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Published Version

Al Qutub, R., Luo, Z. ORCID: https://orcid.org/0000-0002-2082-3958, Essah, E. ORCID: https://orcid.org/0000-0002-1349-5167, Tavassoli, T. ORCID: https://orcid.org/0000-0002-7898-2994, Marcham, H. and Deng, Q. (2026) Impact of indoor environment quality on autistic behaviours in autism schools of Saudi Arabia. Environmental Pollution, 397. 127992. ISSN 0269-7491 doi: 10.1016/j.envpol.2026.127992 Available at https://centaur.reading.ac.uk/129229/

To link to this article DOI: http://dx.doi.org/10.1016/j.envpol.2026.127992

Publisher: Elsevier

Environmental Pollution 397 (2026) 127992

Contents lists available at ScienceDirect

Environmental Pollution

journal homepage: www.elsevier.com/locate/envpol

Impact of indoor environment quality on autistic behaviours in autism schools of Saudi Arabia

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ARTICLE INFO

Keywords:
Indoor environment
Autism
Behaviours
PM_{10}

ABSTRACT

Indoor Environmental Quality (IEQ) strongly influences students' learning outcomes, yet its impact on autistic students remains underexplored. This study investigates the relationship between IEQ parameters and behavioural outcomes of 37 autistic students (DSM-5 Levels 1–2) aged 5–12 years attending two autism-specific schools in Saudi Arabia across winter and summer periods. IEQ parameters - temperature, relative humidity, carbon dioxide (CO_2), particulate matter ($PM_{2.5}$ and PM_{10}), sound level, and illuminance - were continuously monitored, alongside behavioural observations. Behaviour and sensory reactivity were assessed using the Behavioural Assessment of Classroom Sensory Scale–School Observation System (BASC-SOS) and the Sensory Assessment for Neurodevelopmental Disorders (SAND), which capture external behaviours (movement, vocalisation, and task engagement).

Repeated measures correlation analysis revealed significant relationships between PM_{10} concentration and both adaptive ($p = 0.04$) and maladaptive behaviours ($p = 0.05$), sound levels and maladaptive behaviours ($p = 0.05$), and relative humidity and adaptive behaviours ($p = 0.03$). CO_2 levels in hypersensitive autistic students and both adaptive ($p = 0.05$) and maladaptive behaviours ($p = 0.01$). Pupils demonstrated heightened sensitivity to elevated CO_2 and noise fluctuations, highlighting the compounded sensory effects of air quality and acoustics.

These findings underscore the need to tailor environmental conditions in autism-specific educational settings to accommodate the sensory reactivity of autistic students. The study not only advances foundational knowledge of IEQ's impact on autistic behaviour but also offers practical implications for designing educational environments that foster both academic engagement and student s' well-being.

1. Introduction

Indoor Environmental Quality (IEQ) has a direct and significant impact on the health, comfort, and overall performance of building occupants (Frontczak & Wargocki, 2011; Wong et al., 2008). In schools, where students spend long periods, IEQ plays a critical role in shaping the cognitive functions and overall well-being of students. For autism schools, the importance of optimal IEQ is even more pronounced. Autistic students often experience heightened sensitivity to environmental stimuli, such as light, sound, and temperature, making them particularly vulnerable to discomfort and distraction in suboptimal environments (Al Qutub et al., 2024; Black et al., 2022; Marcham, 2024; Martin, 2016). A well-regulated environment has the potential to reduce sensory overload, enabling autistic students to concentrate better, engage more effectively in learning activities, and experience reduced stress (Forsyth & Trevarrow, 2018; Hwang et al., 2020; Rossow et al., 2021). Therefore, prioritizing IEQ in schools not only enhances the general comfort of all students but is also essential in creating inclusive, autism-friendly spaces that support learning, development, and overall well-being (Mostafa et al., 2024).

In Saudi Arabia, the IEQ of autism schools is shaped by a combination of local climate conditions, cultural practices, and architectural

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https://doi.org/10.1016/j.envpol.2026.127992
Received 22 September 2025; Received in revised form 8 March 2026; Accepted 19 March 2026
Available online 25 March 2026

limitations. Dust storms and industrial emissions contribute to poor outdoor air quality, particularly in cities like Dammam, where particulate matter levels frequently exceed WHO guidelines (Elsharkawy et al., 2022; Farahat, 2016; Munir et al., 2016). These outdoor pollutants, combined with indoor sources such as the cultural use of Arabian incense and cleaning detergents - especially during winter - result in air quality failing to meet recommended indoor air quality (IAQ) standards (Amoatey et al., 2020). Such emissions can be particularly problematic for autistic pupils, whose heightened sensory sensitivity makes them more vulnerable to strong odours and volatile compounds (Steinemann, 2018). Autism schools, in particular, show distinct environmental characteristics compared to mainstream schools, driven by sensory preferences and structured activity schedules (Al Qutub et al., 2026). Recent studies highlight that indoor particulate matter is among the top health risks in Saudi Arabia (Rojas-Rueda et al., 2021), raising concerns about its impact on vulnerable populations. For autistic students-who exhibit heightened sensitivity to environmental stimuli - poor IEQ can intensify stress, impair concentration, and trigger maladaptive behaviours (MacLennan et al., 2020). Therefore, understanding and improving IEQ in Saudi autism schools is critical to creating supportive, inclusive, and health-promoting learning environments.

Autistic individuals frequently encounter challenges related to social interaction, communication, and sensory processing (American Psychiatric Association. DSM-5 Task Force., 2013). These difficulties can significantly affect how they perceive and interact with their surroundings environment (Gentil-Gutiérrez et al., 2021). Sensory reactivity in autism is complex, involving hyperreactivity (heightened responses), hyporeactivity (discharge responses), and sensory-seeking behaviours (active pursuit of sensory input) (Lane et al., 2010; MacLennan et al., 2020; Patten et al., 2013; Verhulst et al., 2022). For instance, bright or flickering lights, background noise, or fluctuating temperatures may overwhelm hyperreactive students (Carpenter et al., 2019; Elwin et al., 2013; Forsyth & Trevarrow, 2018), while hyporeactive individuals may seem unresponsive to sensory stimuli such as sound or temperature (Lane et al., 2010; Liss et al., 2006), and sensory seekers may gravitate towards certain sensations they find calming (Pellicano, 2013). These sensitivities can make classroom environments particularly challenging, as overstimulation or discomfort can disrupt their ability to focus and participate in learning activities. As a result, creating an environment that carefully manages these sensory triggers is vital for supporting the well-being and educational progress of autistic (Manning et al., 2023).

