Review

Comparative Analysis of Indoor Air Quality and Thermal Comfort Standards in School Buildings across New Zealand with Other OECD Countries

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Abstract: COVID-19 has improved awareness of the importance of appropriate indoor air quality (IAQ) in indoor spaces, particularly in classrooms where children are expected to learn. Research has shown that poor IAQ and temperature levels affect the cognitive performance of children. In this paper, we critically compare IAQ standards for New Zealand’s Designing Quality Learning Spaces (DQLS Document) against international benchmarks from the Organization for Economic Co-operation and Development (OECD) countries, including ASHRAE 62.1, CIBSE TM57, EN-15251, WHO AQGs, and Building Bulletins 99 and 101. The aim was to ascertain the robustness of New Zealand’s DQLS document, identify areas of superiority, and recommend the required improvement for appropriate IAQ and thermal comfort in classrooms. This comparison review focuses on IAQ parameters: CO₂ levels, temperature, ventilation rates, room size, occupant density, and occupancy rates. The findings illuminate a slight lag in New Zealand’s DQLS standards compared to her international counterparts. For instance, while New Zealand’s standards align closely with WHO standards for IAQ concerning temperature and ventilation rates, the recommended CO₂ range appears slightly inadequate (800 to 2000 ppm) along with occupancy and classroom size for effectively controlling classroom pollutant growth. This paper emphasises the need to align New Zealand’s IAQ and thermal comfort standards with optimal OECD benchmarks. The identified disparities present opportunities for improving learning spaces in terms of CO₂ concentration, size of classroom, and occupant density in schools in New Zealand to meet globally recognised standards, ultimately creating a healthier and more conducive learning environment.

Keywords: school; indoor air quality; thermal comfort; OECD countries; performance; health

1. Introduction

Ensuring healthy air quality is important in school indoor environments to provide conducive conditions for students and teachers [1]. Research on air quality (i.e., indoor environment) and ventilation in school learning spaces is common worldwide [2]. The popularity of this area of research is driven by two primary factors: firstly, school learning spaces accommodate a high number of children exposed to pollutants from diverse indoor and outdoor sources over extended periods [3]. Secondly, school premises often undergo less frequent inspections concerning maintainability and eco-friendliness, contributing to a regular occurrence of reported poor IAQ in schools globally [4].

Children are vulnerable to poor IAQ due to their underdeveloped immune systems, respiratory tracts, and body mass indexes, necessitating a higher air intake within enclosed spaces [3,5]. According to Andamon et al., [2] students spend up to 90% of their developmental years indoors at school, accumulating roughly 13,000 h throughout their academic journey from preschool to Standard 12. Given the extensive time students spend indoors, the presence of indoor air pollutants within school premises potentially compromises a healthy indoor environment, impacting the physical and mental health of children [5,6].
The presence of pollutants within school premises and their impact on the internal environment are influenced by three significant factors: temperature fluctuations, low humidity, and aeration rates [7]. These factors affect indoor environment quality (IEQ), leading to health concerns and thermal discomfort within the school premises [8].

Research has documented extensive reports on the health concerns of poor indoor conditions in classrooms. For instance, Bluyssen [9] noted that unhealthy indoor conditions, marked by pollutants, have been linked to increased student absenteeism, directly affecting their academic performance. Roy [10] observed that prolonged exposure to contaminants in school premises has been linked with a heightened likelihood of developing severe health issues, like respiratory, pulmonary, and cardiovascular illnesses. Andamon et al. [2] showed a direct association of poor ventilation rates within school premises with lower academic performance, emphasising the need to address these issues and create a learning environment that prioritises both students’ cognitive and physical health development.

Likewise, previous studies have quantified the direct correlation between aeration rates and the percentage of aerial disease spread [11,12] in indoor spaces. For example, Wang and Hong [13] emphasise that lower ventilation rates in confined spaces contribute to transmitting airborne diseases like tuberculosis and SARS. Wei et al. [14] note that an elevated risk of airborne disease transmission is pronounced in higher-occupancy spaces, making school classrooms susceptible to hotspots. According to Dai and Zhao [15], in order to keep transmission rates below 1% in confined spaces, a consistent aeration rate of 7 air changes per hour (ACH) should be maintained for 2 h of continuous teaching in classrooms.

Likewise, in New Zealand, poor IAQ classroom standards have been associated with severe health issues in children, including respiratory infections [16]. Various factors contribute to poor IAQ conditions in school classrooms, such as lower ventilation rates causing stale environments, outdated designs, and the age of classrooms without prioritising IAQ [17]. These are exacerbated by higher classroom occupancy rates, which lead to elevated carbon dioxide concentrations, and the accumulation of indoor pollutants further impacts health and learning outcomes.

Addressing poor IAQ conditions in school classrooms requires a holistic approach, necessitating stakeholder collaboration to create conducive classrooms that foster health and academic performance [18]. But then, inappropriate IAQ standards and the impracticality of achieving stipulated standards have led to consistently unhealthy learning environments. Compounded by the recent challenges posed by the COVID-19 pandemic, there is a likely chance that these IAQ classroom standards are insufficient in providing a conducive learning environment for school children. For instance, a critical review of existing school design guidelines in New Zealand by Crooks et al. [19] suggests that maintaining optimal (IAQ) within school rooms may need to be fully addressed, constituting a gap that needs to be filled to ensure safer learning environments.

According to Sutherland et al. [20], strategic steps must be taken to bridge the above gap to minimise exposure to IAQ pollutants, enhance ventilation rates, and improve IAQ standards. Our study aimed to bridge this gap and ascertain the robustness of the New Zealand DQLS IAQ standards in enhancing the resilience of school facilities with measures that prioritise the health and well-being of all users. The aim of the study is to ascertain the robustness of New Zealand’s DQLS document, identify areas of superiority, and recommend the required improvements for appropriate IAQ and thermal comfort in classrooms. Therefore, this paper compares the New Zealand DQLS IAQ standards with the IAQ standards of the OECD countries. Differences among the standards are identified, and improvement opportunities are highlighted for the NZ DQLS IAQ standards.

2. Background
2.1. IAQ in Schools (OECD Countries)

The scientific community has increasingly focused its research on indoor air quality (IAQ) within school classrooms [21]. The Global Burden of Disease Risk (GBDR) assessment has highlighted the significance of IAQ by ranking it ninth among health-related concerns.
This recognition underscores the importance of addressing IAQ issues in educational settings to safeguard the health and well-being of students and educators [22]. The findings from the GBDR assessment shed light on the urgent need for effective measures and interventions to improve IAQ in schools [23].

