicate the assessment of IEQ's effects on autistic behaviours. The need for broader sensory reactivity patterns is emphasized, along with the importance of real-time monitoring systems to understand dynamic IEQ impacts.

Autism classroom designs differ from mainstream schools, requiring unique IEQ considerations. Current design guidelines lack comprehensive recommendations, underscoring the necessity for multidisciplinary research to develop effective, evidence-based practices. Implementing standardized, sensitive approaches will enhance understanding and support the creation of optimal learning environments for autistic pupils.

Table 3
Summary of design practices for autism schools.

IEQ	Study	Design practices
Acoustics	[31]	Provide different sound levels in rooms to be gradually and slowly moving between activities
	[63]	Provide carpeting, wood furniture, transitional spaces and thick or acoustical walls
	[27]	Provide a better HVAC, sound-absorbing materials on walls and floors; a buffer between classrooms and exterior spaces; and attention to whether access to natural views
	[32]	Provide in-floor heat to avoid noise created by heating equipment
	[89]	Eliminate noise filtering into the classroom from outside or other building spaces; create a buffer space
	[26]	Install wall covering material made of lightweight fibreglass—ceiling covering and halogen lights
	[67]	Avoid fluorescent lights, large window areas, and hard floors and ceilings in larger areas caused an echo
	[36]	Provide covering the sound-absorbing surface
	[90]	Material with a high noise reduction coefficient to cover the shutters in the craft-based activity area
Lighting	[91]	Provided in each area should have dimmable lighting and window blinds to prevent glare from flooring in activity areas
	[92]	Provide direct and indirect lighting intensity, colour and the ability to control it
	[67]	Problems with lighting were associated with fluorescent lights due to their and in Different context effect parameter ranking
	[26]	Using nonfluorescent lighting can improve the attention and engagement of pupils with visual hypersensitivity
	[93]	Control daylight light sources by windows opening and hight to avoid problems glazing and solar

6. Limitations and recommendation for future research

The scope of the present paper is to understand the effect of indoor environment parameters on autistic pupils' behaviour. However, the review does not include extent of physical environment aspects of the classroom and their impact on autistic pupils. Additionally, this paper focus on the behaviours as an outcome of interaction with learning experience, there are other possible outcomes such as physical health, require further investigation. This gap highlights the necessity for a broader assessment of how the physical classroom environmental setting influences autistic pupils beyond behaviour, to include health and well-being.

This review presents the current understanding of the relationship between indoor environmental parameters and autistic pupils' behaviours in the classroom. To justify the complexity of this mechanism, multidisciplinary research exploring both with direct and indirect correlation should be conducted [45]. This research can help clarify relationship between the indoor environment in classrooms and behaviours of autistic pupils. As most of the studies have been qualitative research, developing a quantitative evidence base is essential to support and validate design practices. There is a specific need for quantitative studies to complement the existing qualitative research, establishing an evidence base that can inform and justify design practices aimed at optimizing classroom environments for autistic pupils. Such research should not only seek to clarify the effects of indoor environments on autistic behaviours but also aim to contribute to the development of more supportive and effective educational spaces designed to the needs of autistic pupils.

Addressing these gaps necessitates a multidisciplinary research approach, incorporating insights from architecture, education, psychology, and neuroscience to develop assessment tools and educational strategies that are directly relevant and responsive to the needs of autistic pupils. Such an integrated research effort is crucial for advancing our understanding of IEQ's impact on autistic behaviours and fostering educational environments that support the well-being and development of all pupils.

7. Conclusions

The current study aims to establish a framework elucidating the relationship between indoor environmental parameters and the behaviours of autistic pupils, preceding a comprehensive systematic review. To date, conclusive research on how the indoor environment of schools affects autistic pupils is absent, indicating a need for further exploration across various domains to accomplish a more holistic understanding. Even though progress is being made, several critical limitations in the investigation of the relationship between autistic behaviours and IEQ in classroom settings, including.

- A limitation of comprehension understanding of how indoor environmental parameters influence autistic behaviours, indicating a gap in knowledge of mechanism.
- Challenges in associating specific sensory reactivity types in autistic individuals with indoor environmental conditions, emphasizing a need for more research approaches.
- A shortage of studies investigating the effects of various IEQ subparameters on the wide range of behaviours exhibited by autistic pupils, indicating a requirement for further research.
- A lack of quantitative evidence that directly correlates autistic behaviours with various indoor environmental parameters, highlighting an area for future investigation.

Addressing these limitations requires targeted research efforts that investigate the intricate relationship between IEQ and autistic behaviours, using multidisciplinary approaches to fill the existing knowledge gaps and environments that support the unique needs of autistic pupils.

CRediT authorship contribution statement

Rahaf Al Qutub: Writing – review & editing, Writing – original draft, Visualization. **Zhiwen Luo:** Writing – review & editing, Supervision. **Carolina Vasilikou:** Writing – review & editing. **Teresa Tavassoli:** Writing – review & editing. **Emmanuel Essah:** Writing – review & editing. **Hannah Marcham:** Writing – review & editing.

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

No data was used for the research described in the article.

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