The behaviours of autistic students provide a direct and measurable way to understand how they respond to variations in their environment. As behaviour is a clear indicator of comfort or distress, observing changes in behaviour in relation to adjustments in IEQ can offer valuable insights into their sensory experiences (Marcham, 2024). For example, maladaptive behaviours such as repeated motor or self-injurious actions can indicate discomfort or sensory overload due to loud sound (Kanakri et al., 2017). Conversely, adaptive behaviours such as engaging in activity, following instructions may indicate that the environment is more adjusted to their needs (O'Donnell et al., 2012). Understanding these behavioural responses is essential for developing effective teaching strategies that accommodate their sensitivities and for designing autism-friendly learning spaces.

Current literature finds that most studies on the impact of IEQ parameters on autistic students is frequently constrained by several methodological limitations, such as small sample sizes, reliance on subjective assessments, and insufficient consideration of the diversity within the autism spectrum (Ashburner et al., 2008; Kanakri et al., 2017, 2017; Mostafa, 2008; Shabha & Gaines, 2013; Ueno et al., 2019). These factors hinder the ability to generalisable conclusions, as they often fail to capture the wide range of sensory sensitivities and behavioural responses seen among autistic individuals (Al Qutub et al., 2024). Additionally, most studies have not thoroughly examined the effects of different IEQ parameters, such as variations in lighting, acoustics, air quality, and thermal conditions, on autistic behaviours. Bias in some studies has influenced research outcomes, contributing to conflicting or erroneous results regarding IEQ and autistic behaviours in classrooms (Dargue et al., 2021). Addressing these limitations could significantly enhance the interpretative validity of study findings, leading to generalisable and replicable research outcomes (Chinazzo et al., 2022).

Emerging literature underscores a significant yet nascent relationship between IEQ and the behavioural responses of autistic children in classroom settings. A systematic review by Al Qutub et al. (2024) synthesises existing empirical studies, highlighting that key IEQ parameters - particularly acoustics and lighting - exert measurable effects on both externalising and internalising behaviours. Elevated noise levels (exceeding 45 dB) and exposure to flickering fluorescent lighting are shown to trigger sensory hyperreactivity, resulting in behaviours such as repetitive movements, ear covering, and reduced cognitive performance (Kanakri et al., 2017; Keith et al., 2019). Conversely, modifications to the environment, such as substituting halogen lighting for fluorescent fixtures or enhancing acoustic conditions, are associated with improvements in attention and engagement (Kinnealey et al., 2012). While lighting and sound are most studied, the effects of thermal comfort and air quality remain largely unexplored, underscoring the need for broader, evidence-based research tailored to autistic sensory profiles (Al Qutub et al., 2024; Dargue et al., 2021).

Recognising the importance of sensory sensitivities and the unique learning needs of autistic students, it is critical to develop classrooms that enhance educational progress. Without comprehensive research, educators and architects lack the evidence required to design environments that meet autistic students' diverse needs (Manning et al., 2023; Mostafa et al., 2024). This study focuses on autism-specific schools in Saudi Arabia that serve pupils aged 5–14 years diagnosed with autism at DSM-5 Levels 1 and 2, representing individuals who require support to substantial support. The research aims to identify and understand correlations between IEQ parameters and autistic behaviours, and to quantify the impact of IEQ factors on behaviour through in-situ environmental monitoring and behavioural assessment. This approach provides a foundation for more effective design guidelines and interventions. Evidence-based strategies can then be implemented to create autism-supportive classrooms that enhance attention, reduce behavioural disruptions, and promote social interaction, ultimately improving educational outcomes and well-being.

2. Method

2.1. Study context

The IEQ was assessed in two specialised schools for autistic children located in Dammam, the third-largest city in Saudi Arabia, situated in the Eastern Province. This region experiences hot, dusty conditions, with an annual average temperature of 27 °C, high summer peaks, and 51% average relative humidity (National Oceanic and Atmospheric Administration, 2022). Due to extreme summer heat, air-conditioning is widely used, while winter months rely on natural ventilation. Dammam also records the highest air pollution levels in the country, driven by industrial and traffic emissions (Munir et al., 2016), with average PM_{10} concentrations reaching 95 μg/m^3 in winter and 88 μg/m^3 in summer (Al Qutub et al., 2026).

Both schools, located in the Eastern Province of Saudi Arabia, differ in design, orientation, and environmental features. School A is a renovated two-storey residential building near a major highway, with 48 m^2 classrooms, natural ventilation, and fluorescent lighting offering limited daylight. School B is a purpose-built single-storey facility, with 55 m^2 classrooms, mechanical ventilation, LED lighting, and large windows providing exterior views.

2.2. Materials

2.2.1. IEQ measurement in two autism schools

This study assessed the IEQ of two schools designed for autistic children by monitoring key environmental parameters across different seasons. The two selected schools serve autistic children aged 4–12 and provide both education and therapy. IEQ monitoring focused on acoustics, lighting, thermal conditions, and air quality. Thirteen classrooms were included in the study, with one classroom monitored per day during standard school hours (7:00 a.m.–12:00 p.m.). Measurements were conducted across winter (December 2022–January 2023) and summer (July–September 2023) to capture seasonal differences in building operation, specifically free-running conditions in winter and air-conditioned operation in summer. The average indoor temperature recorded across both schools was 23.8 °C during winter and 26.7 °C during summer, reflecting seasonal differences in thermal conditions.