Children across the globe spend a significant time in classrooms as mandatory instruction hours for primary and secondary education. Figure 1 shows the compulsory average instruction hours between 2015 and 2021 in OECD countries. As shown in Figure 1, children in developing countries typically spend 10 to 15 percent of their first 18 years of school life in educational premises, primarily within the confines of a classroom [24–29]. The X-axis in Figure 1 shows the OECD year from 2015 to 2021, and the Y-axis shows the annual hours.

![Mandatory instruction hours per year, OECD (2015–2021).](image)

Classrooms often struggle to maintain healthy indoor air quality. Extensive research conducted in developing countries has consistently demonstrated the significant health implications of poor IAQ [30]. A compelling body of research underscores the critical need for strategic actions and improvements to safeguard the health and well-being of students in these environments [31–35].

Achieving good IAQ in conventional classroom designs is often strenuous. Due to their complex designs, conventional classrooms have less indoor mobile space and less availability to adapt or adjust to the surrounding environment [36]. To maintain healthy IAQ within the classroom, the teaching staff completes most of the adaptive measures, like opening windows and doors, either at the children’s request or because of their discomfort [37].

The impact of pollutants is dependent on indoor and outdoor air quality. Some of the pollutants which make IAQ worse are human generated; for instance, the odourless gas, carbon dioxide, and pollutants emanating from materials used in the building [38]. In addition, pollutants coming from cleaning materials and resources used in performing educational tasks affect the indoor environment [39]. Pollutants generated from the outside environment result from outdoor activities, weather conditions, location, and the proximity of school classrooms to roads [40]. Another factor that seriously impacts the IAQ includes window operating actions, as in naturally ventilated classrooms, it plays a vital role compared to mechanically ventilated classrooms [32].

2.2. Factors Impacting IAQ in School Classrooms

In a comprehensive study conducted by [35], the factors impacting IAQ in school classrooms were examined through the lens of three main categories: context, occupant, and building. Two distinct levels were identified within the context category: macro and micro. The macro level encompassed climatic and outdoor conditions such as weather...
patterns or seasonal variations, while the micro level focused on factors like outdoor temperature and airflow through windows [41]. Occupant-related aspects were found to play a crucial role and included behavioural actions, the number of occupants, specific tasks performed within the dwelling, the age and nutritional habits of occupants, maintenance and operational practices, the duration of time spent indoors, and the individual comfort levels of occupants [42]. The building-related aspects identified in the study included the location of the premises, the number of windows and doors present, the design of the building envelope, ventilation rates and system type, the total volume of the area, carbon dioxide levels resulting from exhalation, and the level of air tightness [43].

This comprehensive categorisation provides a framework for understanding the various factors contributing to IAQ in school classrooms. Policymakers and researchers can develop targeted strategies to improve indoor air quality and promote healthier living environments by considering the context, occupant, and building-related aspects [44]. As shown in Figure 2 below, occupant-related elements can significantly impact indoor air quality. Children’s bodies are less mature than adults, making them more susceptible to environmental hazards. Due to smaller body organs, their immune systems are not fully developed.

![Figure 2. Occupant-related factors impacting IAQ. Source: [35].](image)

Moreover, their respiratory tracts are in a developmental stage, so their breathing rates are higher in comparison to adults [45]. In addition, the heat released from children’s bodies is approximately 85% more than that released from adults due to their higher metabolism rates. The metabolism process in the human body is associated with the generation of carbon dioxide, which ranges between 3.3 cm$^3$/s and 5.8 cm$^3$/s for children, depending upon the activities they are engaged in [35].

2.3. New Zealand Classrooms and IAQ

The New Zealand Building Code recommends incorporating natural ventilation in buildings by requiring a minimum net openable area for windows and other openings to be equivalent to at least 5% of the floor space [46]. Learning spaces achieving air changes per hour (ACH) rates above five to six ACH have CO$_2$ concentrations below 800 ppm, indicating adequate ventilation. Recent collaborative studies in New Zealand classrooms show that a 5 cm window opening, around 50% of the window, with a 10% net ground area ratio, can quickly achieve ventilation rates of 5 ACH [46]. Partially open windows and additional support like fans can readily achieve adequate ventilation rates. But then, achieving adequate ventilation rates in naturally ventilated classrooms requires behavioural adaptability. Understanding the factors that support or hinder adequate ventilation is crucial [46]. Figure 3 [47], illustrates the recommended CO$_2$ concentration and ventilation standards in New Zealand schools and classrooms. The New Zealand Ministry of Education aims to provide adequate outdoor air for each learning space to allow students and teachers...
to learn and work comfortably. Indoor carbon dioxide (CO₂) levels indicate general indoor air quality and ventilation effectiveness. Figure 3 illustrates the relationship between indoor CO₂ concentrations, ventilation rates expressed as air changes per hour (ACPH) and litres per second per person (L/s/p), and the subjective occupant response. Figure 3 clearly demonstrates that higher ventilation rates lowered carbon dioxide, improving subjective occupants’ responses. Hence, the visual representation underscores the importance of adequate ventilation in maintaining acceptable indoor air quality and occupant comfort in educational settings [47].

![SCHOOL INDOOR AIR QUALITY & VENTILATION](image)

**Figure 3.** Recommended standards for CO₂ concentration and ventilation. Source: [47].

### 2.4. Indoor Air Quality Parameters

Human beings spend a substantial amount of their time indoors, approximately 90 percent. For children, a significant part of this indoor time is spent in classrooms at school, essentially making school premises their second home environment where they spend a considerable portion of their day [48,49]. This high indoor exposure emphasises the significance of IAQ, especially in places like schoolrooms where maintaining substantial distance can be challenging. The pandemic has intensified the focus on classrooms as potential sources of COVID-19 transmission, primarily through airborne means [50].

In order to balance costs and maintain both standard thermal comfort and healthy IAQ, natural aeration is recommended as the optimal solution. Natural ventilation effectively reduces the transmission of airborne pathogens [51,52]. However, managing thermal conditions in colder months, crucially dependent on natural ventilation, adds complexity to spaces like classrooms. The guidance in [53] suggests circulating more cycles of fresh air to achieve healthy indoor air quality, especially during colder weather. Recommendations from [54] include purging spaces, increasing window opening cycles, and prioritizing clerestory openings in colder conditions.
2.4.1. Carbon Dioxide and Ventilation

Carbon dioxide is a natural gas that is harmless in lower concentrations. Monitoring its levels in parts per million (ppm) is a way to check indoor ventilation. CO_2_ concentrations vary throughout the day. Higher ppm can indicate poor ventilation [55]. However, low CO_2_ levels are a positive indicator but they do not guarantee a clean atmosphere. Other airborne contaminants, like pathogens, might still be present. Ventilation is crucial for designing and operating schools. It involves naturally or mechanically replacing contaminated air with clean air [56]. Ventilation rates are measured in litres per second per person or per square meter. The choice of ventilation method depends on the building type, usage, and activities [57].