Instruments were placed consistently at 0.8 m height and away from external influences to measure noise, illuminance, temperature, relative humidity, CO_2, and particulate matter. Lighting was manually recorded at 7 a.m., 10 a.m., and 12 p.m. each day, while other parameters were sampled every minute. Lighting was recorded using a Gossen M502B digital lux meter (±3%, 0.1–199,900 lux) at three fixed points (front, middle, back of the classroom). Measurement accuracy was ensured through the use of calibrated instruments, including a Casella 62x Sound Level Meter (20–140 dB), an Onset HOBO MX1102A Data Logger (±50 ppm CO_2, ±0.21 °C, ±2% RH), and a GrayWolf PC-3016A for particulate matter within 10–40 °C and 20–95% RH conditions. The detailed specifications of these instruments and installation are provided in the supplementary materials A & B and our prior study (Al Qutub et al., 2026).

2.2.2. Sensory sensitivity assessment

Sensory reactivity differences were assessed using the Sensory Assessment for Neurodevelopmental Disorders (SAND) (Siper et al., 2017), which combines structured observation and teacher interviews to evaluate hyperreactivity, hyporeactivity, and sensory-seeking behaviours across visual, tactile, and auditory domains. A full description of the procedure and scoring criteria is provided in the Supplementary Material C.

2.2.3. Externalising behaviour observation

Classroom behaviours were measured using the Behaviour Assessment System for Children – Student Observation System (BASC-SOS) (Kamphaus & Reynolds, 2015), a validated observational tool that distinguishes adaptive behaviours, which support learning and classroom engagement (e.g., following instructions, participating in activities, interacting appropriately with teachers and peers), from maladaptive behaviours, which may hinder learning or disrupt classroom functioning (e.g., inattention, inappropriate movement, or disruptive vocalisation). Details on observation protocol, behavioural categories, and psychometric properties are included in the Supplementary Material D.

2.2.4. Participant

The study involved fifty students aged 5-14 years (6 females and 44 males) with a clinical diagnosis of autism, recruited from two autism schools in Saudi Arabia. The gender distribution reflects broader diagnostic trends in autism, where males are more frequently identified than females, consistent with international prevalence ratios of approximately 4:1 and reported patterns within Saudi Arabia; the underdiagnosis of females is widely attributed to subtler presentations and diagnostic bias (Alnemary et al., 2017). All participants were classified as having Autism at DSM-5 Levels 1 and 2, representing individuals who require support to substantial support. All students had an Education Health and Care plan with high support needs, as reflected in a staff-to-student ratio of 1:4. Although fifty pupils were recruited, only thirty-seven participants completed two Behaviour Assessment System for Children (BASC-SOS) observations due to absences on scheduled observation days and variability in daily school attendance, while fifty participants completed the Social and Nonverbal Development (SAND) assessments.

2.3. Ethical approval

Ethical approval for this study was granted by the University of Reading Research Ethics Committee (UK) prior to data collection in Saudi Arabia (see: https://www.reading.ac.uk/internal/research/research-ethics.aspx). Data were collected during Dec 2022- Jan 2023 (winter) and June -Sept 2023 (summer).

As all participants were under 18 years of age, ethical approval required enhanced safeguarding procedures. Written informed consent was obtained from parents or legal guardians via paper consent forms prior to participation. Due to their cognitive profiles, participants were unable to provide informed written or verbal consent; however, all students were informed in an age-appropriate manner about the activities involved, including cognitive tasks and behavioural and sensory observations.

During data collection, students were continuously monitored by the research team all of whom were familiar with the pupils' behavioural cues. If a participant showed signs of distress or anxiety, or if a member of school staff raised concern, the research activity was immediately paused or terminated.

2.4. Research design

This study employed a repeated-measures correlational design, with two repeated observations per participant (Bakdash & Marusich, 2017), which is well suited to examining within-participant relationships between environmental conditions and behavioural outcomes. Such designs, combined with repeated observations and transparent reporting, are recommended to enhance reliability and reduce bias in behavioural research (Shrout & Rodgers, 2018). No participants were exposed to researcher-controlled or experimental stimuli; all IEQ measurements and behavioural observations were conducted under natural classroom conditions during routine educational activities.

Participants completed two BASC-SOS classroom behaviour observations on separate days, each lasting 15 min, during staff-led structured lessons (e.g., mathematics, science, group activities, or art). The SAND assessment was completed once per participant in the students' usual classroom environment, with the caregiver interview conducted by the researcher.

IEQ monitoring and behavioural observations were conducted concurrently. For each behavioural observation, IEQ data were averaged over the corresponding 15-min observation period to ensure temporal alignment between environmental exposure and behavioural outcomes. Data collection occurred between 7:00 a.m. and 1:00 p.m. across 31 school days. The experimental timeline is summarised in Supplementary Figure E.

2.5. Statistical analysis

2.5.1. Descriptive statistics

Thirty-seven participants completed the BASC-SOS on two occasions, resulting in 74 externalising behaviour observations, while 50 participants completed the sensory reactivity assessment (SAND). Descriptive statistics were calculated for all IEQ parameters across measurement periods and behavioural observations. Data normality was assessed using the Kolmogorov–Smirnov test. Depending on distribution characteristics, parametric or non-parametric correlation methods were applied. All descriptive analyses and normality testing were conducted using IBM SPSS Statistics (version 24).

2.5.2. Correlation analyses

Pearson's r and Spearman's rho correlation coefficients were used to examine relationships between sensory reactivity, externalising behaviours, and IEQ parameters. These analyses were performed using IBM SPSS Statistics (version 24).

To examine within-participant associations across repeated observations, repeated-measures correlation (rmcorr) was applied. This method estimates a common regression slope while allowing individual-specific intercepts, accounting for non-independence of repeated measures without requiring data aggregation (Bakdash & Marusich, 2022). Repeated-measures correlation analyses were conducted using the rmcorr package in R (version 0.4.6). All statistical tests were two-tailed with a 95% confidence interval, and statistical significance was set at $p < 0.05$. The magnitude of correlation coefficients was interpreted using conventional thresholds: $|r| \approx 0.10–0.29$ = weak, $|r| \approx 0.30–0.49$ = moderate, and $|r| \geq 0.50$ = strong, with the sign indicating the direction of the association (positive or negative).

3. Results

3.1. Descriptive statistics

Descriptive statistics are based on pooled measurements across both schools and all measurement periods, as no inter-school comparison was conducted. Across 37 participants, mean adaptive behaviour score was 15.9 (SD = 6.8), while mean maladaptive behaviour score was 17.8 (SD = 8.5) (SI Section G). The most frequently observed maladaptive behaviours were inattention (Mean = 6.89), inappropriate movement (Mean = 4.76), and inappropriate vocalisation (Mean = 2.70) (SI Section H).

Sensory reactivity scores indicated higher sensory-seeking behaviour (Mean = 17.0) compared to hyperreactivity (Mean = 7.4) and hyporeactivity (Mean = 5.8). Total sensory reactivity scores ranged from 20 to 43, with a mean of 30.3.

For IEQ parameters, the mean sound level was 70.24 dB (maximum 79.34 dB), and mean illuminance was 647.15 lux (maximum 1612.44 lux). Mean concentrations of $PM_{2.5}$ and PM_{10} were 30.49 μg/m^3 and 100.19 μg/m^3, respectively. CO_2 concentrations ranged from 405 to 2656 ppm, with a mean of 663 ppm. Complete descriptive statistics for all IEQ parameters are provided in SI Section G.

3.2. Sensory reactivity and behaviours correlation

Correlation analysis between sensory reactivity scores (SAND) and behavioural outcomes (BASC-SOS) showed a moderate negative correlation between total sensory reactivity score and adaptive behaviours ($r = -0.33$, $p = 0.02$). No statistically significant correlations were observed between individual sensory subdomains (hyperreactivity, hyporeactivity, sensory seeking) and maladaptive behaviours. All correlations were tested at the 0.05 significance level (supplementary I).

3.3. Repeated-measures correlation analysis

Repeated-measures correlation analyses examined associations between IEQ parameters and behavioural outcomes derived from two BASC-SOS observations per participant, pooled across schools. Table 1 summarises the direction, magnitude, and significance of these associations.

A moderate negative correlation was observed between PM_{10} concentration and adaptive behaviours ($rrm = -0.36$, $p = 0.04$), alongside a moderate positive correlation with maladaptive behaviours ($rrm = 0.35$, $p = 0.05$). Relative humidity showed a moderate negative correlation with adaptive behaviours ($rrm = -0.34$, $p = 0.03$). Sound level demonstrated a moderate positive correlation with maladaptive behaviours ($rrm = 0.30$, $p = 0.05$). No statistically significant repeated-measures correlations were observed for air temperature, $PM_{2.5}$, or illuminance.

Table 1
Repeated-measures correlation results (pooled across schools).

IEQ Parameter	Adaptive behaviours (rrm)	p-value	Maladaptive behaviours (rrm)	p-value
CO_2	−0.17	0.31	0.14	0.24
$PM_{2.5}$	−0.27	0.16	0.16	0.40
PM_{10}	−0.36	0.04*	0.35	0.05*
Air temperature	−0.09	0.60	0.39	0.39
Relative humidity	−0.34	0.03*	0.26	0.11
Sound level	−0.25	0.11	0.30	0.05*
Light level	−0.09	0.58	0.23	0.17

*Significant at $p < 0.05$ (two-tailed).

3.3.1. Air quality

3.3.1.1. *CO_2 concentration.* Among pupils classified as hyperreactive based on SAND scores, repeated-measures correlation revealed a moderate negative association between CO_2 concentration and adaptive behaviours ($rrm(18) = -0.44$, $p = 0.05$) and a moderate positive association with maladaptive behaviours ($rrm(18) = 0.54$, $p = 0.01$). Data points represent aggregated observations from both schools, with numerical IDs indicating anonymised pupils across the two schools (Fig. 1).

3.3.1.2. *PM_{10} concentration.* A moderate negative association was observed between PM_{10} concentration and adaptive behaviours ($rrm = -0.36$, $p = 0.04$), alongside a moderate positive association with maladaptive behaviours ($rrm = 0.35$, $p = 0.05$) (Fig. 2).

3.3.2. Thermal conditions

During behavioural observation periods, air temperature ranged from 19.28 to 29.31 °C, and relative humidity ranged from 30% to 70%. Relative humidity showed a moderate negative correlation with adaptive behaviours ($rrm = -0.34$, $p = 0.036$). The association with maladaptive behaviours was positive but not statistically significant ($rrm = 0.26$, $p = 0.114$) (Supplementary K). No statistically significant association was observed between air temperature and externalised behaviours.

3.3.3. Acoustic conditions

Sound level demonstrated a weak negative association with adaptive behaviours ($rrm = -0.25$, $p = 0.13$) and a moderate positive association with maladaptive behaviours ($rrm = 0.30$, $p = 0.05$) (Supplementary L). During observation periods with higher inattention scores, classroom sound levels frequently exceeded 60 dB, with recorded values ranging from 65 to 79 dB. Measurements below this threshold were associated with lower observed inattention scores.