Spacing management and design are vital in efficient ventilation, especially in densely populated buildings. Natural and mechanical ventilation methods are standard, but natural ventilation is recommended for indoor air quality (IAQ) [58]. Studies during and post-COVID-19 emphasise natural ventilation’s effectiveness in maintaining good IAQ and minimising contagion risk. The World Health Organization recommends natural ventilation, especially during winter, when inadequate ventilation is standard in schools [59].

Impact of Carbon Dioxide and Ventilation in the School Classroom

A substantial body of research has investigated the link between carbon dioxide (CO_2_) concentrations and potential health impacts, focusing on respiratory and cardiovascular problems [60–62]. Studies focusing on children’s performance and cognitive abilities suggest a noteworthy correlation with exposure to carbon dioxide levels. Chatzidiakou, Mumovic, and Summerfield [63] propose that monitoring carbon dioxide serves as a useful proxy for assessing Indoor Air Quality (IAQ), indicating lower indoor pollutants and toxic particle elimination. However, a study challenges the concept that carbon dioxide exposure solely causes declines in children’s cognitive performance, highlighting the multifaceted nature of IAQ effects [61].

While elevated carbon dioxide levels in classrooms may signal ventilation issues, it is crucial to recognise other factors influencing the indoor environment and cognitive abilities. Indoor pollutants, allergens, temperature, relative humidity, illuminance, and individual factors like sleep cycles, health, and nutrition collectively contribute to performance [64]. This complexity underscores the need for a comprehensive investigation beyond carbon dioxide levels to understand the intricate relationship between IAQ and cognitive performance [60].

The global facts on the adverse physical conditions and implications of prolonged connection to poor IAQ are expanding rapidly, particularly impacting the respiratory and cardiovascular systems [65]. Respiratory illnesses, exacerbated by factors like air pollution, poor IAQ in homes and schools, and changing weather patterns, are predominant in Western countries. Associations between unhealthy IAQ and asthma development have been established, with ongoing research exploring cardiovascular implications [66,67].

Moreover, the primary cause of poor IAQ is often linked to higher carbon dioxide concentrations [68]. Although poor ventilation rates may not directly impact health, they contribute to environmental conditions, potentially leading to sick building syndrome. Inadequate ventilation can facilitate the spread of infections within indoor environments, emphasizing the significance of optimal ventilation rates in schools for healthy IAQ [69]. Ventilation is crucial in controlling contaminants, maintaining comfort, and removing classroom odours. Studies indicate that increased ventilation rates lead to improved attendance and health among school children, demonstrating a positive correlation between IAQ and academic outcomes [70–73].

New findings directly link carbon dioxide concentration, ventilation rates, IAQ, and children’s academic outcomes. Lowering carbon dioxide levels resulted in a substantial improvement in children’s performance and accuracy. A decrease from 2000 to 900 ppm led to a 12% and 2% enhancement in performance and accuracy, respectively. Improved attendance was also noted, reinforcing the connection between IAQ improvements and overall health and productivity in educational settings [60]. Adequate ventilation is critical.
in cultivating a healthy indoor environment, potentially reducing harmful contaminants, and enhancing overall well-being.

Maintaining proper ventilation rates of 5–6 (ACH) is crucial, and partially active windows and doors can support achieving these rates [74]. Clerestory openings offer relief by reducing draught effects, and a combination of purging and heating in the cycle ensures good air quality and comfortable thermal conditions. The WHO [75] recommends 10 litres per second per person (L/s/p) of outdoor air for healthy indoor air quality. This is supported by [76], emphasizing the importance of maximising classroom airflow rates through window and door openings. Refer to Table 1 for standards on indoor air quality and thermal comfort in school classrooms in Western countries.

2.4.2. Thermal Comfort

Assessing the indoor environment’s thermal comfort is often called independent evaluation, as it considers individual satisfaction. However, children and adults differ in their assessment due to children’s vulnerability to higher temperatures, influenced by their higher metabolism rates and multitasking during school hours [77,78]. The adaptable thermally comfortable range for individuals is influenced by their exposure to outdoor conditions. Occupants spending more time in buildings relying on natural ventilation are less vulnerable than those in mechanical ones, with a broader thermally comfortable range. It is crucial to note that an individual’s comfort range varies based on factors like outdoor temperature, airflow, humidity activity level, and clothing [79,80]. The key variables determining thermal comfort include air temperature, mean radiant temperature, relative humidity, and air velocity. Relative humidity (RH) and temperature are interconnected, with temperature variations often causing RH fluctuations. However, within the 40 to 70% RH range, occupants are generally not highly sensitive to humidity changes [81]. While humidity variations do not directly impact thermal comfort, their influence becomes more pronounced at higher temperatures and metabolic rates [82,83]. In addition, the relative humidity can vary in New Zealand in the context of diversified climatic conditions. The acceptable RH range for all indoor spaces in New Zealand is within 40 to 70%.

Impact of Thermal Comfort in a School Classroom

Thermal comfort is a crucial aspect of indoor environmental quality (IEQ), influencing occupants’ physical and mental conditions, and is subject to individual thermal behaviours and cultural expectations [84]. Described by [85] as “a state in which there are no driving impulses to correct the environment by behaviours”, thermal comfort is more of a mental state than a fixed condition. ASHRAE defines it as “the condition of the mind in which satisfaction is expressed with the thermal environment” [86]. Al-Abasi et al. [87] identified six primary factors affecting thermal sensation, depicted in Figure 4 below.