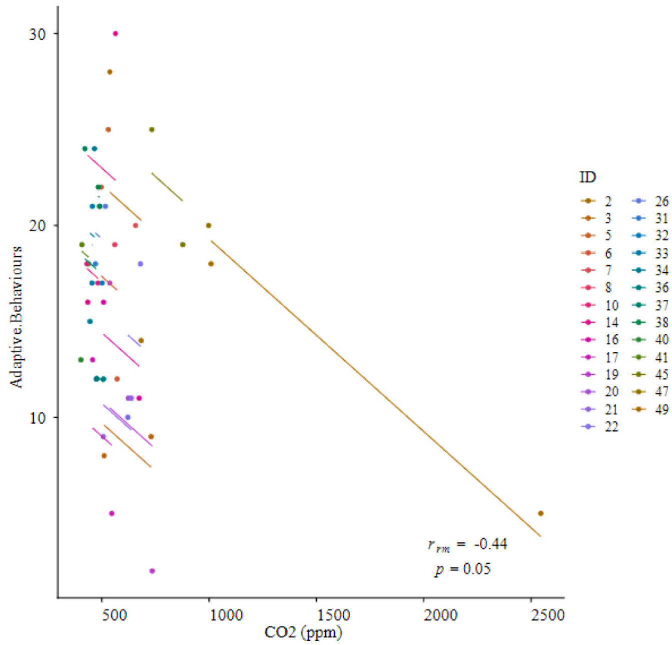
3.3.4. Lighting

Classroom illuminance showed substantial variability across observations, ranging from 210 to 1612 lux (M = 647 lux). Most classrooms relied on a combination of overhead artificial lighting (fluorescent or LED luminaires) and limited daylight contribution, with artificial lighting being the dominant source during observation periods.

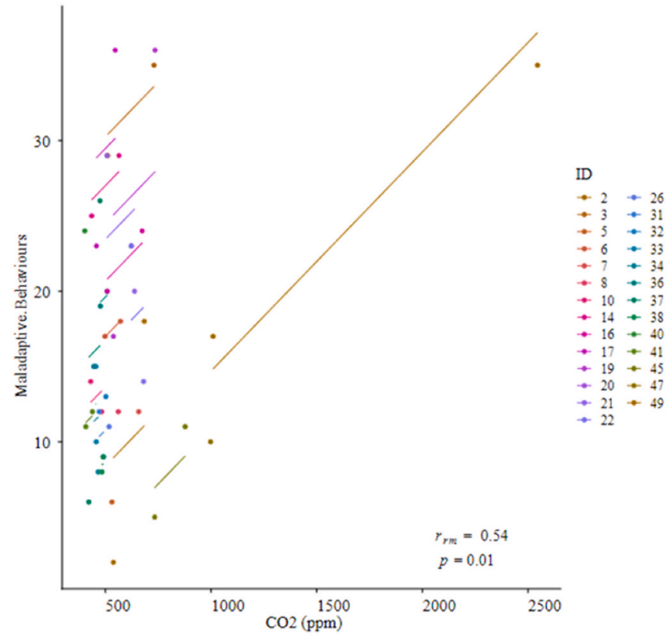
Repeated-measures correlation analysis indicated no statistically significant association between lighting level and adaptive behaviours ($rrm = -0.09$, $p = 0.58$) or maladaptive behaviours ($rrm = 0.23$, $p = 0.17$).

4. Discussion

This study investigated the relationship between IEQ factors (sound level, light, temperature, relative humidity, CO_2 and $PM_{2.5}$ and PM_{10}

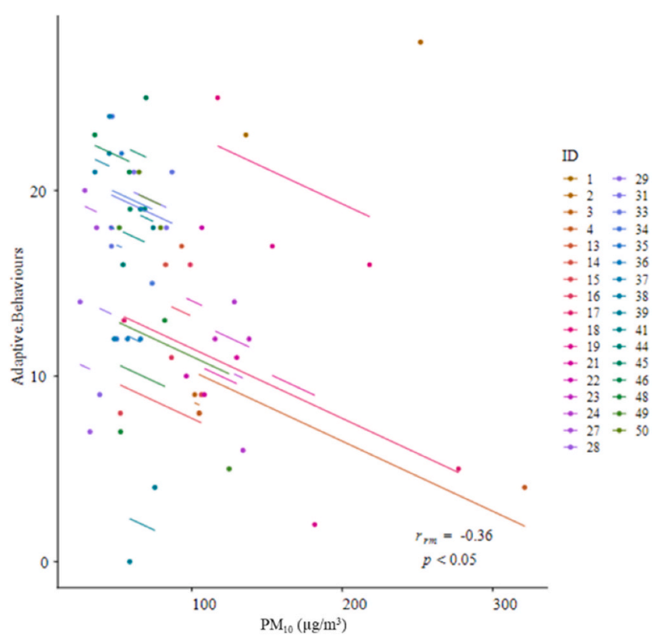


A. CO_2 level and Adaptive behaviours of hyperactivity

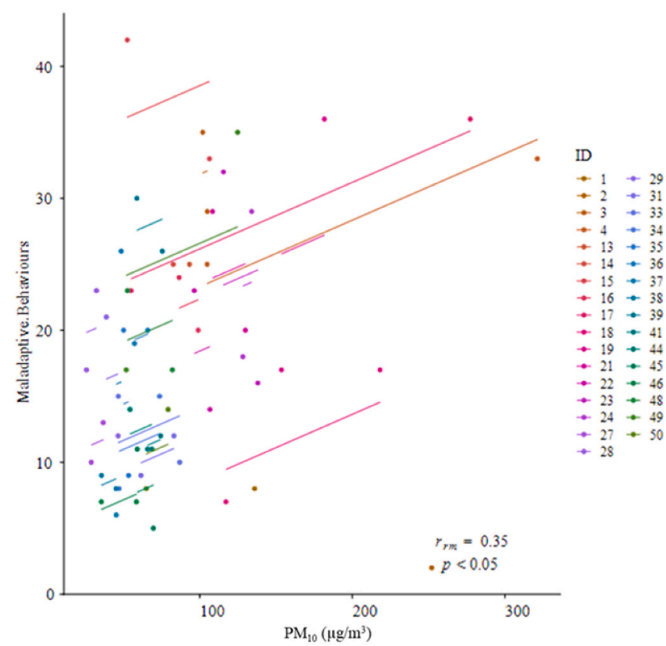


B. CO_2 level and Maladaptive behaviours of hyperactivity

Fig. 1. Scatterplot depicting the correlation between CO2 levels and externalised behaviours for sensory reactivity.



A. PM_{10} levels and adaptive behaviours



B. PM_{10} levels and maladaptive behaviours

Fig. 2. Scatterplot depicting the correlation between PM_{10} levels and externalise behaviours.

concentration) and their correlations with classroom behaviour of autistic students for two time points.

4.1. Interpretation of significant findings

The analysis of IEQ parameters in autism-specific classrooms has granted significant correlations that justify attention, particularly with respect to PM_{10}, relative humidity and sound levels. These findings provide valuable insights into how environmental parameters can influence externalise behaviours in autistic individuals.

4.1.1. Air quality and behaviours

Our work is the first study to experimentally investigate the impact of air quality on the classroom behaviour of autistic students. Numerous studies have examined the long-term health effects of air quality on non-autistic students in mainstream schools, while few have focused on short-term outcomes (Amanzadeh et al., 2020), nor on autistic children (Al Qutub et al., 2024). Nevertheless, short-term outcomes, especially those affecting cognitive functions, are critically important as they directly influence learning progress. For instance, a recent study demonstrated that short-term reductions in indoor particle concentrations significantly improved non-autistic students' test scores, indicating enhanced cognitive function (Xu et al., 2023). There is a significant gap in research concerning the impact of air quality on the learning outcomes of autistic students, both in the long and short term.

Existing studies have primarily investigated the aetiology of autism in relation to exposure to air pollution during pregnancy. Findings suggest that prenatal exposure to poor air quality - particularly traffic-related pollutants, VOCs, and heavy metals - may contribute to autism by inducing brain tissue damage and mitochondrial dysfunction in the developing central nervous system (Chauhan & Chauhan, 2006; Kim et al., 2016; Larsson et al., 2009; Rahman et al., 2022). However, most research has focused on outdoor or general environmental exposures, with limited attention to the role of indoor air quality in postnatal developmental settings such as classrooms. This study addresses this gap by focusing on how specific indoor environmental factors in autism-specific learning environments might uniquely influence behavioural and cognitive outcomes in autistic children.

The study found that high PM_{10} concentrations can negatively affect the externalise behaviour of autistic students. We observed a significant negative correlation between PM_{10} levels and adaptive behaviours, as well as a significant positive correlation between PM_{10} levels and maladaptive behaviours. In contrast, Marcham (2024) did not find a correlation between PM levels and externalised behaviours in their study conducted in the UK, where PM levels were within the acceptable range with minimal variation in measurements. The differences in our findings may be attributed to elevated PM levels in Saudi Arabia, likely influenced by cultural practices such as burning incense and frequent use of cleaning sprays (Al Qutub et al., 2026). During observations, the periodic use of fragranced products and Arabian incense was noted in both schools, particularly during morning cleaning contributing to variations in indoor particulate matter levels. Such contextual factors help explain fluctuations in indoor air quality within the studied classrooms.

A similar finding reported that higher PM_{10} levels were associated with lower test performance (Amanzadeh et al., 2020). These findings suggest that higher levels of particulate matter could exacerbate behaviours such as distraction, irritation, or respiratory discomfort. Autistic individuals often exhibit heightened sensory sensitivities, making them particularly vulnerable, like non-autistic children with developing respiratory systems (Zeman, 1998). As the high PM concentration collated with fatigue, sleepiness, headache (Shao et al., 2023), these symptoms may further compromise autistic students' capacity for sustained attention, sensory regulation, and classroom engagement. Such conditions can significantly hinder engagement and active participation in learning activities, thus negatively affecting educational progress.

Our results did not identify a statistically significant association between CO_2 concentration and overall externalising behaviours across the full sample. CO_2 itself is not directly perceived by occupants but serves as an indicator of ventilation adequacy and the accumulation of indoor pollutants. Although mean CO_2 levels during observations were generally within the acceptable range defined by EN 16798-1:2019 (approximately 600–800 ppm for sensitive populations), prior research has reported behavioural and cognitive effects at higher concentrations (Marcham, 2024; Satish et al., 2012). When the analysis in this study was restricted to pupils classified as hyperreactive, a significant negative association was observed between CO_2 concentration and adaptive behaviours ($p = 0.05$), alongside a positive association with maladaptive behaviours ($p = 0.01$). These findings indicate that ventilation-related air quality may be particularly relevant for autistic pupils with heightened sensory sensitivity, consistent with previous evidence in both autistic and non-autistic populations (Gentil-Gutiérrez et al., 2021; Jones et al., 2020; Manning et al., 2023; Williams et al., 2023).

4.1.2. Sound level and maladaptive behaviours

A significant positive correlation was found between sound levels (dB) and maladaptive behaviours. Numerous studies have observed similar results, indicating that externalised behaviours are influenced by sound levels for autistic children (Kanakri et al., 2017; Kinnealey et al., 2012; Mostafa, 2008). Our study focuses on educational progress, with behaviour assessments conducted during learning activities. We found that inattention behaviours were most prevalent during activities, with most measurements exceeding 60 dB. Kanakri et al. (2017) documented a significant correlation between elevated noise levels above 50 dB and increased instances of repetitive behaviours and noise production by students ($p < 0.001$). While Kanakri et al. (2017) study examined only a limited set of seven behaviours, our study encompasses a broader and more comprehensive range of maladaptive behaviours. We utilized the Behaviour Assessment System for Children (BASC), which assesses a wide range of classroom behaviours, both adaptive and maladaptive (Kamphaus & Reynolds, 2015). Autistic students can exhibit different behavioural responses to noise depending on their sensory (Landon et al., 2016), and including various behaviours provides a stronger correlation.

Previous research typically involved small sample sizes of 4-40 participants observed at a single time point. These small sample sizes limit the statistical power and robustness of findings, raising concerns about the generalizability of results (Chinazzo et al., 2022). Although the present study included 37 participants, the repeated-measures design does not increase the sample size but improves analytical sensitivity by reducing within-subject variability (Bakdash & Marusich, 2017). This approach reduces the error variance associated with individual differences, allowing for more accurate detection of the true effects of sound levels on behaviours.