Achieving thermal comfort is crucial as it positively impacts our well-being and performance. Consequently, building design should prioritize thermal stability to enhance comfort levels. Thermal comfort refers to the state of satisfaction with the surrounding thermal environment. This satisfaction is influenced by factors affecting both the environment (air temperature, relative humidity, air movement, and mean radiant temperature) and the individual (activity and clothing). These six factors form the basis of Fanger’s classic equation for thermal comfort, which determines the human body’s heat balance under steady-state conditions [87]. The comfort within a classroom is vital for students’ productivity and well-being [88]. Various studies have established a correlation between improved academic performance and children’s thermal comfort, emphasising the impact of even slight temperature changes on learning abilities. Maintaining optimal conditions, particularly in the temperature range of 20 to 25 °C, positively influences learning outcomes. Temperature and carbon dioxide levels, along with adequate ventilation, can effectively maintain occupants’ cognitive functioning and well-being. Adequate ventilation rates are quite effective in diluting the pollutants and maintaining acceptable ranges for carbon dioxide concentrations. The total number of occupants in the classroom and their activity level significantly influence the concentration of carbon dioxide and heat gains, which
further require necessary adjustment with ventilation strategies. The size of the classroom can positively influence the effectiveness of ventilation rates.

Figure 4. Primary factors affecting thermal sensation.

3. Methodology

This study aimed to establish the robustness of the prevalent IAQ standard for CO₂ and temperature levels in the NZ DQLS document. To achieve the aim of this study, we compared the NZ DQLS’s IAQ standard with standards from the Organisation for Economic Co-operation and Development (OECD) countries. This ensures that the comparison is carried out between similar economic and climatic countries selected for comparison.

Firstly, we selected the IAQ standards in the following OECD countries: the United States of America, the United Kingdom, European Union Countries, and Canada. These standards include ASHRAE 62.1, CIBSE, WHO Air Quality Guideline (AQGs), EN-15251, Building Bulletin 99 and Building Bulletin 101. These IAQ standards were compared with the current NZ DQLS document’s IAQ standard (version 2.0, 2022) [47] published by New Zealand’s Ministry of Education (MOE) and the Building Research Association of New Zealand (BRANZ).

ASHRAE 62.1 [89] is a recognised standard for designing ventilation systems and establishing acceptable ranges for IAQ. It provides measures for both new and older non-residential dwellings and aims to minimise the adverse health effects resulting from poor IAQ. CIBSE [90] offers valuable information related to school buildings, covering various stages from early design to completion. The document focuses on aspects such as acoustic design, lighting design, ventilation design, overheating and cooling design, heating and thermal comfort design, and energy demand. The WHO Air Quality Guidelines (AQGs) [75] underscore the critical importance of addressing indoor air quality (IAQ) and thermal comfort in the school environment. Children spend a significant portion of their time in classrooms; the guidelines emphasise the need for standards to safeguard their health and wellbeing. The WHO aims to mitigate the adverse health conditions associated with poor indoor environmental conditions by setting minimum guidelines for temperature, ventilation, and pollutants. EN-15251 [91] establishes measurable parameters for indoor environmental quality in commercial dwellings, specifically addressing the design and evaluation of energy efficiency, quality of indoor air, comfort performance, lighting, and sound levels. The document provides a clear understanding of non-statutory standards for educational learning spaces. It presents minimum space requirements for school classrooms, ensuring adequate areas for occupants to maintain a healthy IAQ. The
standard for comparison includes temperature range, carbon dioxide concentration, ventilation rates, classroom size, occupancy, and occupant density. This study’s Findings and Discussion section presents the findings from these reports. Building Bulletin 99 by [92] is a comprehensive document developed by the Department for Education in the United Kingdom. It provides guidance and standards for creating safe, healthy, and conducive learning environments in schools. Building Bulletin 99 aims to meet high standards for school indoor environments focusing on the well-being, comfort, and academic achievement of students. The document provides technical guidance on IAQ standards and thermal comfort criteria with respect to design, number of occupants, space planning, ventilation, and performance. Building Bulletin 101 is a guidance tool published by the Department for Education in 2006 in the United Kingdom. The latest version, BB101 version 1, which was recently updated in 2018. The BB101 version 1 tool sets out the regulations, standards, and guidelines on school ventilation, thermal comfort, and indoor air quality. The main drivers of this guidance tool include establishing ventilation standards and minimum ventilation rates for schools to ensure an adequate fresh air supply for occupants, highlighting the importance of thermal comfort and providing guidance on maintaining a comfortable room temperature, prioritising the health and well-being of students by addressing air quality concerns and temperature regulation, providing comprehensive recommendations related to ventilation, air quality, and thermal comfort in educational settings to promote a conducive learning environment for students [76].

The MOE-initiated DQLS provides guidelines for appropriate IAQ and thermal comfort in NZ classrooms and learning spaces. The document aims to ensure optimal learning environments in newly constructed schools. Originally released in 2007 as separate documents for IAQ and thermal comfort, the DQLS was updated and combined in 2017 (version 1.0). The 2022 update (version 2.0) incorporates revised standards for air quality, thermal performance, heating, and ventilation in classrooms. DQLS 2.0 also outlines mandatory requirements for air quality, temperature, thermal performance, and indoor environment monitoring. The DQLS 2.0 update strengthens the mandatory requirements to align with the Ministry of Education’s (MOE) 2030 School Property Strategy. This strategy prioritises well-being and fosters quality learning environments that support diverse teaching and learning approaches. The update in DQLS 2.0 reflects the evolving landscape of educational space design and commissioning, now overseen by governing bodies [47]. A key driver for the stricter IAQ and TC requirements is the recognition that most New Zealand primary schools (roughly 90%) rely heavily on natural ventilation through windows and doors. These requirements aim to ensure thermally comfortable learning spaces that can effectively support various teaching styles and learning activities. The emergence of COVID-19 in New Zealand (February 2020), mirroring global concerns, spurred the Ministry of Education (MOE) to update the DQLS 2.0 (2022) with a renewed emphasis on ventilation’s role in mitigating airborne disease spread, including COVID-19. This revision aims to create healthier and more comfortable learning environments through enhanced requirements for fresh air intake and distribution with higher air changes per hour (ACH) or litres per second per person (L/s/p) and lowered carbon dioxide (ppm), improved guidance for heating and cooling in temperatures (°C) tailored to regional climates, enhanced design verification and compliance measures, including mandatory modelling for larger buildings with increased window to wall ratio in percentage (WWR), and the incorporation of indoor environmental monitoring tools in each classroom to facilitate continuous monitoring of ventilation system performance.