4.1.3. Thermal and behaviours

The relationship between the thermal environment and behavioural performance is multifaceted and influenced by both physiological and perceptual factors. While air temperature is often considered a primary determinant of comfort, evidence indicates that humidity may exert a more consistent influence on performance when temperatures remain within a moderate range (Ghanbariazarneir, 2023).

Several studies have reported associations between elevated indoor temperatures and reduced adaptive performance (Marcham, 2024), although findings remain mixed and appear sensitive to exposure duration and activity patterns. Autistic individuals have been shown to demonstrate thermal sensitivities comparable to non-autistic populations (Cascio et al., 2016; Noble, 2018; Williams et al., 2019). However, growing evidence indicates that autistic individuals may experience greater discomfort and higher variability in thermal perception under non-neutral conditions (Lackovicova et al., 2025; Zaniboni et al., 2025). Experimental investigations under extreme thermal exposures have identified heightened tactile and sensory responses in autistic individuals (Failla et al., 2020; Pernon et al., 2007), suggesting that only substantial deviations from thermal comfort may elicit pronounced behavioural effects (Rasdan et al., 2009).

In this study, temperature and relative humidity did not vary independently, as measurements were conducted under a predominantly hot–humid climatic context typical of the Eastern Province of Saudi Arabia (Al Qutub et al., 2026), where elevated temperatures are frequently accompanied by high atmospheric moisture. Under such conditions, the combined thermal–moisture load may intensify discomfort beyond that predicted by temperature alone (Yan et al., 2020).

In contrast, relative humidity has been consistently linked to both physiological comfort and cognitive efficiency. Elevated humidity, particularly in combination with higher temperatures, has been associated with fatigue and reduced concentration (Zuo et al., 2021). In educational contexts, suboptimal humidity has been related to poorer learning outcomes, including slower reading performance and reduced test accuracy (Liu et al., 2021; Ryan et al., 2022). Moreover, humidity levels exceeding 50% may increase susceptibility to respiratory and infectious conditions (Gao et al., 2014).

For autistic pupils, who often exhibit heightened sensory sensitivity, such environmental discomfort may lower tolerance thresholds and compromise adaptive classroom behaviours. Discomfort associated with elevated humidity has been linked to irritability and reduced attentional capacity (Tsutsumi et al., 2007), thereby limiting opportunities for effective learning and social participation.

4.1.4. Lighting and behaviours

Our study did not find a correlation between lighting levels and externalised behaviours in autistic students, which is consistent with the findings of Marcham (2024). We suggest that autistic students' visual sensitivity may vary, as reflected in the different classrooms showing a wide range of lighting levels (Al Qutub et al., 2026). This could explain why autistic individuals may not be equally influenced by lighting levels alone, nonetheless other lighting matrix, such as light colour, light length wave, might have a significant impact on autistic (Al Qutub et al., 2024).

4.2. Factors influence the correlation

The interaction between IEQ and autistic behaviours involves complex interplay and is potentially influenced by additional factors that could drive these correlations. A distinguished aspect is the absence of significant correlations between temperature, light levels, and autistic behaviours, which challenges previous assumptions and highlights the need for further investigation into which IEQ parameters significantly affect autistic behaviours.

- **Adaptation and Adjustment strategies:** such as coping mechanisms for sensory reactivity documented in literature (Pfeiffer et al., 2019; Robertson & Simmons, 2015), might explain the observed insignificant impact of certain IEQ parameters. Autistic students, who spend approximately 6 h daily in school settings, may gradually adapt to their indoor environments, becoming less sensitive to sensory stimuli that before proposed challenges. This adaptation could involve the use of tools like headphones to mitigate the effects of noisy environments, enhancing their capacity to cope with sensory inputs (MacLennan et al., 2021; Pfeiffer et al., 2019).
- **Externalise and personal moderator** such as teacher support and the students' mood, also play a crucial role in moderating the impact of IEQ parameters on sensory reactivity and, consequently, on learning progress. Relaxed or rested states may enhance tolerance to sensory stimuli, whereas stress and fatigue can exacerbate sensory discomfort (Verhulst et al., 2022).
- **Sensory integration:** Cross-modal perceptual phenomena, such as synaesthesia—reported to be more prevalent in autistic populations—may influence how environmental stimuli are integrated across sensory domains, thereby moderating behavioural responses to IEQ conditions (Baron-Cohen et al., 2013).
- **Sensory reactivity** can impact on classroom behaviours results. Individuals who are hyposensitive (i.e., under-responsive) to sensory input often require more intense stimuli to notice or react to environmental cues. In a classroom setting, this can result in reduced behavioural engagement—they may appear drowsy, inattentive, withdrawn, or slow to respond (Lane et al., 2010). This lower activity level can affect the accuracy and interpretation of classroom behaviours assessments.

4.3. Application and interpretation

4.3.1. Saudi Arabia in comparative perspective

In Saudi Arabia, autism education infrastructure is still evolving, with many schools operating in retrofitted buildings that often lack design elements tailored to autistic students' sensory needs (Alnemary et al., 2017). Environmental challenges such as high ambient dust levels, industrial emissions, and the frequent indoor use of incense contribute to elevated PM_{10} levels, significantly exceeding WHO recommendations (Al Qutub et al., 2026; Munir et al., 2016). These factors result in classrooms with compromised air quality, which this study has linked to negative behavioural outcomes in autistic children.

In contrast, countries like the UK and Australia have adopted more mature, evidence-informed frameworks. The UK's National Autistic Society (NAS) promotes autism-friendly design guidelines, which are increasingly embedded into school planning and refurbishment (Manning et al., 2023). Such guidelines consider sensory zoning, lighting quality and acoustic management —areas where Saudi classrooms currently show significant deficiencies. Furthermore, multidisciplinary collaboration involving architects, educators, and clinicians is standard practice in these countries, enabling the creation of environments that align with the diverse needs of autistic learners (Shabha & Gaines, 2013).