The New Zealand Ministry of Education prioritises healthy classrooms through improved IAQ and thermal comfort. The DQLS mandates address these aspects alongside acoustics and lighting, demanding a holistic design approach. As the IEQ is a complex system of interrelated variables (IAQ, thermal, acoustics, and lighting), designers must consider their combined impact during design and commissioning to ensure the optimal learning environment [47,93].
The IAQ standards were compared based on the following factors relating to IAQ and thermal comfort:

- Temperature (°C)
- Carbon dioxide (ppm)
- Ventilation rate (l/s/p and ACH)
- Occupancy (number of occupants)
- Occupancy density (m²)
- Classroom size (m²)

The key factors selected for this comparative study are intrinsically linked to the assessment and optimisation of IAQ and thermal comfort in a classroom environment. These factors influence indoor vital conditions and directly impact health, well-being, and performance. For instance, temperature is a critical factor affecting thermal comfort and is associated with cognitive functioning and productivity. Carbon dioxide concentrations are widely used as a proxy measure to calculate ventilation efficiency and overall IAQ. Higher CO₂ concentrations are associated with an inadequate supply of fresh air. Moreover, ventilation rates directly influence the dilution and removal of indoor pollutants, including excessive CO₂, and the thermal regulation of the indoor space.

The number of occupants and their density within the classroom is directly associated with generating carbon dioxide and indoor pollutants. Appropriate occupant density ensures sufficient air volume per person, preventing overcrowding, which can lead to poor IAQ and thermal discomfort. The classroom size plays an important role in air volume and achieving optimal ventilation, temperature distribution, and overall healthy environmental quality. Hence, all the above factors chosen for this comparative study across OECD standards help to identify best practices and highlight the areas of improvement to achieve optimal IAQ and thermal comfort in the classroom.

The findings and discussion are provided in Section 4 below. These are discussed based on the underlying theories supporting these standards.

4. Findings and Discussion

Table 1 below provides an overview of the IAQ standards compared with the NZ DQLS IAQ and Thermal Comfort Standard. The table shows that the NZ DQLS standards differ slightly from most OECD countries’ standards. For temperature, the NZ DQLS standards stipulate a range similar to WHO AQG, Building Bulletin 101, and EN 15251 standards. While the minimum CO₂ level is the same as CIBSE and EN 15251, the maximum CO₂ differed significantly. For ventilation rate, the NZ DQLS standard was closely aligned with the WHO AQG standard and CIBSE standards but higher than the ventilation rate specified in ASHRAE 62.1 and EN 15251. For occupancy, occupant density, and room size, the standards differed significantly. While ASHRAE 62.1 and BB 99 specified the occupancy and occupant density required in particular classroom sizes, CIBSE only identified the required occupant density. EN 15251 specified the occupancy and occupant density, while NZ DQLS noted the required occupancy for a classroom size.

<table>
<thead>
<tr>
<th>OECD International Standards</th>
<th>Temperature (°C)</th>
<th>Carbon Dioxide (ppm)</th>
<th>Ventilation Rate (l/s/p)</th>
<th>Occupancy (Numbers)</th>
<th>Occupant Density (m²)</th>
<th>Size (m²)</th>
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<tr>
<td>ASHRAE 62.1 [89]</td>
<td>22 °C Average</td>
<td>1000 ppm</td>
<td>6.7–7.4 l/s/p</td>
<td>25</td>
<td>4 m²</td>
<td>100 m²</td>
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<tr>
<td>CIBSE [90]</td>
<td>21 °C Maximum</td>
<td>800–1000 ppm</td>
<td>10–15 l/s/p</td>
<td>-</td>
<td>2–4 m²</td>
<td>-</td>
</tr>
<tr>
<td>NZ DQLS [47]</td>
<td>18–25 °C</td>
<td>800–2000 ppm</td>
<td>5–10 l/s/p</td>
<td>30</td>
<td>-</td>
<td>75 m²</td>
</tr>
<tr>
<td>WHO AQG [75]</td>
<td>18–24 °C</td>
<td>1000–1500 ppm</td>
<td>10 l/s/p</td>
<td>-</td>
<td>-</td>
<td>-</td>
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Table 1. Cont.

<table>
<thead>
<tr>
<th>OECD International Standards</th>
<th>Temperature (°C)</th>
<th>Carbon Dioxide (ppm)</th>
<th>Ventilation Rate (L/s/p)</th>
<th>Occupancy (Numbers)</th>
<th>Occupant Density (m$^2$)</th>
<th>Size (m$^2$)</th>
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<td>EN 15251 [91]</td>
<td>20–24°C</td>
<td>800–1400 ppm</td>
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<td>BB 99/101 [76,92]</td>
<td>20–25°C</td>
<td>1500 ppm</td>
<td>8–10 L/s/p</td>
<td>30</td>
<td>2.3 m$^2$</td>
<td>70 m$^2$</td>
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4.1. Carbon Dioxide and Ventilation Rate Standards

In the post-pandemic era, natural ventilation in educational settings has become increasingly important for maintaining adequate ventilation rates. Evidence suggests that natural ventilation ensures a supply of fresh air, thereby reducing the risk of airborne contagions. Studies suggest that approximately 4 square meters of window openings are needed in classrooms for 8 to 9 litres per second per person ventilation rates in summer, and around 2 square meters are sufficient in winter with effective heating [17]. An optimum average CO$_2$ concentration of 800–900 ppm is linked to improved health and academic performance. Concentrations close to 900 ppm or lower significantly enhance children’s performance. Ventilation rates and cognitive ability studies show that increasing ventilation rates from 15 to 25 litres per second per person can improve cognitive performance by an additional 10 percent [94]. A concentration of 2100 ppm indicates very low ventilation rates, causing discomfort to occupants.

International standards recommend minimum ventilation rates for classrooms. Studies show that doubling ventilation rates significantly improves learning outcomes, with a more substantial improvement observed in schools compared to office buildings [60]. Approximately 90 percent of classrooms in New Zealand rely on natural ventilation [46,95]. While there are no specific standards for minimum ventilation, regulations propose CO$_2$ concentration as a proxy. It suggests that average CO$_2$ should not exceed 1500 ppm during the day or exceed 3000 ppm during peak learning hours [6]. However, the DQLS 2022 represents a significant improvement and a tightening of indoor carbon dioxide requirements for New Zealand school classrooms. The recommended daily average CO$_2$ concentration during occupied hours is set at 800 ppm. This 800 ppm is considered the ideal “Design Goal” to maintain optimal IAQ. However, the mandatory maximum daily average for CO$_2$ concentration during occupied hours is 1250 ppm. This 1250 ppm represents the upper limit before the IAQ is deemed inadequate and in need of improvement. Furthermore, the DQLS 2022 specifies that the maximum permissible peak CO$_2$ concentration must not exceed 2000 ppm at any point during the teaching period. The maximum permissible limit of 2000 ppm acts as an emergency limit, indicating the need to take immediate action to purge the indoor air and try to lower the CO$_2$ concentration to the “Design Goal” of 800 ppm. Overall, the designed limit for CO$_2$ of 800 to 2000 ppm in the DQLS 2022 document appears considerably reasonable to maintain a healthy and comfortable IAQ.