This comparison highlights the urgent need for Saudi Arabia to develop context-sensitive, autism-specific environmental standards. These must account not only for universal design principles but also for local climatic, cultural, and infrastructural variables. Without such systemic integration, environmental stressors will continue to exacerbate behavioural and educational challenges for autistic students in the region.

4.3.2. Future design guidelines

Emerging empirical evidence provides a foundation for developing targeted, evidence-based design guidelines for autism classrooms (Martin, 2016; Mostafa, 2018). To effectively support autistic students' behavioural and learning outcomes, future design interventions must go beyond static or generalised IEQ standards by incorporating continuous environmental monitoring and individual sensory profiling. Short-term fluctuations in IEQ—such as CO_2 or PM_{10} levels—can differentially affect students based on their sensory reactivity type (Patten et al., 2013); for instance, elevated CO_2 may trigger distress in hyperreactive individuals but not in others.

Thus, autism-friendly classrooms must adopt a data-driven, individualised design strategy, integrating real-time IEQ metrics with behavioural and sensory data (Al Qutub et al., 2024). Adaptive technologies—such as dynamic lighting, sound-absorbing materials, and flexible spatial layouts—should be tailored to accommodate diverse sensory needs, recognising that lighting may influence autistic pupils indirectly through circadian regulation, visual comfort, and cross-modal sensory processing, even where direct behavioural correlations are not statistically evident (Dargue et al., 2021; Kinnealey et al., 2012). Aligning design practice with empirical insights ensures classrooms are not only inclusive and supportive but precisely calibrated to the complex sensory and behavioural profiles of autistic students.

5. Limitation and future study

This study focused on four IEQ parameters but did not consider other personal, behavioural, and contextual environmental factors that may influence autistic students' behaviours due to the dynamic, subjective, and difficult-to-measure nature of these variables. Such factors include individual sensory profile severity, emotional regulation, fatigue, medication use, classroom activity level, teacher interaction style, peer density, and task cognitive demand, which fluctuate over time and lack standardised real-time measurement tools. Key limitations also include the restricted range of IEQ parameters, with temperature and CO_2 levels measured within acceptable ranges, potentially missing extreme conditions that could impact behaviours. Current tools may lack the sensitivity to detect subtle behavioural changes, and the study's reliance on only two repeated measures may reduce predictive accuracy. The requirement for the participating pupil's presence during behavioural observation may have introduced reactivity effects, whereby behaviour is altered due to awareness of being observed, potentially affecting data reliability. Despite these challenges, the research provides valuable insights into the role of IEQ in autism classrooms.

The replicability crisis in psychology and related fields has highlighted the importance of methodological rigour, including the need for more reliable and transparent research designs (Wiggins & Christopherson, 2019). Reliance on two-point measurements in repeated-measures studies can obscure temporal trends and limit sensitivity to short-term behavioural fluctuations, increasing the risk of spurious correlations. In contrast, using multiple time points enhances statistical power, allows better modelling of within-subject variability, and strengthens the interpretive validity of observed effects. Addressing such design issues is essential to producing replicable, generalisable findings, particularly in applied fields like environmental psychology where behaviour–environment interactions are dynamic.

Future studies should expand IEQ parameters to include surface temperatures, reverberation time, clarity (D50), and varied lighting conditions. Acoustic parameters are particularly important in autism-friendly environments and should be assessed in line with established indoor acoustic requirements (Bettarello et al., 2021). Increasing the sample size and diversity of school settings will improve generalizability. Controlled laboratory studies and intervention-based experiments could establish causal relationships between IEQ and autistic behaviours, while advanced statistical methods, including mixed-effects models, could account for individual variability. Additionally, increasing the frequency of repeated measures would offer a more nuanced understanding of the relationship between environmental factors such as PM_{10} concentration and adaptive behaviours. These steps will help create more supportive learning environments for autistic students.

6. Conclusion

This study provides the first empirical evidence from Saudi Arabia examining relationships between IEQ parameters and behavioural outcomes in autism-specific educational settings. By integrating objective environmental monitoring with behavioural and sensory assessments, the research addresses a critical gap in the evidence base for autism-supportive school design.

The findings indicate that PM_{10} concentration, relative humidity, and sound levels are significantly associated with externalised classroom behaviours among autistic pupils. In addition, indicators of ventilation adequacy, reflected by indoor CO_2 concentrations, were associated with behavioural outcomes among pupils with heightened sensory sensitivity, highlighting the importance of air exchange and pollutant accumulation rather than direct perception of CO_2 itself. These results emphasise the need to consider sensory reactivity profiles when interpreting IEQ–behaviour relationships.

Collectively, the findings support the implementation of sensory-responsive IEQ strategies, including effective ventilation, humidity regulation, acoustic control, and adaptable lighting systems. Coordinated efforts by educators, designers, and policymakers are essential to translate these insights into practice and to create learning environments that promote the health, engagement, and well-being of autistic pupils.

CRediT authorship contribution statement

Rahaf Al Qutub: Writing – original draft, Visualization, Methodology, Investigation, Formal analysis. **Zhiwen Luo:** Writing – review & editing, Supervision, Conceptualization. **Emmanuel Essah:** Writing – review & editing, Supervision. **Teresa Tavassoli:** Writing – original draft, Supervision, Methodology, Conceptualization. **Hannah Marcham:** Writing – review & editing, Methodology, Formal analysis. **Qihong Deng:** Writing – review & editing.

Ethics

This study received ethical approval from the Research Ethics Committee of the University of Reading for data collection conducted in Saudi Arabia. All procedures involving children were carried out in accordance with institutional and national ethical standards. Informed consent was obtained from parents/guardians, and assent was sought from child participants where appropriate.

Funding information

The authors declare that no funds, grants, or other support were received during the preparation of this manuscript.

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.

Acknowledgement

The authors would like to acknowledge the Saudi Arabian Cultural Bureau in London for sponsoring the scholarship and KFUPM for providing the equipment for IEQ measurements.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.envpol.2026.127992.

Data availability

The data that has been used is confidential.

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