In comparison with other OECD countries’ standards, ASHRAE 62.1 caps CO$_2$ concentration at 1000 ppm, CIBSE recommends the range of 800–1000 ppm, WHO AQS allows up to 1500 ppm, Building Bulletin 101 recommends up to 1500 ppm, and the EN15251 range is 800–1400 ppm. However, it is important to note that the DQLS, 2022 version 2.0, also specifies a recommended daily average of 800 ppm and mandatory average daily limit of 1250 ppm. These limits clearly confirm that the DQLS thresholds align closely with the OECD standards. Although the peak limit for CO$_2$ is 2000 ppm in DQLS 2022, may still be higher in comparison to other OECD countries, the overall CO$_2$ concentration limits appear to be a concerted effort. This advancement in DQLS 2022 to regulate CO$_2$ concentrations, clearly signifies the New Zealand Ministry of Education’s commitment to provide optimal IAQ for students, staff, and co-workers for their health and productivity. The advancement reflects the positive attitude in aligning with international standards for IAQ.
The ventilation rate standards for school classrooms vary across the OECD countries. The ASHRAE standard specifies a range of 6.7 to 7.4 litres per second per person (L/s/p), while the CIBSE guidelines recommend a higher range of 10 to 15 L/s/p. In contrast, the New Zealand DQLS document outlines a lower ventilation rate of 5 to 10 L/s/p. The WHO Air Quality Guidelines (AQGs) align more closely with CIBSE, suggesting a rate of 10 L/s/p. The EN-15251 standard falls in the middle, prescribing a range of 5 to 8 L/s/p. Interestingly, the Building Bulletin 101 (BB101) standard recommended a ventilation rate of 8 to 10 L/s/p, which sits between the upper and lower bounds of the other guidelines. This diversity in ventilation rate requirements reflects the different approaches and priorities adopted by each country or organization in balancing factors such as indoor air quality, energy efficiency, and practical feasibility for school design and operation.

4.2. Temperature Standards

The prevalent indoor temperature levels determine thermal comfort in any given space. Likewise, the indoor temperature is influenced by the outdoor temperature and fluctuates in accordance with this temperature variability. Interestingly, occupants in colder regions have been noted to be more adaptable and accommodating to exposure to colder temperatures, influencing their adaptability to colder indoor settings. As such, in classrooms where temperatures may fall below the recommended 18°C, children would likely find temperatures below this threshold comfortable.

This explains why various countries have diverse thermal comfort standards (Table 2 below). For example, ASHRAE suggests an average of 22°C, while the Regional Education Laboratory recommends different ranges for winter (20–24°C) and summer (23–26°C). Recommendations from the United Kingdom vary, with CIBSE suggesting a maximum of 21°C and the National Education Union recommending a minimum of 18°C. Canada and the European Union have different ranges, with Canada suggesting 20–26°C, EU recommending 24–26°C, and the Building Bulletin 101 recommending between 20°C and 25°C. New Zealand, with varied climates, sets a recommended range of 18–25°C for classroom temperatures, according to the Ministry of Education. However, performance varies based on factors like design, climate, occupancy, and behaviour.

Table 2. Recommended international institutional bodies’ classroom temperature ranges.

<table>
<thead>
<tr>
<th>Western Countries (OECD)</th>
<th>Institutional Bodies</th>
<th>Recommended Temperature Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>United States of America</td>
<td>ASHRAE [89]</td>
<td>22°C (Average)</td>
</tr>
<tr>
<td>United Kingdom</td>
<td>CIBSE [90]</td>
<td>21°C (Maximum)</td>
</tr>
<tr>
<td>United Kingdom</td>
<td>National Education Union [96]</td>
<td>18°C (Minimum)</td>
</tr>
<tr>
<td>United States of America</td>
<td>Regional Education Laboratory [97]</td>
<td>20–24°C (Winter) 23–26°C (Summer)</td>
</tr>
<tr>
<td>Canada</td>
<td>National Joint Council [98]</td>
<td>20–26°C</td>
</tr>
<tr>
<td>New Zealand</td>
<td>Ministry of Education [47]</td>
<td>18–25°C</td>
</tr>
<tr>
<td>Europe</td>
<td>EN 15251 [91]</td>
<td>24–26°C</td>
</tr>
</tbody>
</table>

Source: [20].

Achieving these temperature standards remains a complex topic. While some authors recommend using natural ventilation, which supports the sustainability crusade, others recognise the limits of natural ventilation and promote mechanical or even mixed-mode ventilation systems. For instance, NZ DQLS’s IAQ and thermal comfort document emphasises the preference for natural ventilation and only recommends that mechanical or mixed-mode ventilation (with cooling, where appropriate) may be considered for summertime temperature control, where natural ventilation cannot reasonably achieve the maximum temperature criteria. The mode for acceptable ventilation strategies depends upon locations based on heating and cooling degree days. Likewise, depending on the
number of heating and cooling days required annually, different countries set out the climate zones that suit the ventilation system required to meet adequate IAQ and thermal comfort conditions. Additionally, the ASHRAE 62.1 offers mechanical or mixed modes of ventilation strategies. In contrast, CIBSE, BB 101, and EN-15251 allow natural, mechanical, and mixed ventilation modes depending on the building type, climate zone, occupancy levels, and budget. In response to the pandemic, CIBSE issued specific guidance on ventilation to help mitigate the spread of airborne diseases like COVID-19. This guidance emphasises increasing ventilation rates, improving air filtration, and encouraging natural ventilation where possible. The emphasis in BB99 on ensuring reliable natural ventilation through doors and windows, along with the DQLS standards, suggests a strong focus on utilising natural ventilation whenever possible, aligning well with New Zealand’s climate.

Using natural ventilation in classrooms during winter may cause discomfort due to temperature variations, known as the stack effect. That said, the performance of natural ventilation in reducing temperature levels improves in winter compared to summer due to increased airflow [99]. In particular, cross ventilation and vertical displacement ventilation are effective against COVID-19 transmission but have limitations such as contaminant movement and heat loss. Balancing thermal comfort, energy needs, and the risk of airborne transmission is crucial when selecting ventilation modes for school classrooms [100]. Aniebietabasi [88] recommends deploying combined sensors for temperature and humidity in naturally ventilated areas to understand their spatial connection better.

Most thermal comfort standards worldwide rely on two thermal comfort models to evaluate temperature levels in buildings—Fanger’s model and the Adaptive Model. Fanger’s model recommends that the temperature range for thermal comfort is 20 ± 1 to 24 ± 2 °C, varying based on climatic conditions [101]. The newer adaptive thermal comfort model considers a broader temperature range, acknowledging the influence of individuals’ interactions with and adaptability to their environment.

Fanger’s equations, including the predicted mean vote (PMV) index, commonly assess thermal comfort in indoor settings [86,102].

\[
T_{\text{m(resi)}} = 0.26 \times T_{\text{pma(out)}} + 16.75 \quad (1)
\]

\[
T_{\text{lower 80% acceptability limit}} = 0.26 \times T_{\text{pma(out)}} + 12.25 \quad (2)
\]

\[
T_{\text{upper 80% acceptability limit}} = 0.26 \times T_{\text{pma(out)}} + 21.25 \quad (3)
\]

Further, this Equation (1) upholds an 80% acceptability band (Equations (2) and (3)) [103].

But then, Fanger’s model has a limitation in that its PMV model does not encompass a wider range of thermal adaptability and dissatisfaction. As depicted in Figure 5, with variables such as activity levels kept constant, a minimum % dissatisfaction rate of 5% persists even when the PMV index is 0 [104]. This suggests that some individuals will remain dissatisfied with the prevalent temperature, emphasising the influence of personal preferences and perceptions of thermal comfort.

Despite this limitation, the PMV-PPD model developed by Fanger is broadly acknowledged and utilised for assessing indoor thermal environments. It has gained prominence in mechanically ventilated buildings and is notably employed by ASHRAE [86] for evaluating thermal comfort in dwellings with mechanical ventilation heat recovery systems (MVHR) [105]. International comfort standards like ASHRAE and ISO based on Fanger’s model are regarded as reliable references for evaluating thermal comfort.

ISO [102], a global standard, employs Fanger’s PMV-PPD model as the recommended method for assessing thermal comfort. Annexure A of ISO 7730 [102], outlines specific criteria for thermal conditions, primarily focused on sedentary activities in the winter heating period. To achieve a satisfaction rate of 80% for occupants, the specified conditions must be met [106]:

1. Temperature between 20 and 24 °C.
2. Air temperature difference of <3 °C (vertical).
(3) Floor temperature between 19 and 26 °C.
(4) Mean air velocity lower than 0.15 m/s.
(5) Radiant temperature from cold surfaces of <10 °C.
(6) Radiant temperature from warm surfaces of <5 °C.

![Figure 5. Relationship of PMV versus PPD. Source: [104].](image)

The conditions for acceptable thermal comfort predicted by ASHRAE [86] for an RH of 50%, mean air velocity < 0.15 m/s, and mean radiant temperature equivalent to air temperature are mentioned below:

- **Cold climate conditions:** the operational warmth is suggested as 24.5°C with a satisfactory range between 23 °C and 26 °C.
- **Hot climate conditions:** the operational warmth is suggested as 22 °C with a satisfactory range between 20 °C and 23 °C.

The satisfactory range for thermal comfort can be categorised into three distinct zones based on the scale of PMV and PPD % ranges. This framework allows for the evaluation of indoor thermal environments. Furthermore, by integrating factors like temperature, humidity, air speed, and clothing level, these comfort zones inform the design and operation of HVAC systems, ultimately promoting occupant thermal satisfaction [86]. The three distinct climate zones for a satisfactory range of thermal comfort are as follows:

- **Climate zone 1:** most people (around 94%) will feel most comfortable when PPD is less than 6%, and the scale of PMV is within −0.2 < PMV < 0.2.
- **Climate zone 2:** around 90% of people will feel comfortable when PPD is less than 10%, and the scale of PMV is within −0.5 < PMV < 0.5.
- **Climate zone 3:** as the PPD % gets higher by 15%, fewer people will feel comfortable, and the scale of PMV is within −0.7 < PMV < 0.7.

The primary rationale behind the adaptive comfort model for dwellings relying on natural ventilation is that human nature alterations, including psychological and physiological adjustments, can lead to broader current thermal conditions [107]. The adaptive comfort model (ASHRAE 55) is limited in application, with dwellings deemed unsuitable to all the occupants if they tend to spend more time beneath one temperature. The adaptive comfort model, pioneered by researchers such as de Dear and Brager, was not developed specifically for residential dwellings in New Zealand relying on natural ventilation. Rather, the adaptive comfort approach has been studied and applied in various commercial buildings like schools and offices. The reason is that occupants in schools and offices have greater control over their thermal adaptability via window and door operations and another adaptive mechanism [107]. However, it is important to note that DQLS 2022 is not explicitly based
on the adaptive comfort model. Instead, it aligns more with the Fanger’s model scale of PPD and PMV indices. The distinction highlights the differences with the thermal comfort model used across OECD countries’ standards, with some adopting the adaptive approach and New Zealand relying more on the established Fanger-based framework.

The adaptive model mechanism (see Figure 6) for thermal comfort presented below is a theoretical model based on the Black Box theory, which considers several aspects: climate, culture, social, physiological, and human nature adaptations. The model is known as an adaptive predicted mean vote (aPMV) model. Research shows that using the (aPMV) model, in free-running dwellings relying on natural ventilation, the predicted mean vote (PMV) is greater than the actual mean vote (AMV). This indicates that occupants with natural ventilation strategies can tolerate wider temperature ranges than those with mechanical ventilation. The aPMV comfort model might overestimate how hot students feel in naturally ventilated classrooms, common in New Zealand (cold and temperate climate). This could lead to classrooms being designed cooler than necessary, wasting energy and potentially making students uncomfortable [108]. Primary school classrooms in cold and temperate climates, relying on natural ventilation, often experience high temperature fluctuations due to high occupancy, lower ventilation rates, and excess heat entering through windows designed for daylight [109].

![Adaptive model mechanism for thermal comfort](source)

**Figure 6.** Adaptive model mechanism for thermal comfort. Source: [79].

Factors such as comfort temperature, dwelling typology, solar gains, incidental gains, ventilation level, and occupants can add to overheating in dwellings, which can change the thermal comfort standards [91].

### 4.3. Occupancy, Occupant Density, and Room Size Standard

Ensuring a healthy and productive learning environment for children in school classrooms necessitates focusing on multiple aspects, including indoor air quality and thermal comfort. These factors are significantly influenced by classroom design and layout features, particularly when considering occupancy (number of students), occupant density (space per student), and classroom size. This section delves into a comparative analysis of these parameters, which strictly influence the IAQ and thermal comfort in indoor environments across OECD countries.

The recommended number of students within a classroom, or occupancy, varies across OECD countries’ standards. ASHRAE recommends a maximum occupancy of
25 students with a corresponding density of 4 m\(^2\) per person to a 100 m\(^2\) classroom. This approach ensures ample personal space and potentially better air quality by reducing CO\(_2\) concentration through increased air volume per person. However, it may not be possible for all schools due to space constraints and cannot be applied to universal guidelines. CIBSE, on the other hand, adopts a flexible approach by not specifying the occupancy and size of the classrooms, but it does recommend an occupant density of 2 to 4 m\(^2\)/p. This allows room for future adjustments based on the actual classroom size to obtain desired learning outcomes, as without clear guidelines, it might not be easy to achieve optimal IAQ.

Whereas in New Zealand classrooms, the occupancy is slightly higher, with 30 in a 75 m\(^2\) classroom, implying an occupant density of around 2.5 m\(^2\)/p. This recommendation balances providing sufficient space for student activities while maintaining a reasonable classroom size. While it might achieve acceptable IAQ in some cases, the findings by [110,111] state carbon dioxide in classrooms in comparison to office buildings is approximately four times. Hence, it becomes potentially significant to additional ventilation strategies, particularly when occupancy density is at the recommended limit [35].

EN-15251 suggests a lower occupancy of 23 students with a 2 to 3.1 m\(^2\)/p occupant density. This approach prioritizes providing enough space per student, potentially achieving better IAQ and minimizing carbon dioxide concentrations. Findings from multiple studies state that a lowered occupant density (m\(^2\)) in the classroom is directly associated with higher carbon dioxide concentrations [33,73,112,113]. According to Organization and Eurostat [114], in order to maintain a carbon dioxide concentration within 1000–1500 ppm, it is recommended to maintain (2 to 3.1 m\(^2\)/p) occupant density with a maximum of 22 students. According to Building Bulletin 99, it is recommended to have an occupancy of 30 students within 70 m\(^2\) of classroom size, which aligns with the density of occupants similar to New Zealand, 2.3 m\(^2\)/p, but differs in occupancy and classroom size. Mydlarz et al. [112] state that a minimum occupant density of 2.3 m\(^2\)/p with no additional strategies (adequate ventilation rates) can significantly lead to higher carbon dioxide concentrations. Hence, maintaining adequate ventilation and healthy IAQ in such complex environments becomes challenging for designers and architects. To counter the issue of occupant density, it is recommended to increase the height of the classroom to 3.3 m, as it can maintain significantly better IAQ [115].

An overpopulated classroom can result in high CO\(_2\), higher body heat, and odour, creating less productive space, with discomfort and a stressful environment impacting performance. Korsavi, Montazami, and Mumovic [35] also state classrooms with a 2.3 m\(^2\)/p occupant density will require more fresh air circulation to maintain optimal environmental conditions for children. The slight differences in classroom sizes, occupancy, and occupant density, other than the ASHRAE standards, across OECD countries’ standards could be due to factors like educational practices, student–teacher ratios, and cultural and space utilization in different countries. Moreover, bigger classrooms offer flexibility with layouts and space management and provide an overall better learning environment, keeping health and productivity equal. In addition, mechanical or HVAC ventilation may not be a feasible option in the context of cost measurement and maintenance. Still, classrooms relying on natural ventilation can be a viable strategy to balance IAQ conditions. Notably, the New Zealand classrooms offer an occupant density of 2.5 m\(^2\)/p (based on a 75 m\(^2\) classroom and 30 students). The slight difference in occupant density in comparison to CIBSE and EN–15251 states that the New Zealand standard is not far below. However, there is still room for future research as ASHRAE offers 4 m\(^2\) of occupant density.

The commonalities and differences show the need for a holistic approach to designing and regulating school learning environments. Continuous improvement of IAQ and thermal comfort in the classroom carefully requires considering all classroom sizes, occupancy, and occupant density together.
5. Conclusions

This study extensively reviews existing indoor air quality (IAQ) and thermal comfort guidelines, focusing on international standards and OECD countries. Despite ongoing research on IAQ and thermal comfort in educational learning spaces globally, many studies briefly address the health and performance impacts of poor indoor air quality. The Findings and Discussion section critically compares IAQ and thermal comfort standards, revealing significant variations among international standards adopted by OECD countries. Factors influencing these differences include climate, occupancy, building design, spatial considerations, and local environmental exposures.

The study employs standards such as ASHRAE, CIBSE, WHO, EN-15251, Building Bulletins 99 and 101, and DQLS, concluding its three-part review: thermal comfort, carbon dioxide with ventilation, and classroom attributes. New Zealand’s standards are found lacking in addressing pandemic situations, indicating a need for improvement through scientific research. In order to bridge this gap, strategic steps must be taken to enhance IAQ standards, minimise exposure to pollutants, and improve ventilation rates. In the thermal comfort comparison, the study examines the permissible indoor temperature ranges across international standards. New Zealand’s more comprehensive range aligns with WHO and Canada’s National Joint Council standards, while ASHRAE, CIBSE, and the UK’s National Union of Education specify narrower limits. The study highlights the importance of considering occupant behaviours and providing training, knowledge, and guidance to enhance thermal comfort.

The comparison of carbon dioxide and ventilation rates delves into recommended concentrations and rates for healthy IAQ. New Zealand’s standards align with CIBSE and WHO, recommending a minimum of 10 L/s/p. However, ASHRAE’s mechanical ventilation focus suggests a lower range. The study emphasises the significance of ventilation in reducing airborne pathogens and improving indoor air quality. Examining classroom attributes, the study underscores the impact of occupant density on carbon dioxide levels. International standards recommend a minimum occupant density of 2.3 m²/p. The study suggests reducing occupants or increasing ceiling height to meet IAQ standards (see Section 4.3). It calls for improvements in New Zealand’s DQLS document regarding carbon dioxide concentration. Therefore, this study advocates for the holistic optimisation of standards and guidelines, emphasising health, well-being, and performance. It identifies areas for improvement in the current guidelines, particularly in addressing pandemic situations and aligning standards with health-oriented objectives. Future research should focus on a more flexible and versatile approach to indoor air quality, considering both classroom design and occupancy levels.

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